Utilisation of Restored Wetlands by Fish and Invertebrates

Philip Gibbs, Tracey McVea and Brett Louden

NSW Fisheries Office of Conservation
Locked Bag 9, Pyrmont, NSW 2009
Australia

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Acknowledgments

This project would not have begun without the persistence and foresight of Phil March from the then NSW Commercial Fishing Advisory Council who has maintained focused on the purchase and restoration of the Yarrahapinni Broadwater. Phil maintained an avid interest in the project throughout, assisted in site selection for the Macleay and Nambucca Rivers and kept us abreast of local changes in the Yarrahapinni Broadwater and floodgate conditions.

We thank various staff at NSW fisheries including Judy Upston, Lesley Diver, and Will Macbeth for assisting in the field and in the sorting of samples. John Matthews assisted with graphics and the cover of this report. Dr Nick Otway provided considerable advice regarding the analytical design and assisted in the statistical analysis of the data.

Bruce Coates from the Department of Land and Water Conservation (DLWC) arranged installation of the water quality data loggers and provided access to the data.

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Non technical summary

95/150 Utilisation of restored wetlands by fish and invertebrates

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Objectives:

1. To demonstrate whether fish and invertebrates use 'restored' wetlands.
2. To determine if the restored habitat sustains fish and invertebrate communities similar to other sites within the adjacent estuary and at sites within comparable reference estuaries.
3. To determine appropriate mechanisms for minimising the impacts of releasing low dissolved oxygen and low pH acid soil drainage water to the estuary when the levees and floodgates are initially breached.
4. To identify the initial rate of recovery following opening/removal of the flood mitigation works and to determine whether additional intervention is required to assist the regeneration of fish habitat.

The Yarrahapinni Land Management Trust planned to restore the wetlands of the Yarrahapinni Broadwater by opening the floodgates to the area during February 1997.

Due to delays in the preparation and approval of the EIS for the changes in management of the Yarrahapinni floodgates they were not opened during the period of this study and no after data were collected. Consequently objectives (3) and (4) could not be fully investigated. As this event did not occur till midway through the study our original experimental design was also compromised.

Therefore, we compared the conditions in the Yarrahapinni Broadwater during the study against the conditions at the estuaries with managed/modified floodgates/barriers (Ironbark Creek and the Rockdale Wetlands) and the external reference estuaries. We then used these results to predict the conditions and rate of recovery in the fish and invertebrate community expected to occur at Yarrahapinni when the floodgates were opened.

Non technical summary:

The loss of estuarine fish habitat is of considerable concern at the National, State and Local government and community levels. A variety of funded government programs have addressed this problem through the Natural Heritage Trust, Environment Australia and the various Research and Development Corporations.

An inventory of barriers impeding tidal flow has been completed for NSW. Initiatives to develop management plans for estuaries via Estuary Management Committees and Total Catchment Management Committees (TCM) have been implemented. The purchase of drained and degraded wetlands is a further initiative with the 600 ha Yarrahapinni Broadwater an early Government land purchase.

Modification of the existing management regime of floodgates to increase tidal flow is an attractive strategy for restoration of wetlands. This should improve water quality including the adverse effects of acid soil drainage, restore a more estuarine environment and possibly improve wild fish resources. Monitoring the floodgate modification and the biota of the wetlands is a priority task to provide a performance measure of the changes in the wetland habitats.

The Yarrahapinni and Ironbark Creek TCM programs had a very high commercial fishing industry involvement which strongly supported initiation of the current study to investigate the utilisation of restored estuarine wetlands by fish and invertebrates.

Samples of fish and invertebrates were collected from estuaries with a restored wetland, estuaries proposed for future restoration and from 3 reference estuaries (Nambucca River, Manning River and Wallis Lake). Samples were collected seasonally using a 20 metre long seine net with a 6 mm mesh size. This collection method targeted new recruits and juveniles, of both fish and invertebrates. Information on species composition, size and age of the catch was recorded. Salinity, temperature and pH were measured at each site and water samples were collected for nutrient analysis.

The wetlands being investigated and their relationship to the overall study are:

a) The Yarrahapinni Broadwater on the Macleay River, which has been closed off from the main estuary by the presence of levee banks and floodgates for over 20 years. Prior to this, based on historical catch records the area was highly productive, providing important nursery habitats for many economically important fish and invertebrates. The Yarrahapinni Land Trust propose to modify the floodgates and restore the area to an estuarine condition including remediation of the acid sulphate soils in the area. This component of the study was to enable collection of data on conditions *before and after* restoration, which is important to accurately quantify any expected improvements in fish resources.

b) The Hexham swamp Ironbark Creek on the Hunter River has also been influenced by floodgates erected during the early 1970's. Due to reduced tidal exchange, water quality in Ironbark Creek was found to contain high nutrient levels, low dissolved oxygen and low pH from acid sulphate soils. Controlled opening of the floodgates was used as a management method to improve these conditions. Sampling from this area enables assessment of the initial impacts of a restoration project.

c) The Rockdale Wetlands Corridor is connected to Botany Bay by a 700m underground channel. The channel is open between the wetlands and Botany Bay and this allows tidal exchange and a modified access route for fish and invertebrates. This modified area is important in the study as it represents conditions for an existing restored wetland even though it is highly modified. It may also indicate where future action is necessary to enhance fish resources in restored wetlands.

This study showed the fish community structure above and below the tidal barriers to estuarine wetlands varied considerably dependent upon the degree of tidal exchange. Where floodgates were completely closed (Yarrahapinni wetlands Macleay River), the upstream community was dominated by freshwater species such as gudgeons (*Philypnodon* sp., *Philypnodon grandiceps* and *Gobiomorphus* spp.), the goby (*Pseudogobius olorum*), the southern blue-eyes (*Pseudomugil signifer*), the mosquitofish *(Gambusia holbrookii)* and aquatic insects such as dragonfly nymphs, damselfly nymphs and water boatman. There were very few commercially or recreationally important fish and invertebrate species collected from this area.

In comparison, the community above the partially open floodgates at Ironbark Creek in the Hunter River, was very diverse and included juveniles of several species of economic importance and few of the freshwater species found in the Yarrahapinni wetlands. Overall, the community structure in Ironbark Creek was comparable to the main channel of the Hunter River but actually supported a greater number of juvenile sea mullet (*Mugil cephalus*), yellowfin bream (*Acanthopagrus australis*) and school prawns (*Metapenaeus macleayi*) than the main channel of the river.

Commercial fish species dominated the samples collected from the Rockdale wetlands area in Botany Bay. This area supported a significantly greater abundance and biomass of juvenile commercial fish than from sample sites in Botany Bay. It appeared that the Rockdale wetlands provides an important nursery area, especially for yellowfin bream and mullet which were able to move through the permanently open 700 m long pipe into the modified wetlands.

Species absent or in very low densities inside the restored wetlands compared to other locations in the parent estuary or the reference estuaries were silver biddies (*Gerres subfasciatus*), tarwhine (*Rhabdosargus sarba*), blackfish (*Girella tricuspidata*), striped trumpeter (*Pelates sexlineatus*) and king prawns (*Penaeus plebjeus*).

The spatial analysis of the data clearly demonstrates the parent estuary and external reference estuary similarity of below barrier sites and their similarity to the Ironbark Creek, Hunter River above floodgate sites. The analysis shows Ironbark Creek with a moderate tidal exchange was functioning as a nursery habitat and has a diverse fish community especially of bream, mullet and school prawns.

The study identified the highly modified Rockdale wetlands area with a significant tidal exchange, as another important nursery ground for juvenile bream and mullet. The development of Botany Bay as a major shipping and industrial port including significant reclamation of the natural habitats has limited the available juvenile fish habitat in the Bay especially on the northern and western shores and this accentuated the importance and utilisation of the Rockdale wetlands.

An additional indicator of the functional equivalency of the 'restored' wetlands in Ironbark Creek, Hunter River and Rockdale wetlands, Botany Bay is the presence of small numbers of glass eels, *Anguilla* sp. collected in winter and summer in both years and common jollytails, *Galaxias maculatus* collected in the spring of both years. These migratory species are normally excluded by tidal barriers due to the physical barrier and the habitat and water quality alterations above the barrier.

The influence of tidal exchange in structuring the fish and invertebrate community was apparent in the three differently impacted wetlands.

Active management of the floodgates or tidal barriers does not require their total removal in order to restore and enhance the habitat for fish and invertebrates and improve water quality. "Leaky " or partially open gates and highly modified exchange via pipes can provide access for juvenile and adult animals.

Highly modified habitats can still be used by fish as juvenile nursery areas in the absence of the accepted preferred habitats provided they are of sufficient water area and productivity. The development of stable faunal communities above structures significantly enhances biodiversity conservation.

The Future

An issue for future work is the development of management guidelines for floodgate structures in acid sulphate soil drainage areas, especially the relationship between fish and invertebrate recruitment and the opening size, frequency and timing of opening the tidal barriers.

A second issue is the long term impact of chronic acid drainage, which does not cause major fish kills but which may have less obvious effects on the recruitment of migratory and catadromous fish such as Australian bass, striped mullet, freshwater herring, eels and school prawns.

KEY WORDS:

Wetland restoration, fish, invertebrates, acid sulphate soils, tidal barriers, floodgates, estuarine fish passage, New South Wales, Australia.

1. Introduction

1.1. Background

Expansion of coastal agricultural and urban development is an ongoing process and the encroachment of these activities on the aquatic ecosystem and the effect on fisheries production is a world-wide concern (Hutchings and Saenger, 1987; NRS, 1992; Waste, 1996). A consequence is the modification of the natural environment and alteration in the range of habitats available to fish and invertebrates.

Since the early 1900's flood mitigation schemes have altered the natural flow of many rivers and estuaries along the NSW coast. Works included in these schemes are the construction of floodgates, dams, weirs, and levee banks to control floodwaters, but they are often operated as complete barriers to restrict saltwater inflow and tidal exchange (Williams and Watford, 1997). Land behind the barriers was often reclaimed for agriculture, including grazing of stock (Middleton *et al.*, 1985). However, these barriers also resulted in the destruction of highly productive estuarine habitats such as seagrass beds, mangrove forests and salt marshes and restricted the movements of fish and other aquatic fauna (Pressey and Middleton, 1982). Further, most of the reclaimed wetlands in NSW are on pyritic sediments and low pH drainage to the estuary occurs.

Research in estuaries confirms they are important, and in some cases critical, for many fish and invertebrate species (West and King, 1996; Potter *et al.,* 1990; Bell and Pollard, 1989; Lenanton and Potter, 1987; Pollard, 1984). Estuaries appear to be particularly important as nursery habitats for many well known, economically important species of fish and invertebrates. This is partly because these fish habitats offer structural complexity, shelter and food sources not readily available in other coastal areas.

In response to degradation of estuarine habitats, a philosophy of amelioration has evolved. The terms restored, rehabilitated, mitigated, enhanced, preserved and created all occur in the literature in reference to modification of aquatic ecosystems to reverse anthropogenic impacts. The terms are not mutually exclusive and in this report the definitions of NRC (1992) are used. The terms we use are: Restoration - return of an ecosystem to a close approximation of its condition prior to disturbance and Rehabilitation - improvements of a visual nature to a natural resource; putting back into good condition or working order.

1.2. Need

The Yarrahapinni Broadwater on the Macleay River and Hexham Swamp / Ironbark Creek on the Hunter River are examples of estuarine wetlands that have been altered by flood mitigation structures and are affected by acid drainage. Levees and/or floodgates were constructed at both sites during the early 1970's. Prior to this, the areas were highly productive with seagrass and mangrove habitats, now they are largely vegetated by rushes (*Juncus* sp.) and have reduced faunal diversity (Shephard, 1993). The Rockdale Wetlands corridor also represents an area with altered tidal exchange. This area was originally a tidal creek system but is now connected to Botany Bay by an underground channel, which constricts the area for tidal exchange and acts as a modified access route for fish and invertebrates.

In 1994, the NSW Commercial Fishing Advisory Council (CFAC) applied for and was granted NSW Environmental Trust grants to purchase land and begin restoring the 600 ha Yarrahapinni Broadwater. It was planned to modify the operating regime of the floodgates and increase tidal flow to improve the water quality and thereby improve wild estuarine and marine fish resources. Concurrently the Total Catchment Management (TCM) Strategy for Ironbark Creek was being drafted and included a management strategy for controlled management of the floodgates and tidal flows.

The Yarrahapinni and Ironbark Creek TCM programs had a very high commercial fishing industry involvement which strongly supported initiation of the current study to investigate the utilisation of restored wetlands by fish and invertebrates.

1.3. Objectives

The main objectives of this project are:

i) To demonstrate whether fish and invertebrates use 'restored' wetlands.

ii) To determine if the restored habitat sustains fish and invertebrate communities similar to other sites within the adjacent estuary and at sites within comparable reference estuaries.

iii) To determine appropriate mechanisms for minimising the impacts of releasing low dissolved oxygen and low pH acid soil drainage water to the estuary when the levees and floodgates are initially breached.

iv) To identify the initial rate of recovery following opening/removal of the flood mitigation works and to determine whether additional intervention is required to assist the regeneration of fish habitat.

Initially the project was divided into 3 phases: Phase 1 - a period *prior* to the opening/removal of the floodgates when the natural variability associated with the sampled communities was to be identified. Phase 2 - the period of time *during* which the floodgates are opened/removed and tidal flow is increased. At this time there is the potential for adverse impacts due to the release of waters drained from acid sulphate soils with low dissolved oxygen and low pH into the estuary. The data collected during this phase will be used to identify ways to minimise these impacts in future restoration projects. Phase 3 - a period *after* the opening of the floodgates in which the estuarine communities change in relation to increased water flow and higher salinity regimes.

The Yarrahapinni Broadwater on the Macleay River was to be the subject of investigation for the above 3 phases. The Land Management Trust planned to remove the floodgates from the area during February 1997. This would have allowed us one year prior to and one year following the removal of the gates to investigate any changes that may have occurred. We proposed to use the Ironbark Creek (Hunter River) and the Rockdale Wetlands Corridor (Botany Bay) as examples of wetlands with existing floodgates that have already been managed or modified.

Due to delays in the preparation and approval of the EIS for the changes in management of the Yarrahapinni floodgates they were not opened during the period of this study and no after data were collected. Consequently objectives (iii) and (iv) could not be fully investigated. As this event did not occur till midway through the study our original experimental design was also compromised.

Therefore we compared the conditions in the Yarrahapinni Broadwater during the study against the conditions at the estuaries with managed/modified floodgates/barriers (Ironbark Creek and the Rockdale Wetlands) and the external reference estuaries. We then used these results to predict the conditions and rate of recovery in the fish and invertebrate community expected to occur at Yarrahapinni when the floodgates are opened.

Management of the floodgates at Ironbark Creek also changed at the beginning of the study with one gate partially open allowing some tidal exchange from the Hunter River into the creek. Unfortunately no before data are available to test objectives (iii) and (iv).

Partial gate opening appeared to be sufficient to improve water quality, reduce acid drainage and change the fish fauna of the wetland area as will be demonstrated from our data. The Rockdale Wetlands Corridor is connected to Botany Bay by a 700m underground pipe. The pipe is open between the wetlands and Botany Bay and this allows tidal exchange and a modified access route for fish and invertebrates. This area represents a highly modified restored wetland.

1.4. Impacts of acid water

The effects of acid sulphate soil drainage on aquatic biota can be described at the ecosystem, population and species level. In general the effects can be categorized as mortality of fish and invertebrates; increased susceptibility to disease especially epiozotic ulcerative syndrome (EUS); physiological effects (related to reduced growth, visual and olfactory impairment, bone disorders); and avoidance responses (Sammut *et al.*, 1993 and (Sammut *et al.*, 1995). The cause of the observed effects is not fully understood but the interrelation of pH and its effect on the chemistry of iron and aluminum and their respective toxicity are the key contributors to the impacts on biota.

The physiological effects of low pH and its association with aluminum and iron is well researched for northern hemisphere freshwater fish and other aquatic organisms (Erichsen Jones, 1969; Lloyd, 1992 and Howells, 1994). However, data for Australia are limited to the work by Wilson and Hyne (1997) and Hyne and Wilson (1997) on Sydney rock oyster embryos and larvae of Australian Bass and the Richmond River study on estuarine fish and benthic communities (Roach, 1997).

The associations between acid drainage, *Aphanomyces* fungal infection and "red-spot" ulcer disease or EUS and fish kills have been reviewed by Callinan *et al.,* (1989, 1993, 1995a, b).

Hydrology and rainfall in the catchments govern acid production in a sequence of events that have the following major features and impacts (adapted from the reviews of Alabaster and Lloyd, 1980; Cappo *et al.*, 1997; Howells, 1994 and the research of Sammut *et al.*, 1993, 1995, 1996; Willet *et al.*, 1993).

After rainfall events and a rise in the water table, aluminium, iron, manganese and other ions are stripped out of the soil by sulphuric acid originating from the oxidation of pyritic sediments. The significant quantities of aluminium and iron derive from aluminosilicate clays commonly associated with coastal estuaries. The lower the pH the greater the amount of aluminium and other ions that are mobilised.

Floods and other high flow events drain large "slugs" of this low pH water through floodgates to meet higher pH bicarbonate rich estuarine water. This can produce aluminium hydroxide and iron hydroxide flocs in massive amounts. About 1 tonne of iron floc is produced for every tonne of pyrite oxidised. The Al and Fe flocs disperse through the estuary producing a bluey-green stain. The flocs then bind to clay particles and settle out to produce clear estuarine waters. Smothering of the substrate with flocs of iron hydroxide (up to 1 metre deep) can result in the death of most gilled, benthic life.

During this time fish and invertebrate kills occur for a variety of reasons that depend on the prevailing pH.

- Acid kills most fish and invertebrates at approximately pH 3 - 3.5.
- Aluminium hydroxide flocs bind to clays and attach to skin and block gills at higher pH.
- Above pH 4, iron oxyhydroxides are precipitated and may cause suffocation.
- Inorganic monomeric aluminium [$AlOH_2^{++}$] toxicity kills most fish at pH 5.
- Lack of dissolved oxygen can occur when oxidation of iron occurs from the ferrous iron to ferrihydrate.

Fish with epithelial defenses weakened by metal flocs and acid suffer from *Aphanomyces* fungal infections. These infections produce extensive ulcers ("red-spot", "EUS", "Bundaberg Disease") on fish that often are so deep that the caudal rays or neural spines of the backbone are visible. Survivors of these attacks invest so much energy in healing that there is no reproduction until condition is regained in subsequent years.

Fish with ulcers or healed ulcer scars are unmarketable and have comprised up to 30% of some catches of whiting, bream, mullet and flathead. Lower growth rates of prawns in pond aquaculture occurs because less bicarbonate is available to them in the low pH water and they will not moult. In the Tweed and Hastings Rivers the role of acid drainage in oyster mass mortality, disease, shell erosion and low growth performance is apparent.

The impacts of acid water on non aquatic fauna includes poor crop and pasture growth in acidified parts of the floodplains, lower dairy and beef animal production, corrosion of pipes and cement structures and acidification of aquifers and potential human health problems from groundwater consumption (high aluminium, acidity).

1.5. Experimental design and statistical analysis

In this study, the 'impacted' locations are the Yarrahapinni Broadwater on the Macleay River, Hexham Swamp / Ironbark Creek on the Hunter River and the Rockdale Wetlands in Botany Bay. The impact we refer to is the modification of the area by the presence of floodgates or barriers, which restrict tidal flow and accentuate catchment acid drainage problems. The abundances of fish and invertebrates are monitored and compared with a number of reference sites within the parent estuary (outside the floodgates) and also with a set of external reference estuaries.

Non-metric multidimensional scaling (NMDS) is used to examine trends in the community structure. Univariate ANOVA techniques are used to assess differences in the fish and invertebrate fauna at each of the impacted locations. The degree of impact is different at each of these locations and so they are analysed separately in the analyses of variance models.

2. Pilot Study

2.1. Introduction

2.1.1. Background

A pilot study is used to determine the logistics and statistical sampling protocols and is an essential component of any ecological study. It is the best way to check the efficiency of the sampling device, the size of the sample unit, the number of samples required, and the presence of spatial variation (Elliott, 1977 and Green, 1979). Often this stage is by-passed because of insufficient time or funds. However, the time spent on preliminary sampling will be returned as time and money saved later.

The pilot study will determine the sampling strategy, which is most cost effective and statistically robust to identify any changes in the fish and invertebrate communities following habitat restoration.

2.1.2. Objectives

The purpose of the preliminary sampling was to:

(1) assess the study area and select appropriate sites for sampling;

(2) determine the best method for sampling;

(3) establish the number of replicate samples required and;

(4) finalize the experimental design and statistical methods for the study.

2.2. Methods

2.2.1. Determination of sampling method

Nets, traps, poison and electro-fishing are the most common methods used to sample fish populations in the aquatic environment. Poisoning is usually destructive and may affect non-sampled areas and electro-fishing is not feasible in saline waters. Traps are used for capturing various species but only sample a small proportion of the whole community. Nets are the most effective and efficient way to sample for a range of species in an area and were considered the most appropriate method to use in this study. There are several net options available, including seine nets, gill nets, beam trawls and fyke nets. Fyke nets were originally considered but were inappropriate because they require water movement to operate, and the areas behind the floodgates are not tidal. Gill nets, though biased by the selectivity associated with mesh size are good for collecting large, mobile fish, but need to be left at a site for a specified time, which increases the time required to sample. Beam trawls were inappropriate at a number of locations due to the presence of obstructions. We decided that seining would be the best method to sample the juvenile fish and invertebrate community at all our sites.

To determine the most appropriate size for the seine net, we used two different nets to collect samples from a sandy/mud substrate with a sparse to medium cover of *Zostera* from the Macleay River in December 1995. A large net (30m *x* 2m with graded mesh sizes from 25mm in the wings to 15mm in the cod-end) and a smaller net (20m *x* 2m with a mesh size of 6mm). Eight replicate samples were collected using each net. All fish and invertebrates were identified to species and counted.

Data for the number of individuals, number of commercial taxa, number of non-commercial taxa and total number of taxa were analysed using a one-factor analysis of variance (ANOVA) with net size as a fixed factor. Prior to the analysis, the homogeneity of variances was tested using Cochran's test (Winer, 1971). Where the variances were heterogeneous, the data were transformed to log(x+1).

2.2.2. *Determination of sample number*

Ten replicate samples using the 20 m seine net were collected from the Wallamba River (Wallis Lake) in February 1996. All fish and invertebrate species were identified, counted and weighed for each sample. Variance to mean ratios were used to estimate the most appropriate sample number (Elliott, 1977).

The positive relationship between the number of species found in an area and the size of the area can also be used to indicate sampling efficiency in terms of collecting what is there. The calculation of species area curves was done by using the combinatorial method of Weinberg (1978) as discussed in Gibbs (1987).

The results of the two approaches were compared.

2.2.3. *Spatial variability*

A preliminary evaluation of the spatial variability in the community structure was made. Two replicate samples were collected using the 6mm mesh size seine net from each of 9 sites on the Macleay River and 3 sites on the Nambucca River. All fish and invertebrates were identified to species and counted. The Bray-Curtis similarity measure (Bray and Curtis, 1957) was used to construct a similarity matrix based on abundance data and then non-metric multidimensional scaling (NMDS) was used to construct a two-dimensional ordination plot (Clarke, 1993).

2.3. Results

2.3.1. *Determination of sampling method*

The proposed study locations were assessed and suitable sites for sampling by seining in the estuaries and the impacted wetlands were limited. This resulted from the number of available 'beach' areas to purse the net onto, and also required the absence of oyster leases and other obstructions.

Forty eight taxa were collected in the sixteen samples collected from the Macleay River to determine net size. Four taxa represented by 1 or 2 individuals unique to the large net and 15 taxa represented by 1 to 91 individuals unique to the small net. Significantly more taxa (commercial and non-commercial species) were collected using the small net compared with the large net (Table 2.3.1 and Figure 2.3.1). There were also significantly more individuals collected in the small net (Figure 2.3.1).

Table 2.3.1. Summary of the analyses of variance of the number of taxa and number of individuals collected using nets with different mesh sizes.

ns, not significant, p > 0.05; * significant, p < 0.05; ** significant, p < 0.01.

Source of Variation	**df**	**No. taxa**		**No. commercial taxa**		**No. non-commercial taxa**		**No. individuals**	
		MS	F	MS	F	MS	F	MS	F
Net size	1	370.56	**	27.56	ns	196	**	7.04	**
Residual	15	33.93		8.49		10.55		0.35	
Transformation		none		none		none		log(x+1)	

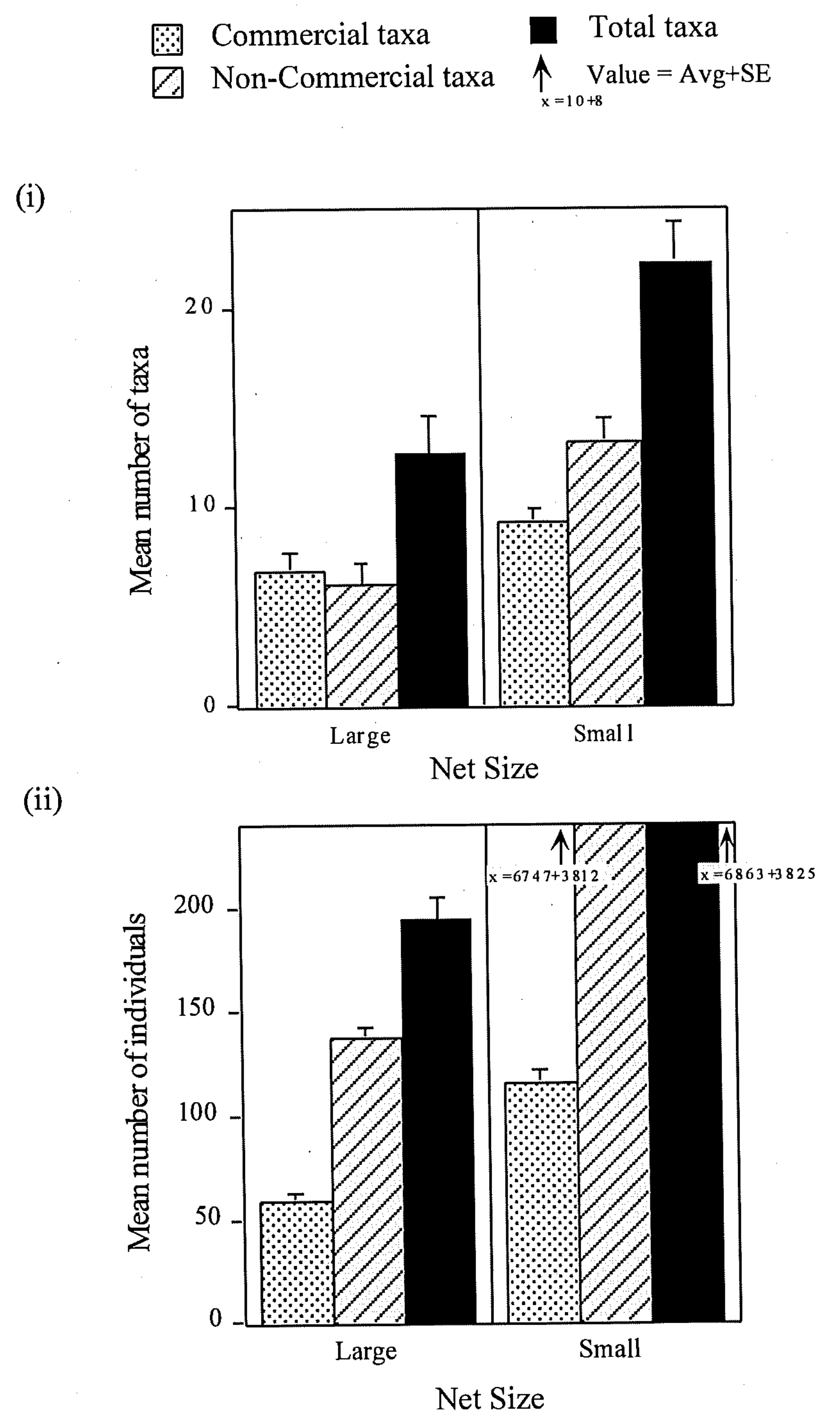

Figure 2.3.1. Small net and large net comparisons for the average number and standard error of (i) number of commercial, non-commercial and total taxa and (ii) number of commercial, non-commercial and total individuals.

2.3.2. Determination of sample number

The 10 seine hauls using the 20 m net yielded a total of 2,164 fishes from 31 species. Optimum sample size based on variance to mean ratios and the sample dispersion was 2 for the number of species and as high as 19 for some individual species (Table 2.3.2).

The species area curve shows that 4 samples catch 84.6% of species present and a doubling of effort increases this by only 10.8% (Figure 2.3.2).

The labour and time resources to collect, sort and process the samples provides additional input to the assessment used in determining the final sampling design. The hypotheses to be tested in the study are based on assessing differences in the fish and invertebrate communities at locations. Using the resource needs, the variance to mean ratio analysis and the species area curve analysis we determined the final design as 3 seine hauls to be collected at each of 3 sites (9 seine hauls) to adequately sample a location.

Table 2.3.2. The number of samples needed to adequately describe the fish community based on variance to mean ratios, for a standard error of 10%. Dispersion is calculated by reference to the Q statistic in Pearson and Hartley's (1966) Table 8.

Variable	**u**	**S^2**	**X^2**	**Dispersion**	**N**
No. of species	17.3	4.9	2.55	random	2
No. of individuals	216.4	9255	384.9	contagious	4
Acanthopagrus australis	2.9	3.65	11.33	random	9
Gerres subfasciatus	5.9	25.8	39.36	contagious	19

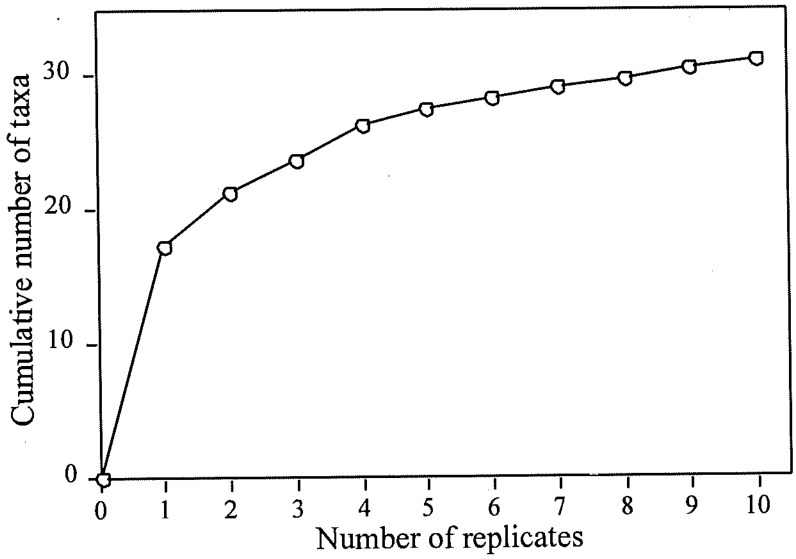

Figure 2.3.2. Species area curve for pilot study seine net samples.

2.3.3. Spatial variability

The NMDS plot for the pilot sampling of the Nambucca and Macleay Rivers was based on 62 fish and invertebrate taxa and shows the within estuary and between estuary reference sites are similar. The wetland sites behind the floodgates on the Macleay River are different. At most sites the replicates were similar (Figure 2.3.3).

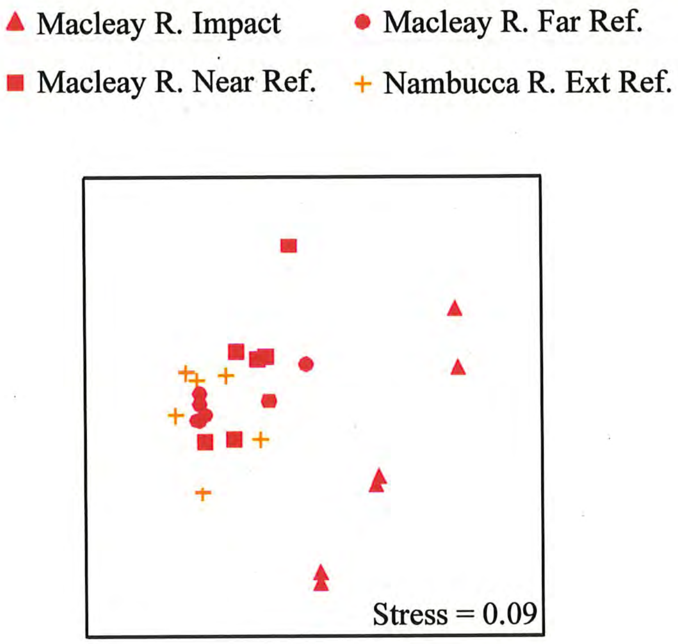

Figure 2.3.3. Non-metric multidimensional ordination plots using community abundance data for the sites sampled on the Macleay and Nambucca Rivers during the pilot study.

3. Methods

3.1. Study area

Juvenile fish and invertebrates were collected from six commercially fished estuaries along the central coast of NSW. Three of the estuaries had tributaries with restricted tidal flow due to floodgates or some other barrier and have either been restored, partially restored or proposed for future restoration. They are the Rockdale Wetlands in Botany Bay (a restored wetland with a modified channel for tidal flow), Ironbark Creek on the Hunter River (a partially restored wetland with floodgates) and the Yarrahapinni Broadwater on the Macleay River (proposed for future restoration by removal of the floodgates). The tributaries in the remaining three estuaries (Nambucca River, Manning River and Wallamba River in Wallis Lake) are the reference estuaries. In these reference estuaries the study locations were not near any floodgates or tidal barriers and are similar in spatial location in the estuary, substrate and seagrass cover to the floodgate sites in the other estuaries.

Twelve locations were selected for sampling, three locations (impacted wetland area, near reference and far reference) in each of the three estuaries with barriers and one location in each of the three reference estuaries. At each location three sites were selected for sampling and three replicate samples were collected from each site yielding 108 seine hauls at each sampling time (Figure 3.1a and Figure 3.1b). All sites were within 7 to 13 km of the river mouth and the site coordinates are given in Appendix 1.

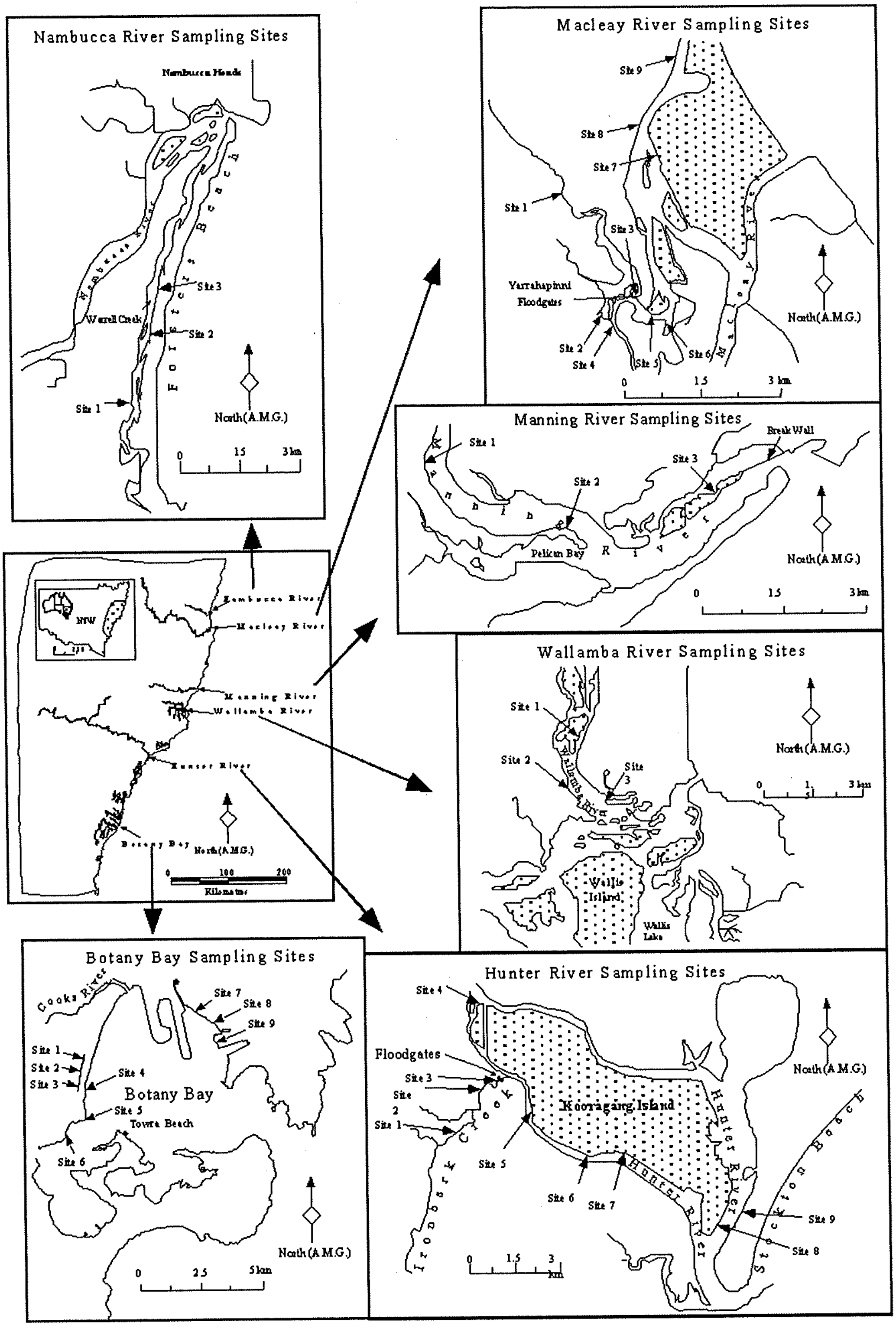

Figure 3.1a. Map of the study area showing the three wetland estuaries (Botany Bay, Hunter River and Macleay River) and the three external reference estuaries (Wallamba River, Manning River and Nambucca River).

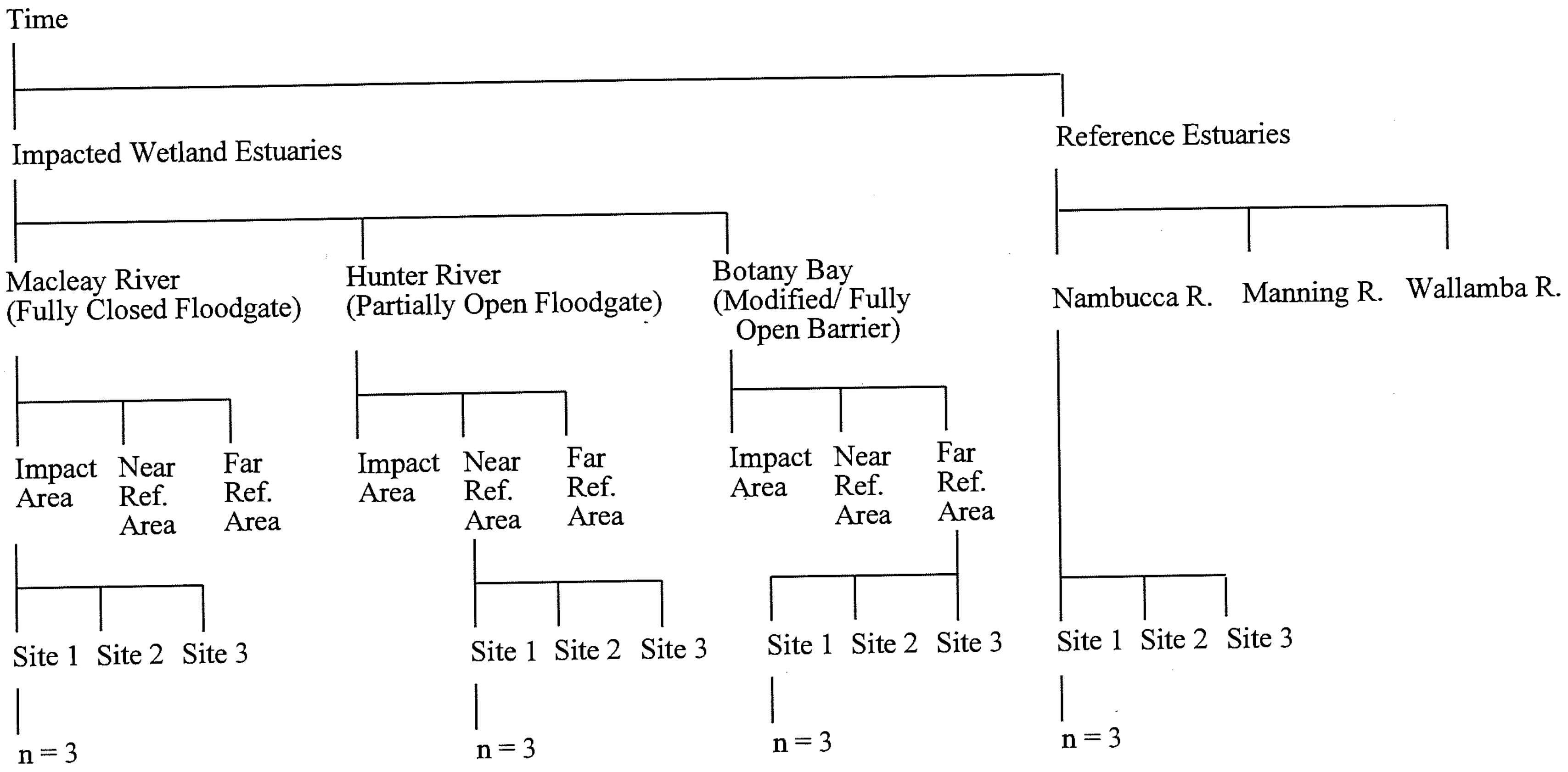

Figure 3.1b. Schematic diagram of the sampling design.

3.2. Field sampling and laboratory techniques

3.2.1. Fish and invertebrates

Following completion of the pilot study in December 1995 and February 1996 routine sampling commenced in March 1996 for all estuaries except Botany Bay which we commenced in June 1996. Samples were collected quarterly and an extra set of samples was collected in February 1997 just prior to the expected opening of the Yarrahapinni floodgates. There was a total of 9 sampling times between March 1996 and December 1997.

Samples were collected using the 20m headline *x* 2 m drop *x* 6mm stretched mesh seine net with a cod-end. The net was set from the shore forming a U-shape and covering an approximate area of 100m^2. The net was then pursed up onto the shore. Three replicate hauls were done at each site and on each sampling occasion. The replicates were positioned to cover the available habitat without overlapping at any point. All sampling was done in daylight hours.

Any large fish caught were measured, weighed and released alive. All remaining animals were firstly euthanased with ethyl p-amino-Benzoate (Benzocaine) and then preserved in 10% formalin/seawater before transporting to the laboratory for processing.

All fish and invertebrates were identified to species and a total number recorded. For each sample the first 50 specimens of each economic important species were measured (fork length) and a length range was recorded for the non-commercial fish species. All measurements were recorded to the nearest millimetre. A total weight in grams for each fish and invertebrate species was obtained.

Some confusion occurred in the separation of small juveniles of *Gobiomorphus coxii* and *Gobiomorphus australis* so we have recorded these two species together as *Gobiomorphus* spp. Large specimens of *Gobiomorphus australis* were easily identified and were kept separate. A few small specimens were too difficult to identify to species and were kept for future identification at the Australian Museum.

There has been some confusion in the description of the eastern population of *Pseudogobius olorum*. McDowall (1996) recognises that the population that extends from Moreton Bay, Queensland to western Victoria and northern Tasmania is an entirely different species, which is known as *Pseudogobius* sp.9. Kuiter (1993) recognises that there may be different populations in the southern part of Australia, but continues to name the species that extends from southern Queensland to western Victoria as *Pseudogobius olorum*. We followed the identification described in Kuiter (1993) throughout the study and have consistently called this species *Pseudogobius olorum*.

Very large samples were sub-sampled. Before sub-sampling, any larger specimens were removed so that specimens in the sub-sample were of uniform size. After sorting, the total number and weight for each species was then multiplied by the sub-sampled factor and the large specimens added. On two occasions there were extremely large catches of *Ambassis jacksoniensis* at the far reference sites in Botany Bay (89,521 individuals SL 13 - 46mm weighing 11,866g in September 1997 and 15,894 individuals SL 12 - 29mm weighing 740g in June 1997). Both of these numbers were reduced to 10,000 individuals in the database so that they were not complete outliers when analysing the data.

Freshwater insects were sometimes present in samples, especially from the impacted wetland areas. The seine net is not an effective method for quantitatively sampling this fauna, however specimens were identified to family level and were recorded as presence/absence data.

3.2.2. Water Quality

Temperature and salinity were measured in the field at each site using a Yeo-kal Model 602 MKII Salinity-Temperature meter. pH was also measured in the field using a Cyberscan10 portable pH meter. At times the pH meter proved unreliable in the field, and pH indicator strips (range 2.0 - 9.0) were used as an alternative method. A TPS model 90FL meter was used to measure temperature, salinity, pH and dissolved oxygen for the September and December 1997 samples.

On five occasions (September and December 1996 and February, September and December 1997) water samples were collected for nutrient analysis. Before we commenced seining at a site a 200mL water sample was collected into a PET bottle then stored on ice and then frozen at the end of the day. Samples were sent to the AWT-EnSight laboratories at West Ryde for analysis of Total Kjeldahl Nitrogen (Metrix Method DW54 and DW56), Total Phosphorous (Metrix Method DW48), and Ammonia (Metrix Method DW40).

The Department of Public Works Manly Hydraulics Laboratory provided data from two data loggers in the Macleay River installed to monitor restoration of the Yarrahapinni Broadwater following the removal of the floodgates. Data loggers were located at Double Island in the main channel of the Macleay River and at Middle Island in the Yarrahapinni Broadwater behind the floodgates. The loggers at Middle Island and Double Island measured conductivity, temperature, pH and dissolved oxygen. Data was measured each hour at each of the loggers. We used the data logged from March 1996 to December 1997 to construct a plot for each variable.

3.3. Experimental design and data analysis

All data were entered into a Microsoft Access database, at the end of each sampling period and manually cross-checked for errors.

The original experimental design underlying this study was based on a 'Beyond BACI' approach (Underwood 1992, 1993). The principle of this design is that samples are taken at replicated intervals of time before and after an impact starts at the potentially impacted location and from a randomly selected set of reference sites. This design was to be used to assess the changes that occur following the removal of the floodgates from the Yarrahapinni Broadwater.

As approval to open the floodgates at the midpoint of the project was not given our experimental design was compromised and we could not address the original objectives. As half the field data were collected we modified our original approach to test the following hypotheses acknowledging the sub-optimal experimental design.

(1) There are no differences between the near and far reference areas of the impacted wetlands and the three external reference estuaries over time (NMDS analysis).

(2) There are no differences between the impacted wetland area, the near reference area and the far reference area over time for each of the three impacted wetlands (three factor ANOVA).

(3) There is no difference between the impacted wetland area and the three external reference estuaries over time (asymmetrical ANOVA).

To investigate these hypotheses we examined the whole community structure using multivariate analysis techniques and then analysed the species richness, abundance and biomass of individual taxa using the Analysis of Variance (ANOVA). For the abundant commercial taxa we assessed the size structure of the sampled population using length frequency histograms.

3.3.1. Fish and invertebrate community structure (multivariate analysis)

Community structure was examined by multivariate techniques using the PRIMER 4.0 software (Plymouth Marine Laboratory). During the study we collected a total of 945 samples. PRIMER analyses are limited to 500 samples. We undertook data reduction by removal of outliers and stepwise pooling of replicates, which were not significantly different.

Abundance data were used, but those taxa contributing less than 1% of the total abundance across all samples were not included in the analysis (Field *et al.*, 1982). When data were pooled the average of the abundances was used and those samples with zero taxa were included in this averaging process. Data were transformed to the fourth root. The Bray-Curtis similarity measure (Bray and Curtis, 1957) was used to construct the similarity matrices. Non-metric multidimensional scaling (NMDS) was then used to construct a two-dimensional ordination plot (Clarke, 1993). Six random starts were used for each ordination. The stress value for each NMDS ordination indicates how well the plot represents the data. Stress values less than 0.05 give an excellent representation, values less than 0.1 correspond to a good ordination, stress less than 0.2 are still usable, but there is a potential for misinterpretation and ordinations with a stress value greater than 0.2 are usually misinterpreted and should not be used (Clarke, 1993).

One-way ANOSIM (Analysis of Similarities) comparisons (Clarke, 1993) were done to test for differences between the impacted wetland areas and reference sites. Five thousand Monte Carlo randomization's were used for the permutation tests. The null hypothesis for the ANOSIM test is that there are no differences in the community composition between the assigned groups. The test is based on differences in the rank similarities between samples in the triangular similarity matrix and examines differences among replicates within a group and differences between groups (Clarke and Warwick, 1994).

A test statistic (*R*) is calculated and is approximately zero if the null hypothesis is true (i.e. on average, the similarities between and within groups are the same) and $R = 1$ if all replicates within groups are more similar to each other than any replicates from different groups. The ANOSIM computes a 'global' *R*, which if significant reflects that a difference occurs between pairs of groups. A series of pairwise tests then computes an *R* value for each pair of groups in the analysis. There must be a minimum of four replicates per group for the pairwise comparisons so as to generate sufficient permutations. The pairwise tests cannot be treated as true 'multiple comparison tests' as the Type I error is not controlled. To account for this the significance level was adjusted according to the number of comparisons in the ANOSIM (i.e. significance level divided by the number of pairwise tests).

The SIMPER (Similarity Percentages) analysis was used to identify the species that contributed most to the average dissimilarity between the ANOSIM groups. Using the Bray-Curtis dissimilarity an average contribution value is calculated for each species for every pair of groups. SIMPER then calculates a ratio based on the average contribution of each species and the standard deviation of the dissimilarity values for that species (see Clarke and Warwick, 1994 for details). If this ratio is large then that species consistently contributes greatly to the dissimilarity between the two groups and is thus a good discriminating species of the two groups.

3.3.2. Species richness, abundances and biomass of species (ANOVA)

The species richness (number of taxa) and total abundance of taxa were examined at each of the impacted wetland estuaries. Taxa selected for individual analysis were chosen according to their commercial/economic importance and/or their abundances at the impacted wetland estuary. The freshwater bug taxa were excluded in all these analyses as only presence/absence data were available.

The analysis of variance (ANOVA) was used to examine these variables and two ANOVA designs were required to investigate the hypotheses and each impacted wetland estuary was analysed separately. This was necessary as the three impacted estuaries have different opening regimes and a combined analysis results in lack of power and confounding of effects.

To test the hypothesis that there are no differences between the impacted wetland area and the near reference area and the far reference area we used a three factor analysis of variance (see Table 3.3.2a). The factors were Times (random factor), Areas (fixed factor), and Sites (nested within Areas - random factor). This arrangement of factors as either fixed or random in the design means that the denominator for an F-ratio for the area term is only derived if pooling is possible. If time were considered as fixed an F-ratio for the area term is possible. However, the ability to generalise the results to future times is lost. In addition the interaction terms were often significant in the fixed time model requiring *post-hoc* pooling in the testing procedure with many, multiple mean comparison tests increasing the likelihood of type II errors.

The *post-hoc* pooling procedures (see Winer, 1971; Underwood, 1981) used in the chosen model to generate an *F*-ratio for the Area term if the Time x Area interaction term is not significant at the 25% probability level required that term to be pooled with the residual. The denominator for Area then becomes the Site(Area) term. When the Time x Site(Area) term is significant it is still permissible to examine the Time x Area term. This is because the Sites are a nested term and if the Time x Area term is significant it means that on average the variation between areas is larger than that between individual sites within an area. However if the Time x Area term is not significant, it is worthwhile examining the Time x Sites(Area) term if it is significant, as this indicates if one or two particular sites or time periods are behaving differently to all others.

Table 3.3.2a. ANOVA model to detect differences between areas.

Source of Variation	**df**	**Denominator for F-ratio**
Time	(a-1)	Time x Site(Area)
Area	(b-1)	After pooling Site(Area)
Time x Area	(a-1)(b-1)	Time x Site(Area)
Site(Area)	c(b-1)	Time x Site(Area)
Time x Site(Area)	(a-1)c(b-1)	Residual
Residual	abc(n-1)	

The second hypothesis requires an asymmetrical design - it involves the comparison of the single impacted wetland area with the three external reference estuaries (see Underwood, 1993). The model is built around two separate ANOVA's. Firstly an analysis using all the estuaries (impacted wetland area and each of the reference estuaries) is done and then a second ANOVA which uses only the external reference estuaries is done (Table 3.3.2b). The mean square estimates are then calculated based on a model, which is fully balanced (i.e. three impacted estuaries and three external reference estuaries). The final asymmetrical ANOVA is constructed by partitioning the factors from the first two analyses (all estuaries and external reference estuaries only) and using the mean square estimates from the fully balanced design to determine the denominator for the F-ratio for each of the factors. The factors used in the analyses are Time (Random), Estuary (Fixed) and Site nested within Estuary (Random). The test for the 'Impact vs Reference' or the 'Among References' terms requires pooling. Similar post-hoc pooling procedures to those used for the 3-factor ANOVA's can be used to generate an *F*-ratio for these terms if the 'Time x Impact vs References' and/or the 'Time x Among References' terms respectively are not significant at the 25% probability level. These terms can then be pooled with the residual to achieve a test. The denominator for the 'Impact vs References' term then becomes the mean square value of the 'Among Controls' term and the denominator for the 'Among References' term becomes the mean square value of the 'Impact vs References' term. Note, however that both of these tests lack power and so are very conservative in detecting a change (i.e. there is a large risk of a Type II error). For this reason, when a test was possible for these terms but gave a non-significant result, the data was graphed to demonstrate the magnitude of difference between the means.

Cochrans test was used to determine if variances were homogenous. Where necessary data were transformed to log(x+1) as this gave the most consistent degree of variance homogeneity for the different variables analysed. Where variances were still heterogeneous after transformation interpretation of the results is approached with caution.

When the ANOVA identified differences, *post-hoc* analyses using the Student Newman-Keuls (SNK) test were done to determine which pairs of means were significantly different from each other. Multiple comparison tests such as the SNK tests are modified for examining differences identified from an asymmetrical ANOVA. The SNK does not adjust for the different number of replicates comprising the means from replicated reference locations versus the single impacted location. Therefore to be conservative we used the number of replicates associated with the 'impacted' means when calculating the standard error to be used in the SNK test rather than the number of replicates comprising the 'reference' means. The graphical presentation of the results are based on arithmetic means for clarity and therefore differ in their magnitude to the analysis which is based on the transformed data.

Table 3.3.2b. Steps for constructing the asymmetrical ANOVA model to detect differences between the impacted wetland area and the external reference estuaries.

Step 1. *Calculate two separate ANOVA's, one with all estuaries (reference and impact) and another with only the reference estuaries. The sums of squares for each of these ANOVA's is required for the final asymmetrical ANOVA.*

Source of Variation	**df**	**Denominator for F-ratio**	**Sums of Squares for asymmetrical design**	
			All Estuaries	Reference Estuaries
Time	(a-1)	Time x Site(Estuary)	A	H
Estuary	(b-1)	No valid F-ratio	B	I
Site(Estuary)	(c-1)	Time x Site(Estuary)	C	J
Time x Estuary	(a-1)(b-1)	Time x Site(Estuary)	D	K
Time x Site(Estuary)	(a-1)b(c-1)	Residual	E	L
Residual	abc(n-1)		F	M
Total			G	N

Step 2. *Calculate an ANOVA model for a data set that would be fully balanced (i.e. if there were equal numbers of reference and impact locations). The denominators for the F-ratio for this ANOVA is required for the final asymmetrical ANOVA.*

Source of Variation	**df**	**Denominator for F-ratio**
Time	(a-1)	Time x Estuary(Treatment)
Treatment	(b-1)	No valid F-ratio
Time x Treatment	(a-1)(b-1)	Time x Estuary(Treatment)
Estuary(Treatment)	b(c-1)	No valid F-ratio
Time x Estuary(Treatment)	(a-1)b(c-1)	Time x Site(Estuary)
Site(Estuary)	db(c-1)	Time x Site(Estuary)
Time x Site(Estuary)	(a-1)db(c-1)	Residual
Residual	abcd(n-1)	

Table 3.3.2b. Continued

Step 3. *Final design for the asymmetrical ANOVA.*

Source of Variation	**df**	**Sums of Squares**[+]	**Denominator for F-ratio**[++]
Time	(a-1)	A	Time x Among References
Estuary	(b-1)	B	
Impact vs Reference		B-I	No valid F-ratio
Among References		I	No valid F-ratio
Site(Estuary)	(c-1)	C	
Site(Impact)		C-J	Residual
Site(Among References)		J	Residual
Time x Estuary	(a-1)(b-1)	D	
Time x Impact vs Reference		D-K	Time x Among References
Time x Among References		K	Time x Site(Estuary)
Time x Site(Estuary)	(a-1)b(c-1)	E	
Time x Site(Impact)		E-L	Residual
Time x Site(Reference)		L	Residual
Residual	abc(n-1)	F	
Total		G	

[+] From Step 1

[++] From Step 2

3.4. Population size structure (length frequency data)

Data collected for the commercially important species were used to construct length frequency histograms for each of the impacted wetland areas and for the near and far reference areas. Data were plotted for each time to identify any differences in size classes over time between the reference and impact areas. There were insufficient commercial taxa collected in the Yarrahapinni Broadwater so the Macleay River data has not been presented.

4. Results

4.1. General trends

A total of 186 taxa and 1,497,404 individual fish and invertebrates with a combined weight of approximately 419 kg were collected during the study period (Appendices 2 and 3). Fifty seven of these taxa were of economic importance (47 fish species and 10 invertebrate species) and accounted for approximately 212 kg of the total weight. Most fish species were juveniles or small cryptic species in the length range 5 -150 mm.

Ten species contributed approximately 90% of the total abundance across all sites and times (Table 4.1). Five of these were non-commercial fish (*Ambassis jacksoniensis*, *Redigobius macrostoma*, *Gobiopterus semivestitus*, *Pseudogobius olorum* and *Philypnodon grandiceps*), two were commercial fish (*Hyperlophus vittatus* and *Mugil cephalus*) and 3 were carid shrimps (*Acetes sibogae australis*, *Palaemon debilis* and *Macrobrachium intermedium*). *Ambassis jacksoniensis*, *Redigobius macrostoma*, *Pseudogobius olorum* and the shrimps were always amongst the top 10 taxa each sampling time, whereas the other four taxa were ranked differently for individual times. *Mugil cephalus* was most abundant in Botany Bay and the Manning River. *Hyperlophus vittatus* was most abundant in the Hunter River and individual samples often contained large numbers of this schooling species.

On average the areas in Botany Bay had the least number of taxa and the areas in Wallamba River had the most taxa of all estuaries sampled (Figure 4.1). Of the impacted wetland areas, Ironbark Creek had the greatest number of taxa, and actually supported more taxa than were sampled in the main Hunter River estuary. In comparison, the area behind the Yarrahapinni Broadwater floodgates had fewer taxa than the Macleay River estuary outside the floodgates (Figure 4.1). Only four taxa and 22 individuals of economic importance (*Anguilla reinhardtii*, *Liza argentea*, *Mugil cephalus* and *Penaeus plebejus*) were found behind the Yarrahapinni Broadwater floodgates (Appendix 2).

Some species were unique to each of the estuaries. There were more unique taxa collected from Botany Bay (23) than any other estuary. Eleven species were unique to the Hunter River and 8, 7, 5 and 7 taxa were unique to the Macleay, Manning, Nambucca and Wallamba Rivers, respectively. Twenty four of all these unique taxa were represented in our sampling with only one specimen. In comparison of the 186 taxa collected, only 36 occurred in all six of the estuaries.

Table 4.1. The fifty most abundant taxa collected from all estuaries and sites between March 1996 and December 1997.

Scientific Name	Time Code									Total	%	Cum
	Mar'96	Jun'96	Sep'96	Dec'96	Feb'97	Mar'97	Jun'97	Sep'97	Dec'97			
Acetes sibogae australis	122077	138920	24516	5368	19503	10116	154370	10853	29071	514794	34.37	34.37
Ambassis jacksoniensis	23248	42530	107499	7662	13712	11905	37238	17040	13064	273898	18.28	52.65
Palaemon debilis	20190	35317	37122	42535	34273	15271	16010	9304	27857	237879	15.88	68.53
Redigobius macrostoma	7466	18327	9293	6532	4553	4631	17613	10288	3729	82432	5.50	74.04
Macrobrachium intermedium	5696	6793	2586	15609	13218	6092	5391	7216	7933	70534	4.71	78.75
Gobiopterus semivestitus	4426	11203	16392	870	4341	3857	17707	5592	2368	66756	4.46	83.20
Pseudogobius olorum	3903	5416	6455	2724	4929	4376	7294	4598	3941	43636	2.91	86.12
*Hyperlophus vittatus**	4306	409	1214	7199	1351	2986	5212	4630	1005	28312	1.89	88.01
Philypnodon grandiceps	360	5310	1251	2563	4073	2873	2245	278	6759	25712	1.72	89.72
*Mugil cephalus**	68	3699	8039	275	193	221	327	1002	76	13900	0.93	90.65
*Acanthopagrus australis**	385	883	5247	595	856	736	2258	1523	1217	13700	0.91	91.56
Favonigobius tamarensis	1021	726	1553	3507	1189	964	674	321	1337	11292	0.75	92.32
*Pelates sexlineatus**	2646	1139	460	511	1609	954	2218	634	1031	11202	0.75	93.07
*Penaeus plebejus**	1040	489	4768	786	305	442	1099	1288	980	11197	0.75	93.81
Favonigobius exquisites	1517	2150	1400	1341	555	624	1792	1160	576	11115	0.74	94.56
Pseudomugil signifer	2079	558	384	353	1951	212	447	723	2736	9443	0.63	95.19
*Metapenaeus macleayi**	687	1733	570	1845	1895	1029	1046	499	121	9425	0.63	95.81
*Liza argentea**	314	701	1543	850	703	479	1257	959	383	7189	0.48	96.29
Chlorotocella leptorhynchus	0	506	1298	37	46	8	2377	673	134	5079	0.34	96.63
Philypnodon spp.	18	358	86	99	754	54	2130	90	1297	4886	0.33	96.96
*Gerres subfasciatus**	1268	644	142	331	684	538	197	125	201	4130	0.28	97.24
*Myxus elongatus**	585	933	462	344	142	1056	301	179	123	4125	0.28	97.51
Ambassis marianus	467	630	508	511	324	438	16	7	327	3228	0.22	97.73
Arenigobius bifrenatus	796	109	147	739	302	446	188	96	238	3061	0.20	97.93
*Rhabdosargus sarba**	130	145	1016	168	111	64	650	629	24	2937	0.20	98.13
*Girella tricuspidata**	91	12	1241	339	24	38	6	923	213	2887	0.19	98.32
Favonigobius lateralis	0	415	421	246	574	406	91	23	636	2812	0.19	98.51
*Sillago ciliata**	478	288	216	222	172	528	260	165	117	2446	0.16	98.67
Centropogon australis	151	119	770	340	223	210	137	98	77	2125	0.14	98.81
Hypseleotris compressus	80	203	611	361	52	148	350	125	91	2021	0.13	98.95
Gambusia holbrookii	122	314	32	175	490	114	149	212	80	1688	0.11	99.06
Gobiomorpus spp.	174	33	551	244	66	18	41	18	16	1161	0.08	99.14
Siphamia roseigaster	272	80	9	3	29	656	44	20	2	1115	0.07	99.21
*Meuschenia trachylepis**	173	54	150	262	90	21	39	62	186	1037	0.07	99.28
Alpheus richardsoni	314	175	52	48	255	11	42	12	5	914	0.06	99.34
Idiosepius notoides	56	30	48	2	57	6	273	149	135	756	0.05	99.39
Latreutes pygmaeus	30	0	57	0	80	0	355	2	156	680	0.05	99.44
Atherinomorus ogilbyi	0	2	8	13	37	37	292	21	164	574	0.04	99.48
Hymenosoma hodgkini	10	345	21	120	16	8	39	3	6	568	0.04	99.51
Monodactylus argenteus	126	133	35	12	12	105	14	1	3	441	0.03	99.54
Urocampus carinirostrus	19	35	34	54	67	14	22	114	63	422	0.03	99.57
Tetractenos hamiltoni	50	43	51	44	40	43	46	27	24	368	0.02	99.60
Arenigobius frenatus	33	53	17	38	38	61	35	16	56	347	0.02	99.62
Amarinus spp.	3	72	16	59	28	20	43	32	72	345	0.02	99.64
Mugilogobius paludis	3	16	62	26	5	3	104	89	7	315	0.02	99.66
*Engraulis australis**	179	20	1	28	5	70	3	0	0	306	0.02	99.68
Pandaculus lidwilla	40	112	104	26	3	3	5	0	0	293	0.02	99.70
Caridina macculochi	24	97	0	1	2	149	5	1	0	279	0.02	99.72
*Penaeus esculentus**	134	21	0	2	23	4	54	3	13	254	0.02	99.74
Microcanthus strigatus	0	18	14	0	0	0	40	164	2	238	0.02	99.76
Remaining 159 species	492	302	567	289	488	378	436	331	442	3725	0.25	100.00
Total	207747	282620	239039	106308	114448	73423	282982	82318	109094	1497979		

* economically important species

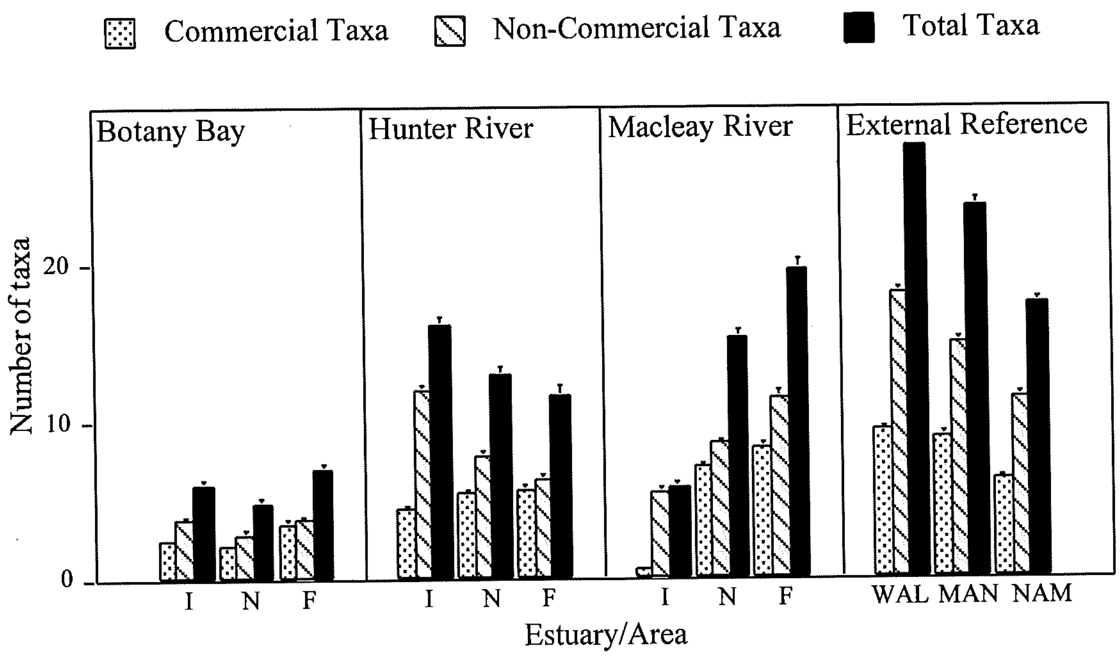

Figure 4.1. Average (+SE) number of commercial taxa, non-commercial taxa and total taxa collected from impacted wetlands, near reference, far reference and each of the external reference estuaries during the study period.

Impacted wetlands (I), near reference (N), far reference (F); External reference estuaries: Wallamba River (WAL), Manning River (MAN), Nambucca River (NAM).

4.2. Fish and invertebrate community patterns (multivariate analysis)

An ordination was done for each time, where each ordination point represented a sample. These analyses identified outliers in the Botany Bay near reference site replicates in December 1996 and two of the Macleay River site 1 (impact area) replicates during March 1997 (Figure 4.2). These outliers were so different from all other sample replicates that the remaining data were forced to concentrate in a very tight cluster (Figure 4.2). These sample replicates differ from all others because of the comparatively low total number of taxa collected in these replicates and also some of the taxa that did occur were quite rare species (e.g. all 13 specimens of *Atherinomorus ogilbyi* collected in December 1996 were from the Botany Bay near reference sites). These outliers were excluded in all subsequent multivariate analyses.

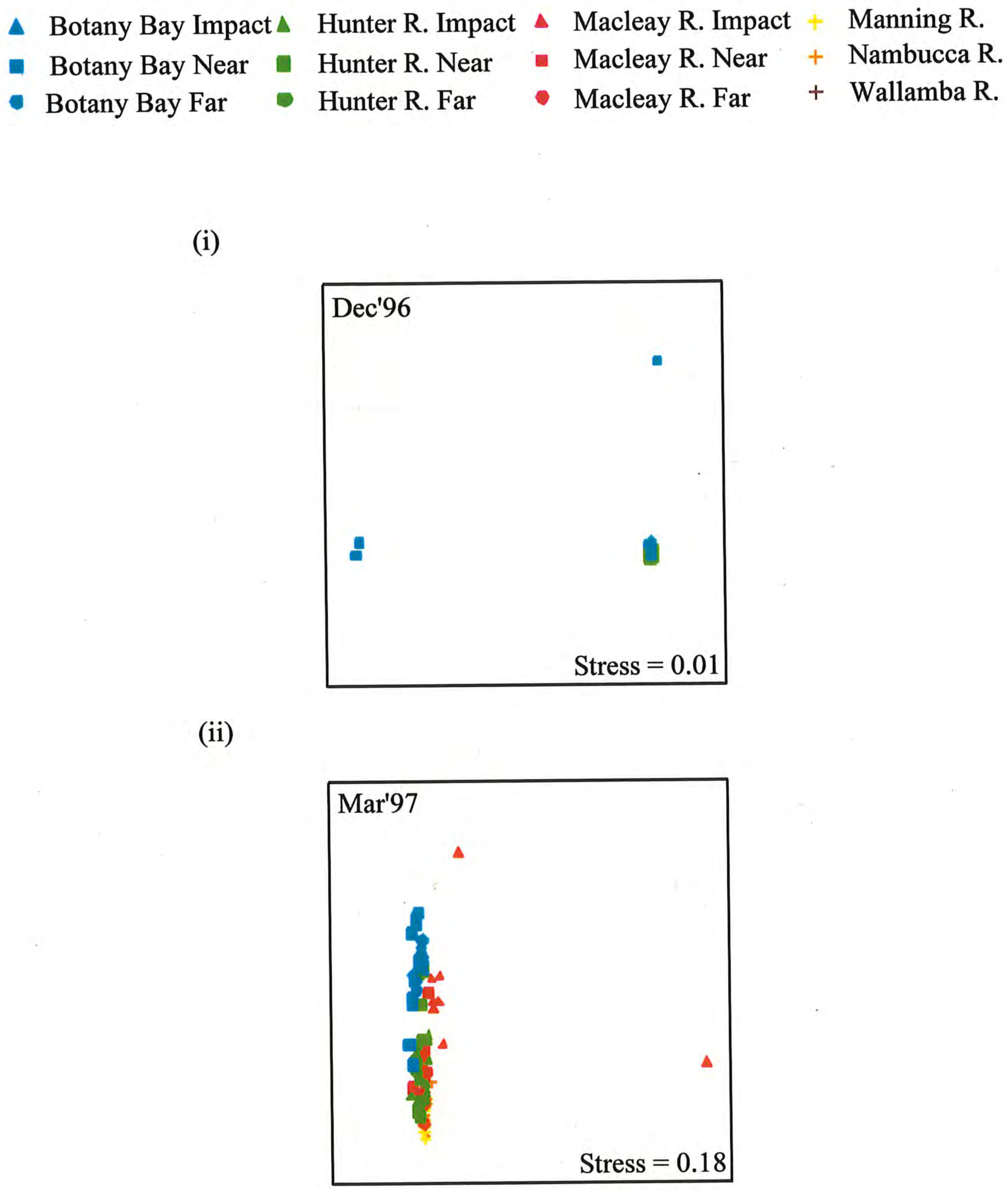

Figure 4.2. Two dimensional plots of the results from non-metric multidimensional analyses using community abundance data for (i) December 1996 showing the Botany Bay near reference outlier samples and (ii) March 1997 to show the Macleay River site one outlier sample.

4.2.1. Spatial patterns

There was a consistent spatial trend in the replicate samples for an area during each sampling period (Figure 4.2.1a). The impacted wetland areas in the Macleay River (Yarrahapinni Broadwater) and Botany Bay (Rockdale Wetlands) always showed a distinct separation from the remaining replicates. The only exception was in September 1997 when there was no separation between any of the areas (Figure 4.2.1a). However the stress value associated with this ordination was 0.24 indicating that this MDS is not a good representation of the data.

Reference locations within an estuary and the external reference estuaries were always grouped together in a large cluster. Also, samples from the impacted area in the Hunter River (Ironbark Creek) were either intermingled with or on the outer edge of the cluster of reference locations, indicating the similarity between these locations.

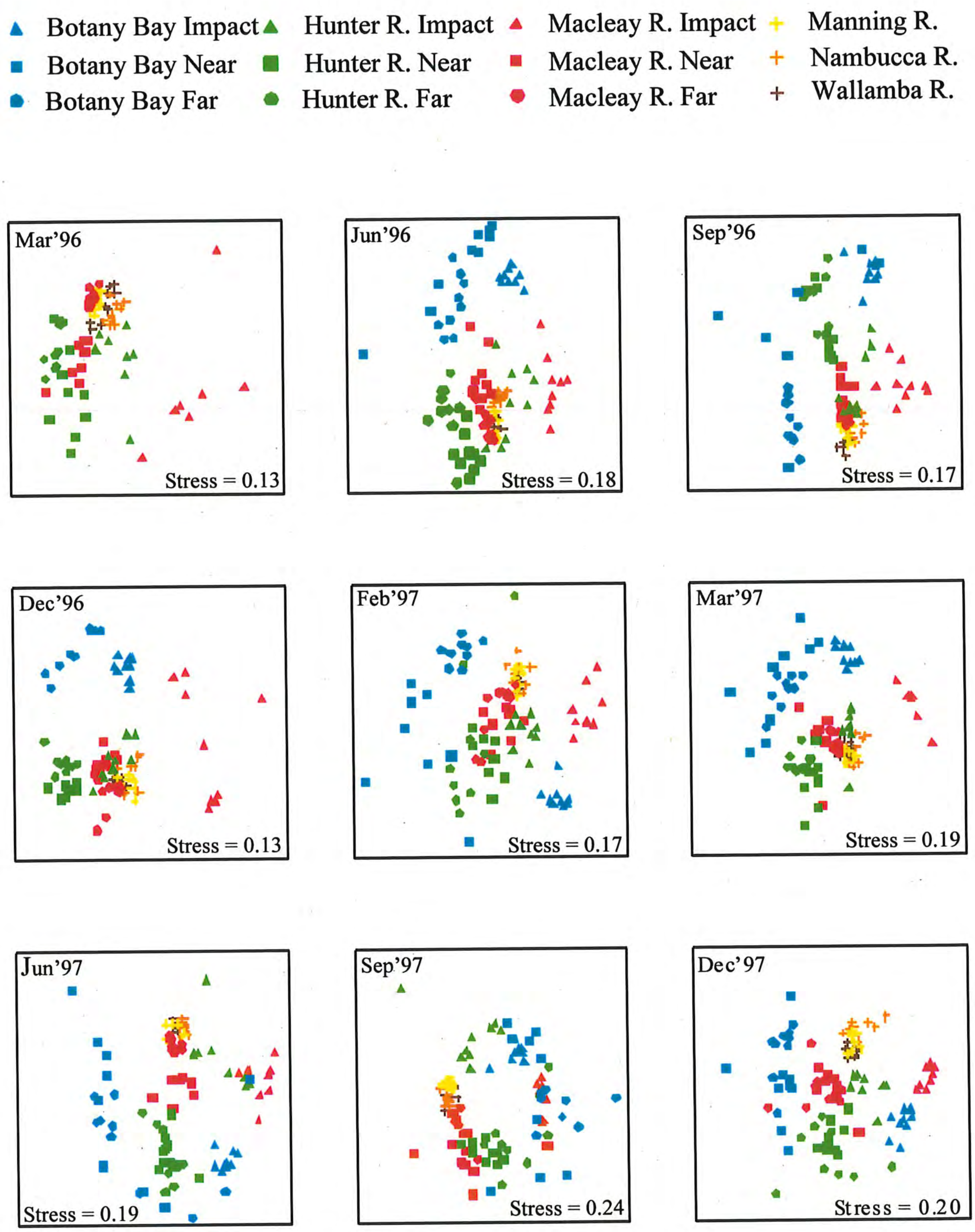

Figure 4.2.1a. Two dimensional plots of the non-metric multidimensional analyses using community abundance data for each of the sampling periods

Data points are replicates. The outlier points were removed prior to the ordination and samples with no taxa were excluded from the analysis.

Since the community spatial pattern followed much the same trend for each sampling time, data reduction proceeded by obtaining a single value for each site by averaging across times (Figure 4.2.1b). The Botany Bay and Macleay River impact sites were clearly separated from all other sites, with a greater variation between the Macleay River sites compared to Botany Bay. Of the estuaries with floodgate structures, the Hunter River showed the least variability between the impact and near and far reference areas.

Sites within the Botany Bay near and far reference areas showed the greatest variability. Botany Bay was different to the other sampled estuaries including the reference estuaries and therefore analysis of the Botany Bay impact location and the reference estuaries (asymmetrical ANOVA) was not done. A partial explanation for this result is Botany Bay is physically very different from the other five estuaries that were sampled. The near and far reference areas in the Bay were typified by a coarse sandy bottom and patches of *Zostera* were relatively sparse at all of the sites. In the other estuaries the sites were typically on a fine mud substrate where beds of *Zostera* were present, they were much more dense, especially in the estuaries north of the Hunter River. The Rockdale wetlands area at Botany Bay were also unusual in that they were located in an urban area where the surrounding area has been altered into parkland. The wetlands are connected to the Bay by a modified channel, which flows under the road for 700 meters.

Sites within each of the external reference sites of the Manning, Nambucca and Wallamba Rivers were very similar to one another and to the Hunter and Macleay near and far reference locations. This affirmation of the hypothesis of no difference between the above reference locations was also supported by analysis of variance (not presented).

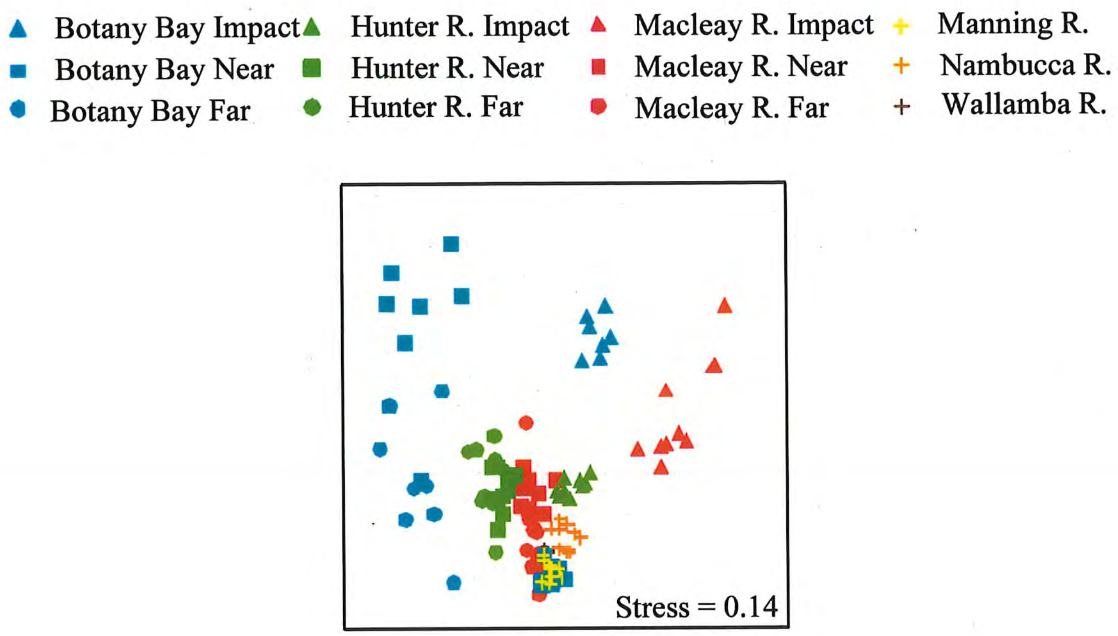

Figure 4.2.1b. Two dimensional non-metric multidimensional plot using community abundance data to show the spatial trends in the community.

Each point represents a site and is the average for that site across all sampling times. Outlier replicates were removed from the data set prior to averaging the data.

The ANOSIM analyses which compared each of the impacted areas with all the reference areas combined, revealed significant variation in the community abundance between the four areas ($R = 0.481$, Table 4.2.1a). The pairwise tests showed that all pairs were significantly different except for the comparison of Hunter River impact sites with the reference sites. The high R value (i.e. $R = 1.00$, Table 4.2.1a) for the comparison of the Botany Bay impact sites and the Hunter River impact sites indicates that all the sites within either of these areas are more similar to each other than any of the site comparisons between the areas again confirming the differences in Botany Bay.

A SIMPER analysis of Macleay River impact, Botany Bay impact and reference areas was done to determine the discriminating taxa between these areas (Table 4.2.1b). The average dissimilarity between each pair of comparisons was always quite large (>70% in all cases) confirming the ANOSIM results that these areas are different. The strongest discriminating taxa (based on the consistency ratio) between areas was for comparison of the Macleay River impact area and the Botany Bay impact area. *Acanthopagrus australis* and *Myxus elongatus* were most consistently found only at Botany Bay while *Pseudomugil signifer* and the dragonfly nymphs of the families Coenagrionidae and Libellulidae were only found at the Macleay River. Taxa discriminating the Botany Bay impact sites from the reference sites included species of *Philypnodon* and *Penaeus plebejus*. The most notable taxa discriminating the Macleay River impact sites from the reference sites was *Gambusia holbrookii*, which occurred, in low abundances at reference sites.

Table 4.2.1a. Summary of one-way ANOSIM results to test for differences between each of the 3 impacted areas (Botany Bay, Macleay River and Hunter River) and all of the reference areas combined.

Replicates for each comparison are an average of all replicates at an area for each time.

Source	***R***	**Signifcance Level (%)**
Among all areas (Global)	0.481	sig <0.01
Pairwise tests		
Botany Impact vs Hunter Impact	1	sig <0.01
Botany Impact vs Macleay Impact	0.977	sig <0.01
Botany Impact vs Reference	0.661	sig <0.01
Hunter Impact vs Macleay Impact	0.922	sig <0.01
Hunter Impact vs Reference	0.011	ns 41.7
Macleay Impact vs Reference	0.802	sig <0.01

Table 4.2.1b. Results from the SIMPER analysis showing the species that discriminate differences in communities between Macleay River Impacted sites, Botany Bay Impacted sites and all other sites.

Species	**Mean Abundance**		**Consistency ratio**	**Percent**	**Cumulative Percent**
Macleay River Impact vs Botany Bay Impact			*(Average dissimilarity = 70.69)*		
	MACI	BOTI			
Philypnodon grandiceps	16.4	306.37	1.88	8.7	8.7
Acanthopagrus australis	0	50.32	5.18	8.23	16.94
Myxus elongatus	0	36.76	3.07	7.21	24.15
Pseudomugil signifer	47.73	0	1.28	5.39	29.54
Mugil cephalus	0.21	25.94	1.45	4.53	34.07
Pseudogobius olorum	91.94	8.89	1.99	4.11	38.18
Liza argentea	0.05	4.58	2.17	3.91	42.08
Gobiomorphus spp.	5.65	0	1.38	3.62	45.7
Philypnodon spp.	52.02	1.68	1.33	3.6	49.31
Hypseleotris compressus	2.64	0	2.15	3.43	52.74
Gambusia holbrookii	17.42	1.86	1.51	3.1	55.85
Coenagrionidae	0.7	0	2.46	2.59	58.44
Libellulidae	0.57	0	2.53	2.46	60.9
Ambassis jacksoniensis	0.05	1.17	1.56	2.26	63.15
Hydrophildae	0.38	0	2.31	2.19	65.34
Caradina maccullochi	1.92	0	0.96	2.09	67.43
Corixidae	0.31	0	1.72	1.87	69.3
All Reference Sites vs Botany Bay Impact			*(Average dissimilarity = 77.78)*		
	Reference	BOTI			
Philypnodon grandiceps	1.82	306.37	1.83	7.41	7.41
Ambassis jacksoniensis	259.97	1.17	1.44	4.89	12.29
Acetes sibogae australis	701.09	0.01	0.97	4.53	16.83
Palaemon debilis	335.76	0.06	1.25	4.09	20.92
Acanthopagrus australis	13.01	50.32	1.32	3.36	24.28
Redigobius macrostoma	110.54	0.01	1.35	3.17	27.44
Myxus elongatus	2.04	36.76	1.38	3.08	30.52
Favonigobius exquisites	15.43	0	1.75	3.05	33.58
Penaeus plebejus	14.59	0.01	1.82	2.73	36.31
Mugil cephalus	16.82	25.94	1.04	2.67	38.97
Macrobrachium intermedium	100.06	0.08	1.14	2.61	41.59
Pseudogobius olorum	42.98	8.89	1.45	2.6	44.19
Hyperlophus vittatus	40.26	0.01	0.93	2.58	46.77
Sillago ciliata	3.45	0	1.44	2.46	49.23
Gobiopterus semivestitus	90.67	0.03	1.27	2.44	51.66
Favonigobius tamarensis	11.83	0.1	1.75	2.11	53.78
Philypnodon spp.	0.04	1.68	2.08	2.1	55.88
Gerres subfasciatus	5.29	0	1.69	2.07	57.94
All Reference sites vs Macleay River Impact			*(Average dissimilarity = 84.75)*		
	Reference	MACI			
Ambassis jacksoniensis	259.97	0.05	1.65	5.16	5.16
Acetes sibogae australis	701.09	1.38	0.96	3.81	8.97
Philypnodon spp.	0.04	52.02	1.77	3.64	12.61
Palaemon debilis	335.76	0.81	1.32	3.39	16.01
Gambusia holbrookii	0.16	17.42	2.11	3.18	19.19
Pseudogobius olorum	42.98	91.94	1.16	3.17	22.36
Pseudomugil signifer	7.8	47.73	1.04	2.65	25.01
Redigobius macrostoma	110.54	0.46	1.41	2.58	27.59
Favonigobius exquisites	15.43	0.02	1.72	2.5	30.09
Macrobrachium intermedium	100.06	1.85	1.09	2.32	32.41
Hyperlophus vittatus	40.26	0	0.94	2.27	34.68
Penaeus plebejus	14.59	0.1	1.67	2.17	36.85
Sillago ciliata	3.45	0	1.44	2.08	38.93
Gobiopterus semivestitus	90.67	0.09	1.2	2	40.93
Philypnodon grandiceps	1.82	16.4	1.1	1.99	42.92
Gobiomorphus spp.	0.58	5.65	1.2	1.96	44.88
Acanthopagrus australis	13.01	0	1.78	1.92	46.8
Favonigobius tamarensis	11.83	0.17	1.68	1.82	48.62
Gerres subfasciatus	5.29	0	1.68	1.78	50.4
Liza argentea	9.69	0.05	1.57	1.77	52.16
Hypseleotris compressus	1.2	2.64	1.51	1.75	53.92
Amarinus spp.	0.09	1.86	1.75	1.61	55.52
Metepenaeus macleayii	9.95	0.49	1.22	1.57	57.09

4.2.2. Temporal patterns

There was a strong temporal pattern in the overall community structure when all the data was pooled for each sampling occasion (Figure 4.2.2). The months sampled in summer and autumn were the most variable and the winter months were the least variable. The March 1996 sampling occasion did not include samples from Botany Bay so this is likely to account for its large separation from the other February/March samples.

There are not enough replicate times for each season for an ANOSIM analysis. The SIMPER analysis shows the average dissimilarity between all pairs of comparisons was quite low (Table 4.2.2) indicating that the groups were not sufficiently different to be represented by individual taxa.

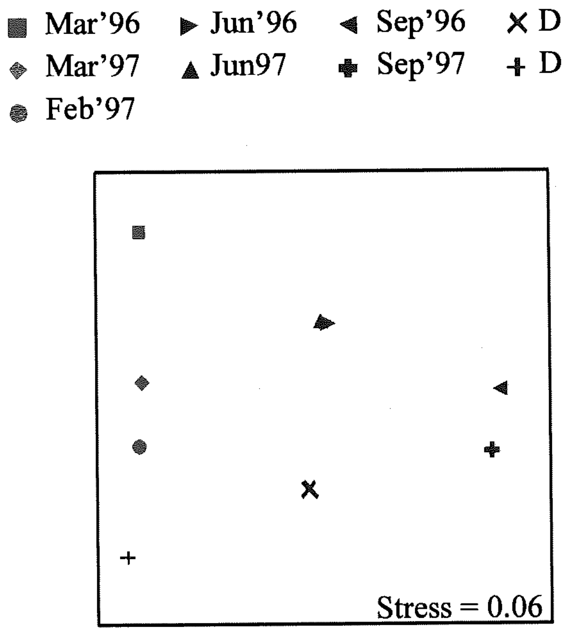

Figure 4.2.2. Two dimensional plot of the non-metric multidimensional analysis using community abundance data to show the temporal trends in the community.

Each point represents a sampling period and is the average data for that time across all estuaries and sites that were sampled. The outlier replicates were removed from the data set prior to averaging the data.

Table 4.2.2. Average dissimilarity values for differences between seasons as calculated from the SIMPER analysis. The values indicate the magnitude of differences between communities in different seasons.

Season comparison	**Average dissimilarty %**
December vs March	21.79
June vs March	21.66
June vs December	23.65
September vs March	25.04
September vs December	23.97
September vs June	21.09

4.3. Species richness, biomass and species abundances

Prior to analysis data were transformed. However, in some cases the variances of the data set remained heterogeneous, thus the interpretation of these specific analyses needs to be approached with some caution (see methods section 3.3.2).

4.3.1. Macleay River

Species richness and biomass

There was a significant temporal and spatial variation in the species richness of fauna in the Macleay River (Table 4.3.1a). There were always fewer taxa collected from the impacted wetland area compared with the near and far reference areas (Figure 4.3.1a) and this difference was significant for the first seven sampling occasions (Appendix 4.1). There were always slightly more taxa collected from the far reference except for December 1997 when there were significantly fewer taxa collected from this area compared to any of the other sampling periods (Figure 4.3.1a, Appendix 4.1). The Macleay River impacted wetland area was also less diverse than the external reference estuaries and this difference was consistent through time (Table 4.3.1b, Figure 4.3.1a, Appendix 4.2).

The total biomass of fish and invertebrates collected from the Macleay River followed a similar trend to the species richness (Table 4.3.1a, 4.3.1b). Also, in June 1996 there was a significant difference in the total biomass between the three areas of the Macleay River (Figure 4.3.1b, Appendix 4.1). For all sampling occasions the biomass at the Macleay River impacted wetland area was significantly less than at the external reference estuaries (Appendix 4.2, Figure 4.4.3b).

Table 4.3.1a. Summary of the three factor Analysis of Variance results for the comparison of the Macleay River impacted wetland area and the near and the far reference areas through time.

The species richness and biomass of fish and invertebrates and the abundances of selected commercial and non-commercial taxa were analysed. Only the mean square (MS) values and the significance levels for the *F*-tests (F) are shown. All data were transformed to log(x+1) and mean square values have been rounded to 3 decimal places. The results of the Cochran's test after transformation are shown at the bottom of the table (s = significant, *p* > 0.05; ns = not significant, *p* < 0.05).

Source of variation	**df**	**Species Richness**		**Biomass**		***Acanthopagrus australis***		***Mugil cephalus***		***Penaeus plebejus***		***Ambassis jacksoniensis***		***Gobiopterus semivestitus***		***Pseudogobius olorum***		***Philypnodon grandiceps***	
		MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F
Time	8	0.159	**	0.889	*	2.883	**	1.643	**	2.976	**	0.450	ns	1.692	**	2.673	**	0.972	**
Area	2	6.752	+	51.365	+	21.533	+	2.168	+	15.963	+	69.654	+	8.618	+	4.015	+	6.016	+
Time x Area	16	0.207	**	1.343	**	1.207	**	0.753	**	1.041	**	1.007	**	1.047	**	3.149	**	1.077	**
Site(Area)	6	0.324	**	2.725	**	0.828	**	0.185	ns	0.216	ns	3.768	**	0.523	*	5.754	**	0.121	ns
Time x Site(Area)	48	0.044	**	0.331	**	0.188	**	0.239	**	0.193	**	0.372	ns	0.210	**	0.524	**	0.166	**
Residual	162	0.011		0.167		0.083		0.101		0.059		0.282		0.070		0.106		0.033	
Cochran's Test		s		s		s		s		s		s		s		s		s	

ns : not significant, *p* > 0.05
* : significant, *p* < 0.05
** : significant, *p* < 0.01

+ : no valid F-ratio

Table 4.3.1b. Summary of the Asymmetrical Analysis of Variance results for the comparison of the Macleay River impacted wetland area with the three external reference estuaries through time.

The species richness and biomass of fish and invertebrates and the abundances of selected commercial and non-commercial taxa were analysed. Only the mean square (MS) values and the significance levels for the *F*-tests (F) are shown. All data were transformed to log(x+1) and mean square values have been rounded to 3 decimal places. The results of the Cochran's test after transformation are shown at the bottom of the table (s = significant, $p > 0.05$; ns = not significant, $p < 0.05$).

Source of variation	**df**		**Species Richness**		**Biomass**		***Acanthopagrus australis***		***Mugil cephalus***		***Penaeus plebejus***		***Ambassis jacksoniensis***		***Gobiopterus semivestitus***		***Pseudogobius olorum***		***Philypnodon grandiceps***	
			MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F
Time	8		0.090	**	0.619	*	3.507	**	1.449	*	1.994	**	1.547	ns	2.068	ns	1.572	**	0.635	ns
Estuary	3		8.307		52.967		11.504		3.540		20.167		94.709		97.390		17.465		2.490	
Impact vs Reference		1	23.300	+	150.765	+	24.875	ns	7.714	ns	39.429	ns	272.293	*	89.046	ns	40.096	+	0.400	+
Among References		2	0.810	ns	4.068	ns	4.818	+	1.453	ns	10.536	+	5.917	+	101.562	+	6.150	ns	3.535	ns
Site(Estuary)	8		0.219		2.684		0.615		0.825		1.543		3.641		0.913		4.786		2.402	
Site(Impact)		2	0.828	**	6.542	**	0.000	ns	0.013	ns	0.015	ns	0.010	ns	0.017	ns	14.595	**	0.341	**
Site(Among References)		6	0.015	*	1.399	**	0.820	**	1.096	**	2.052	**	4.852	**	1.211	**	1.517	**	3.089	**
Time x Estuary	24		0.092		0.665		0.956		0.440		0.420		0.878		1.419		1.278		1.226	
Time x Impact vs Reference		8	0.243	**	1.576	**	1.169	ns,E	0.518	ns,E	0.489	ns,E	0.498	ns,E	0.630	ns,E	3.144	**	3.023	**
Time x Among References		16	0.017	ns,E	0.210	ns,E	0.849	**	0.401	ns,E	0.385	**	1.068	ns^	1.814	**	0.345	ns,E	0.327	ns,E
Time x Site(Estuary)	64		0.028		0.208		0.170		0.373		0.157		0.667		0.412		0.311		0.311	
Time x Site(Impact)		16	0.088	**	0.576	**	0.000	ns	0.048	ns	0.017	ns	0.010	ns	0.011	ns	0.616	**	0.480	**
Time x Site(Reference)		48	0.008	ns	0.085	ns	0.227	**	0.482	**	0.203	**	0.885	**	0.545	**	0.210	**	0.254	**
Residual	216		0.006		0.064		0.051		0.148		0.060		0.128		0.073		0.067		0.068	
Cochran's Test			s		s		ns		s		ns		s		s		ns		ns	

ns : not significant, $p > 0.05$
ns, E : term eliminated from the original model because $p > 0.25$

* : significant, $p < 0.05$
ns^ : not signifcant at $p = 0.05$ but significant at $p = 0.25$

** : significant, $p < 0.01$
+ : no valid F-ratio

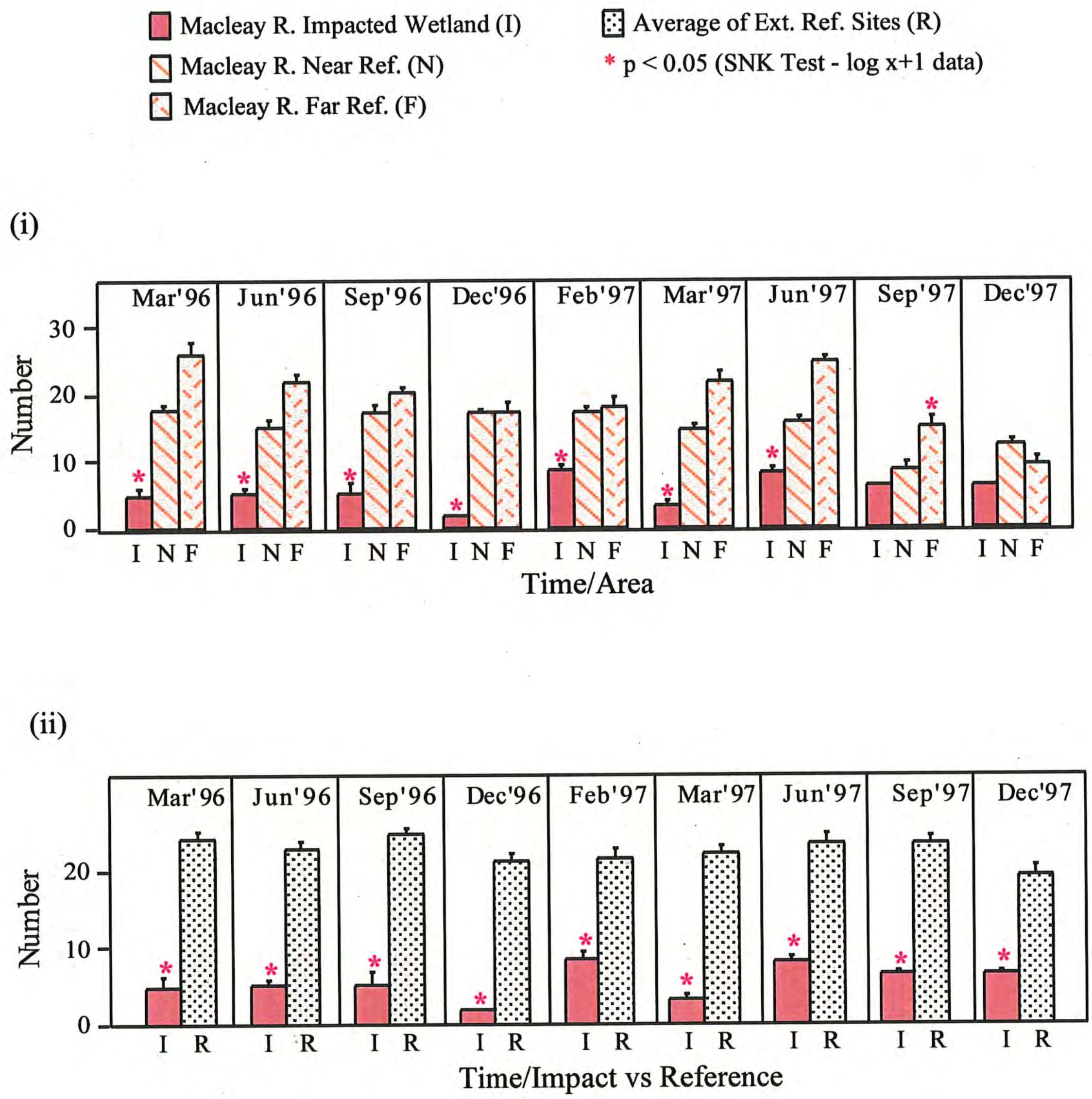

Figure 4.3.1a. Mean (+SE) <u>number of taxa</u> collected from the Macleay River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the differences between the impacted, near reference and far reference areas through time and (ii) the differences between the impacted area and the external reference estuaries through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

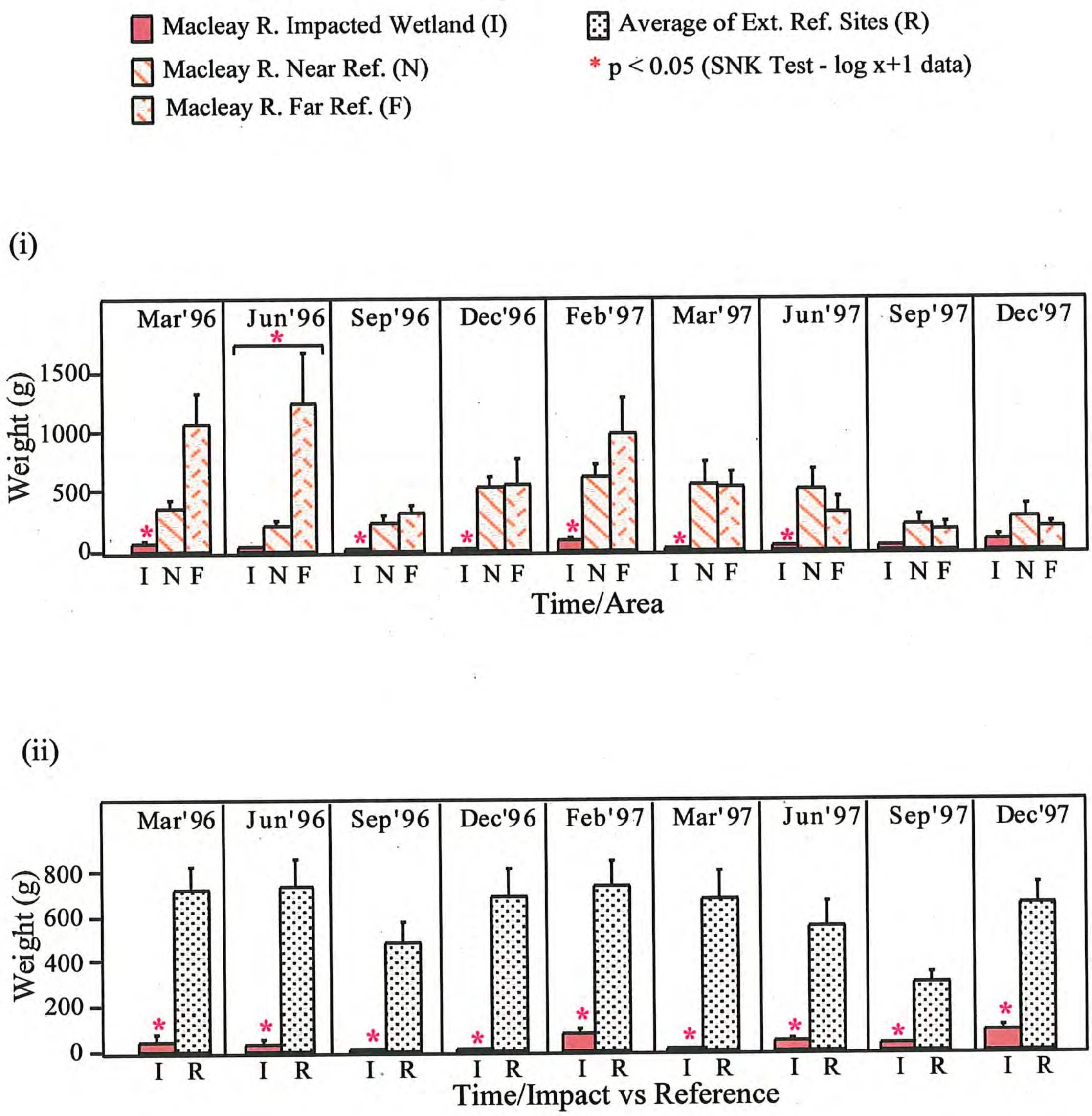

Figure 4.3.1b. Mean (+SE) biomass of fish and invertebrates collected from the Macleay River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the differences between the impacted, near reference and far reference areas through time and (ii) the differences between the impacted area and the external reference estuaries through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

Abundances of selected commercial taxa

Very few commercial taxa were collected from the Macleay River impacted wetland area with a total of only 73 individuals caught over the entire sampling period (Appendix 2). These taxa included 50 prawns (*Penaeus plebejus, Metapenaeus macleayi* and *Metapenaeus bennettae*), 21 mullet (*Mugil cephalus* and *Liza argentea*), one eel (*Anguilla reinhardtii*) and one trumpeter (*Pelates sexlineatus*). However there were numerous species and individuals of commercial importance collected from the Macleay River near and far reference areas. For example yellowfin bream (*Acanthopagrus australis*) were always present at the near and far reference areas and in particular there were significantly large catches from these areas in September 1996 (Table 4.3.1a, Figure 4.3.1c, Appendix 4.1).

The abundance of sea mullet (*Mugil cephalus*) collected from the Macleay River varied significantly between the impacted and near and far reference areas over time (Table 4.3.1a). Generally the numbers collected from the three areas in the river were low except for relatively large catches in September 1996 and June 1997 from the near and far reference areas (Figure 4.3.1d, Appendix 4.1). There were more sea mullet collected from the external reference estuaries than from the Macleay River impacted wetland area (Figure 4.3.1d).

The numbers of king prawns (*Penaeus plebejus*) collected from the Macleay River varied significantly at the three areas in the estuary over time (Table 4.3.1a). There were always fewer or no king prawns collected from the impacted wetland area and the abundances at the near and far reference areas fluctuated through time with greater numbers collected from the far reference area for five of the nine sampling periods (Figure 4.3.1e).There were also more king prawns collected from the external reference estuaries compared to the Macleay River impacted wetland area (Figure 4.3.1e).

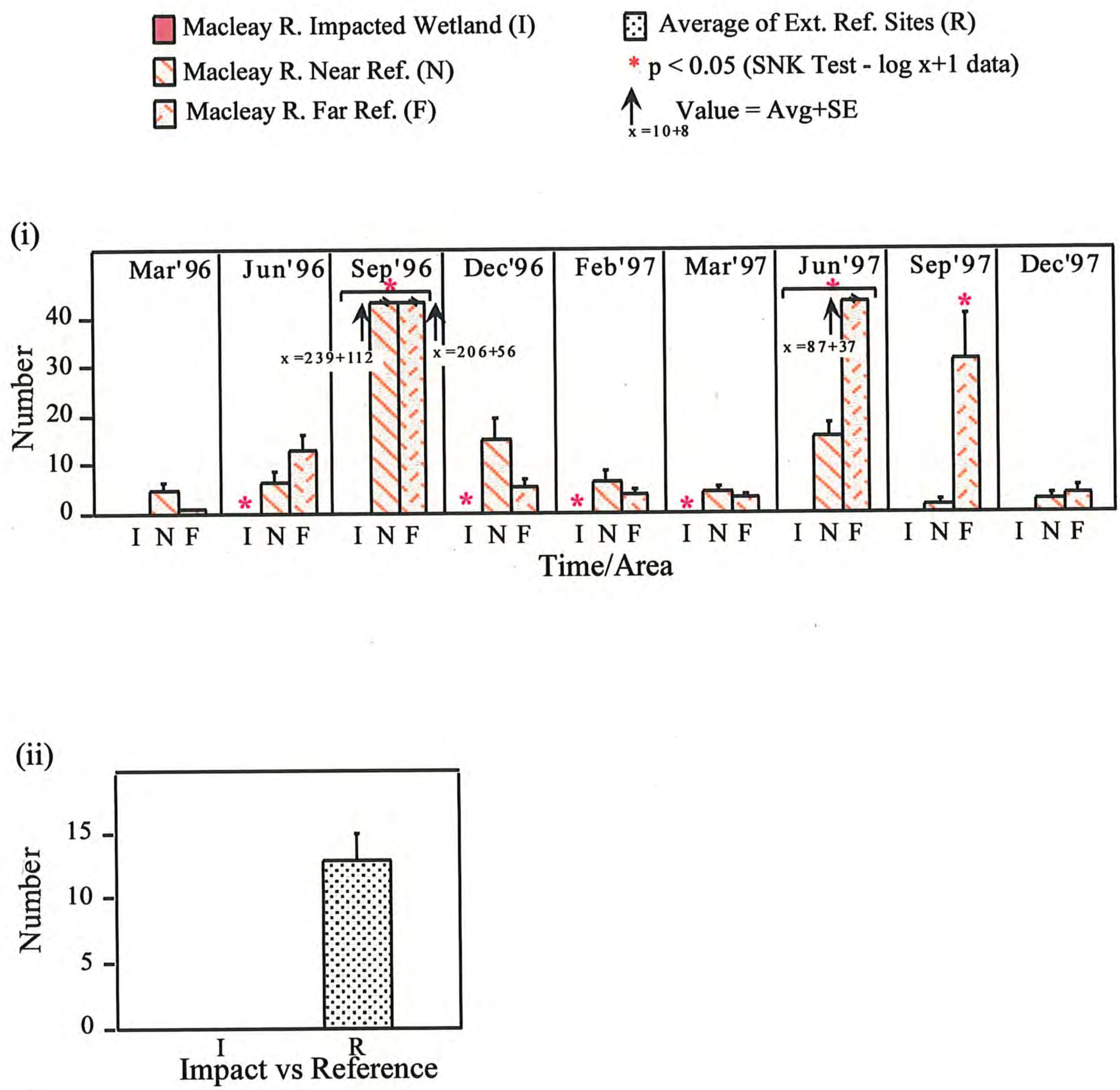

Figure 4.3.1c. Mean (+SE) number of yellowfin bream (*Acanthopagrus australis*) collected from the Macleay River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the differences between the impacted, near reference and far reference areas through time and (ii) the differences between the impacted area and the external reference estuaries (note that the test for this term is not very powerful and no significant differences were identified). Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

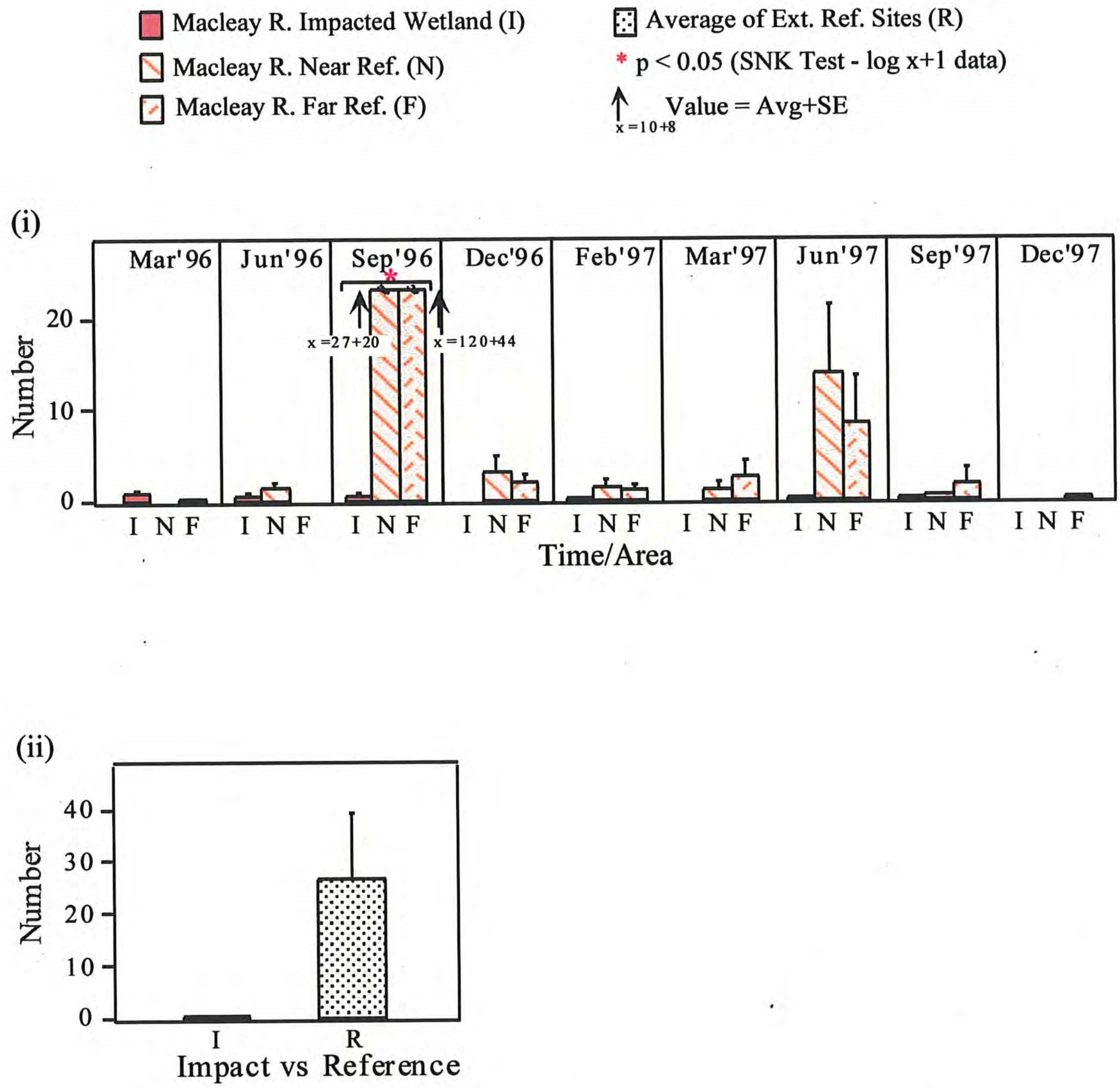

Figure 4.3.1d. Mean (+SE) number of sea mullet (*Mugil cephalus*) collected from the Macleay River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the variation between the impacted, near and far reference areas through time and (ii) the difference between the impacted area and external reference estuaries (note that the test for this term is not very powerful and no significant differences were identified). Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

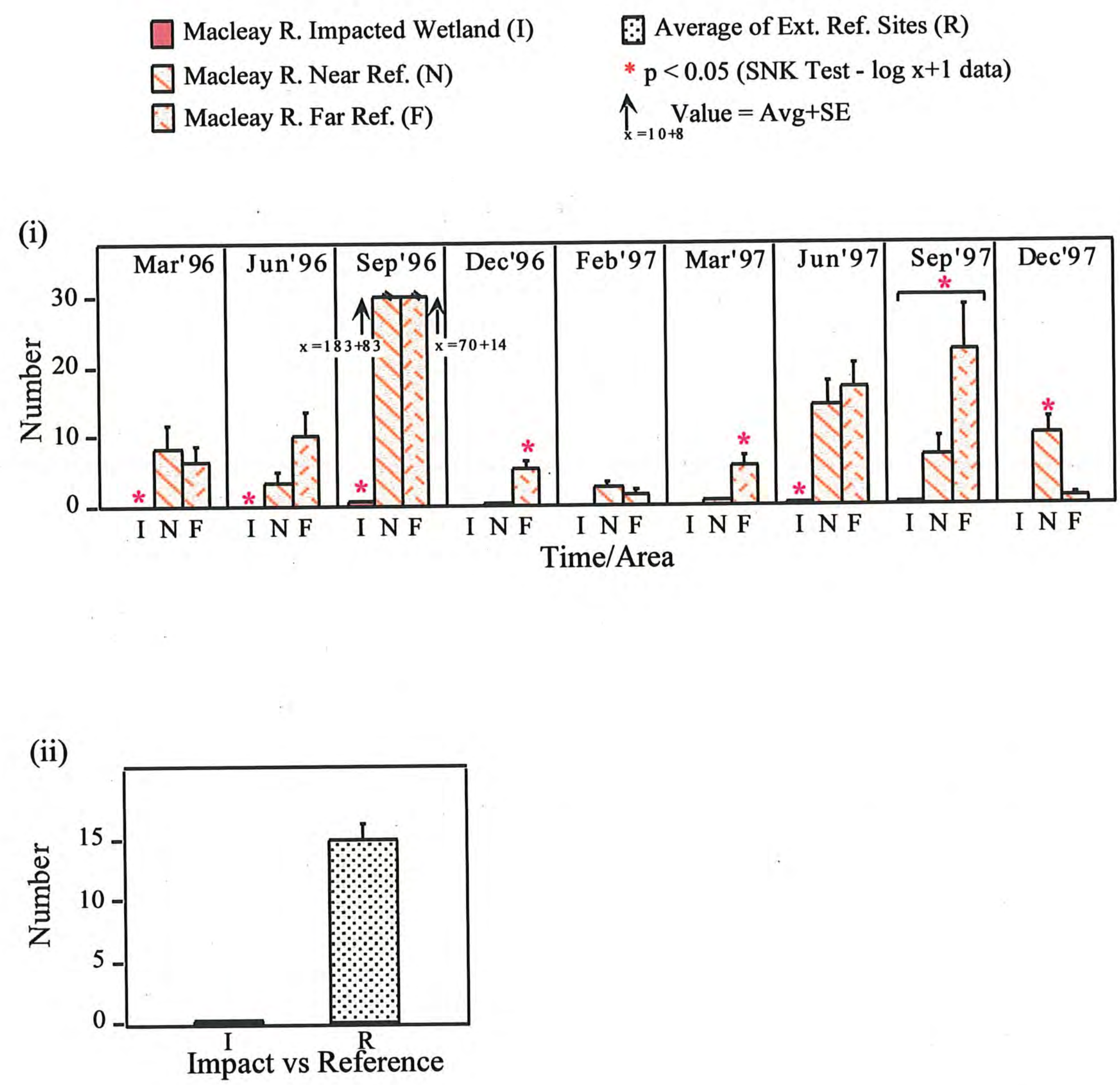

Figure 4.3.1e. Mean (+SE) number of king prawns (*Penaeus plebejus*) collected from the Macleay River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the differences between the impacted, near and far reference areas through time and (ii) the differences between the impacted area and external reference estuaries (note that the test for this term is not very powerful and no significant differences were identified. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

Abundances of selected non-commercial taxa

Glassy perchlets (*Ambassis jacksoniensis*) were never collected from the impacted wetland area in the Macleay River but relatively large catches were collected from the near and far reference areas (Figure 4.3.1f). There were significantly more glassy perchlets collected from the far reference area in March and June 1996 (Figure 4.3.1f, Appendix 4.1).

The numbers of glass gobies (*Gobiopterus semivestitus*) varied significantly in the three areas in the Macleay River through time (Table 4.3.1a). Only relatively small numbers were collected from the impacted wetland area and significantly greater abundances were collected from the near reference area in March and June 1996 and June 1997 (Appendix 4.1, Figure 4.3.1g).

The abundances of the blue spot goby (*Pseudogobius olorum*) and the flathead gudgeon (*Philypnodon grandiceps*) in the Macleay River varied spatially and temporally and even though there were many more blue spot gobies than flathead gudgeons the abundances of the different species followed a similar trend (Table 4.3.1a, Figure 4.3.1h, 4.3.1i). There were significantly more of each species collected from the impacted wetland area in the second half of the study period between February and December 1997 but excluding March 1997 (Table 4.3.1a, Figure 4.3.1h, 4.3.1i, Appendix 2). There were less of these gobies and gudgeons collected from the Macleay River impacted wetland area than from the external reference estuaries between March 1996 and March 1997 (except for February 1997), however between June 1997 and December 1997 this trend was reversed for both species (Figure 4.3.1h, 4.3.1i). December 1997 (Figure 4.3.1h, 4.3.1i, Table 4.3.1b).

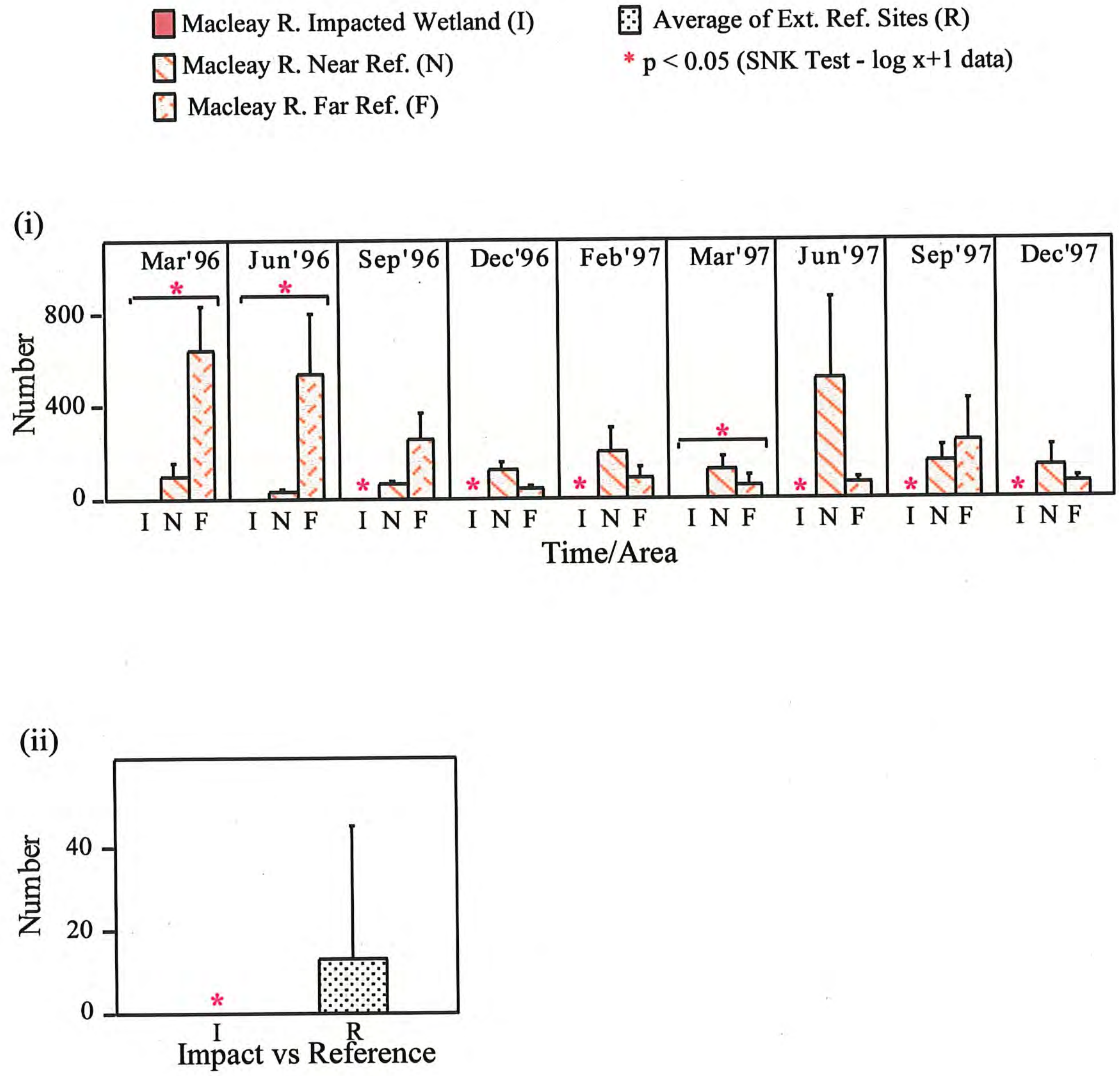

Figure 4.3.1f. Mean (+SE) number of glassy perchlets (*Ambassis jacksoniensis*) collected from the Macleay River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the variation between the impacted, near reference and far reference areas over time and (ii) the difference between the impacted area and external reference estuaries. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

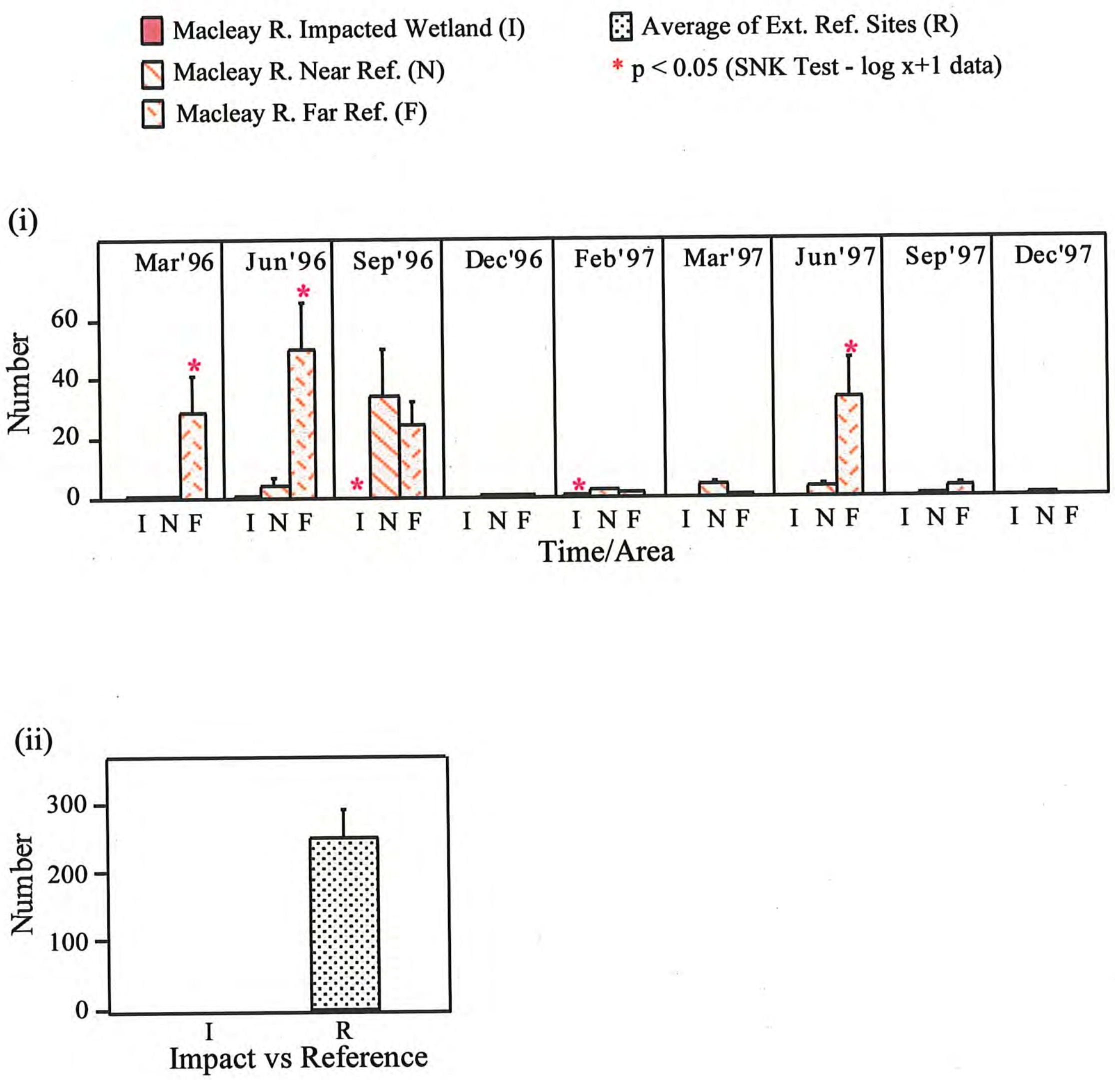

Figure 4.3.1g. Mean (+SE) number of glass gobies (*Gobiopterus semivestitus*) collected from the Macleay River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the difference between the impacted, near reference and far reference areas through time and (ii) the difference between the impacted area and external reference estuaries (note that the test for this term is not very powerful and no significant differences were identified). Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

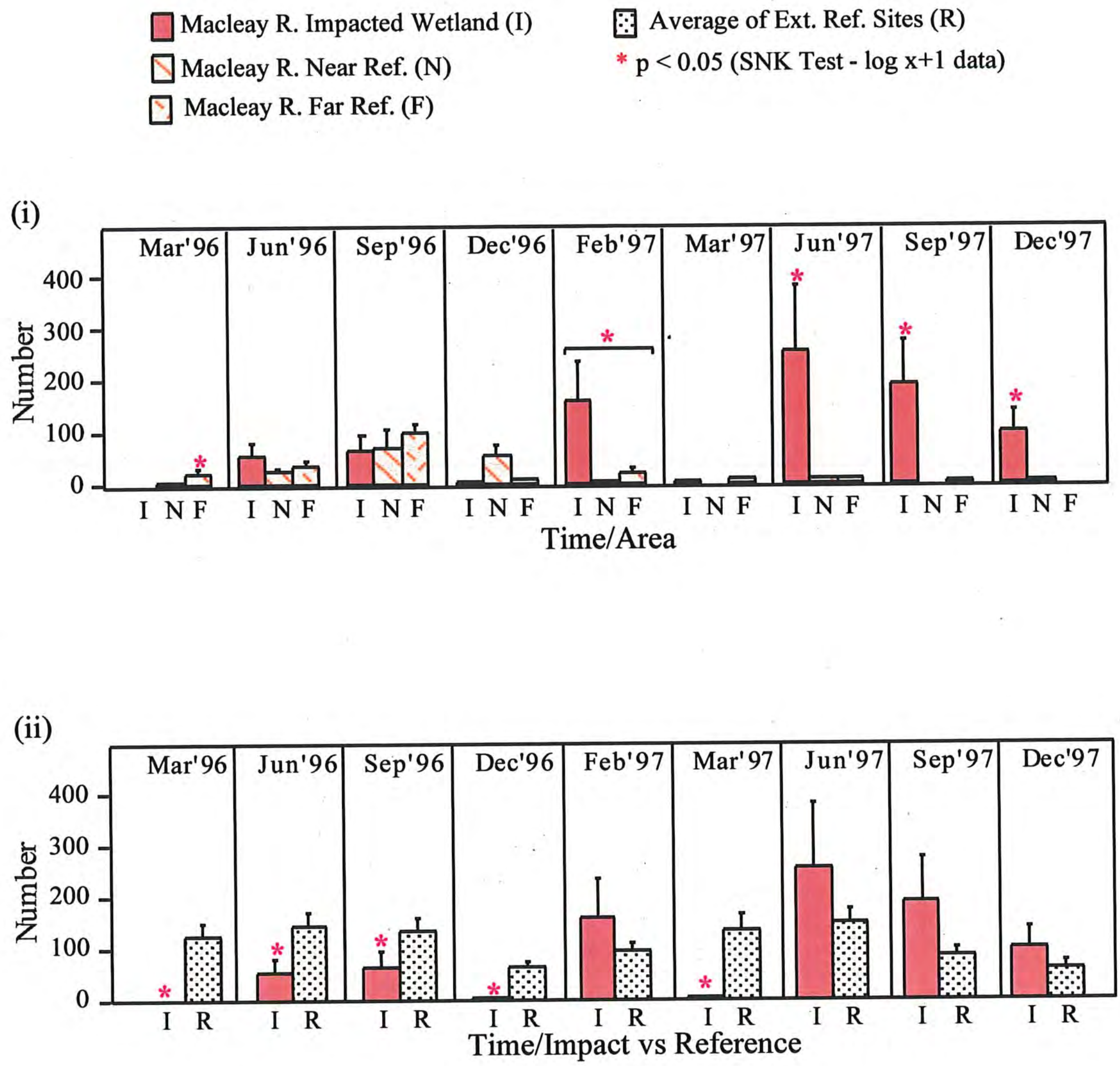

Figure 4.3.1h. Mean (+SE) number of blue spot gobies (*Pseudogobius olorum*) collected from the Macleay River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the variation among the impacted, near and far reference areas through time and (ii) the variation between the impacted area and the external reference estuaries through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

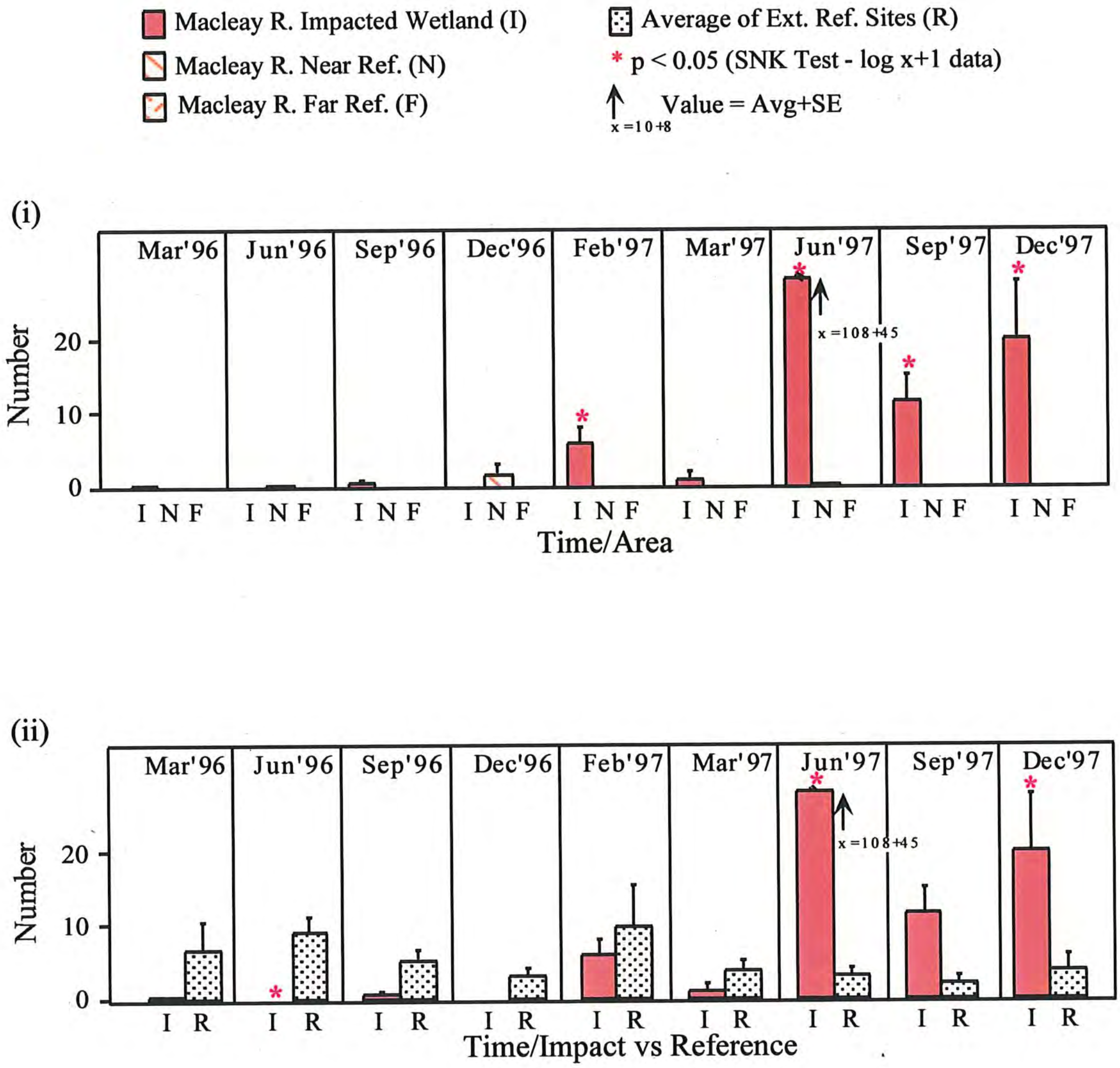

Figure 4.3.1i. Mean (+SE) number of flathead gudgeons (*Philypnodon grandiceps*) collected from the Macleay River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the variation among the impacted, near reference and far reference areas through time and (ii) the differences between the impacted area and external reference through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

4.3.2. Hunter River

Species richness and biomass

The species richness of fish and invertebrates in the Hunter River varied significantly at the three sites within each of the areas (impacted, near and far reference areas) over time (Table 4.3.2a). In particular, there were less taxa at the upper most site in Ironbark Creek compared to the other two sites in the creek and this pattern was consistent through time (Figure 4.3.2a).

The Time *x* Among References term could not be eliminated in the analysis and no test of Impact vs Reference is possible.

There was a significant difference in the total biomass of fish and invertebrates at the impacted, near and far reference areas in the Hunter River through time (Table 4.3.2a). There was no consistent pattern in the weights, however the greatest biomass of fish and invertebrates (1690±717 g) was collected in March 1997 from the far reference area and was probably due to the collection of some larger specimens of bream, tarwhine, whiting and flathead. Compared to the external reference estuaries the biomass was less at the Hunter River impacted area and this difference was significant for both years in the months of June and September (Figure 4.3.2b, Appendix 4.4).

Table 4.3.2a. Summary of the three factor Analysis of Variance results for the comparison of the Hunter River impacted wetland area and the near and the far reference areas through time.

The species richness and biomass of fish and invertebrates and the abundances of selected commercial and non-commercial taxa were analysed. Only the mean square (MS) values and the significance levels for the *F*-tests (F) are shown. All data were transformed to log(x+1) and mean square values have been rounded to 3 decimal places. The results of the Cochran's test after transformation are shown at the bottom of the table (s = significant, $p > 0.05$; ns = not significant, $p < 0.05$).

Source of variation	**df**	**Species Richness**		**Biomass**		***Acanthopagrus australis***		***Mugil cephalus***		***Penaeus plebejus***		***Ambassis jacksoniensis***		***Gobiopterus semivestitus***		***Pseudogobius olorum***		***Redigobius macrostoma***		***Philypnodon grandiceps***	
		MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F
Time	8	0.140	**	2.424	**	0.416	ns	0.114	ns	2.045	**	3.142	**	1.332	**	0.200	ns	0.649	ns	0.355	ns
Area	2	0.482	+	0.864	+	5.422	+	0.704	+	5.247	+	7.329	+	14.020	+	44.171	**	32.179	*	11.252	+
Time x Area	16	0.047	ns^	0.768	*	0.443	ns^	0.234	**	1.203	ns^	1.966	**	1.143	**	0.305	ns,E	0.362	ns,E	0.322	ns^
Site(Area)	6	0.106	**	0.460	ns	0.765	*	0.077	ns	1.069	ns	0.566	ns	0.896	ns	1.748	**	4.683	**	1.001	**
Time x Site(Area)	48	0.029	**	0.338	*	0.254	**	0.087	ns	0.654	**	0.511	**	0.457	**	0.362	**	0.439	**	0.195	**
Residual	162	0.011		0.215		0.063		0.066		0.094		0.264		0.136		0.088		0.074		0.052	
Cochran's Test		s		s		ns		s		ns		s		s		ns		ns		s	

ns : not significant, $p > 0.05$
* : significant, $p < 0.05$
** : significant, $p < 0.01$

ns, E : term eliminated from the original model because $p > 0.25$
ns^ : not significant at $p = 0.05$ but significant at $p = 0.25$
\+ : no valid F-ratio

Table 4.3.2b. Summary of the Asymmetrical Analysis of Variance results for the comparison of the Hunter River impacted wetland area with the three external reference estuaries through time.

The species richness and biomass of fish and invertebrates and the abundances of selected commercial and non-commercial taxa were analysed. Only the mean square (MS) values and the significance levels for the *F*-tests (F) are shown. All data were transformed to log(x+1) and mean square values have been rounded to 3 decimal places. The results of the Cochran's test after transformation are shown at the bottom of the table (s = significant, $p > 0.05$; ns = not significant, $p < 0.05$).

Source of variation	**df**		**Species Richness**		**Biomass**		***Acanthopagrus australis***		***Mugil cephalus***		***Penaeus plebejus***		***Ambassis jacksoniensis***		***Gobiopterus semivestitus***		***Pseudogobius olorum***		***Redigobius macrostoma***		***Philypnodon grandiceps***	
			MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F
Time	8		0.039	ns	1.387	**	3.917	**	1.814	**	3.088	**	1.487	ns	1.262	ns	0.554	ns	1.786	**	0.632	ns
Estuary	3		1.012		8.602		3.216		1.501		11.387		31.321		69.845		7.351		21.398		3.584	
Impact vs Reference		1	1.416	+	17.670	+	0.011	+	1.598	ns	13.088	+	82.130	+	6.412	+	9.755	ns	55.292	+	3.681	+
Among References		2	0.810	+	4.068	+	4.818	+	1.453	ns	10.536	+	5.917	ns	101.562	+	6.150	ns	4.451	ns	3.535	ns
Site(Estuary)	8		0.078		1.226		1.146		0.839		2.142		3.705		1.306		2.324		4.163		3.065	
Site(Impact)		2	0.265	**	0.707	**	2.123	**	0.069	ns	2.412	**	0.265	ns	1.591	**	4.746	**	13.322	**	2.992	**
Site(Among References)		6	0.015	**	1.399	**	0.820	**	1.096	**	2.052	**	4.852	**	1.211	**	1.517	**	1.110	**	3.089	**
Time x Estuary	24		0.025		0.467		1.205		0.442		0.595		2.581		2.611		0.312		0.270		0.534	
Time x Impact vs Reference		8	0.042	ns^	0.981	**	1.917	ns^	0.522	ns,E	1.016	*	5.607	**	4.205	ns^	0.246	ns,E	0.441	ns^	0.946	*
Time x Among References		16	0.017	ns^	0.210	ns^	0.849	**	0.401	ns,E	0.385	ns^	1.068	ns,E	1.814	**	0.345	ns,E	0.184	ns,E	0.327	ns,E
Time x Site(Estuary)	64		0.010		0.118		0.307		0.391		0.243		0.817		0.520		0.369		0.388		0.336	
Time x Site(Impact)		16	0.016	**	0.214	**	0.548	**	0.118	ns	0.364	**	0.614	**	0.446	**	0.848	**	0.757	**	0.580	**
Time x Site(Reference)		48	0.008	**	0.085	ns	0.227	**	0.482	**	0.203	**	0.885	**	0.545	**	0.210	**	0.265	**	0.254	**
Residual	216		0.003		0.086		0.069		0.174		0.072		0.197		0.126		0.093		0.075		0.086	
Cochran's Test			s		ns		ns		s		ns		s		s		ns		ns		s	

ns : not significant, p > 0.05
ns, E : term eliminated from the original model because p > 0.25

* : significant, p < 0.05
ns^ : not signifcant at p = 0.05 but significant at p = 0.25

** : significant, p < 0.01
+ : no valid F-ratio

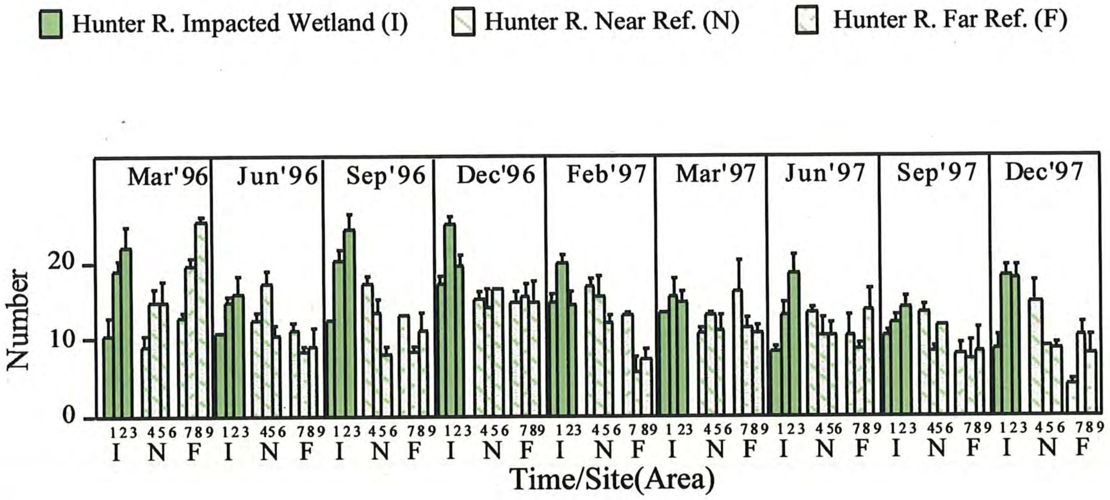

Figure 4.3.2a. Mean (+SE) number of taxa collected from the Hunter River.

The plot shows the significant ($p < 0.05$) term in the 3 factor analysis of variance with the variation among sites at the impacted, near reference and far reference areas through time. Raw data were used for the plot and SNK tests were not done for nested terms in the analysis of variance.

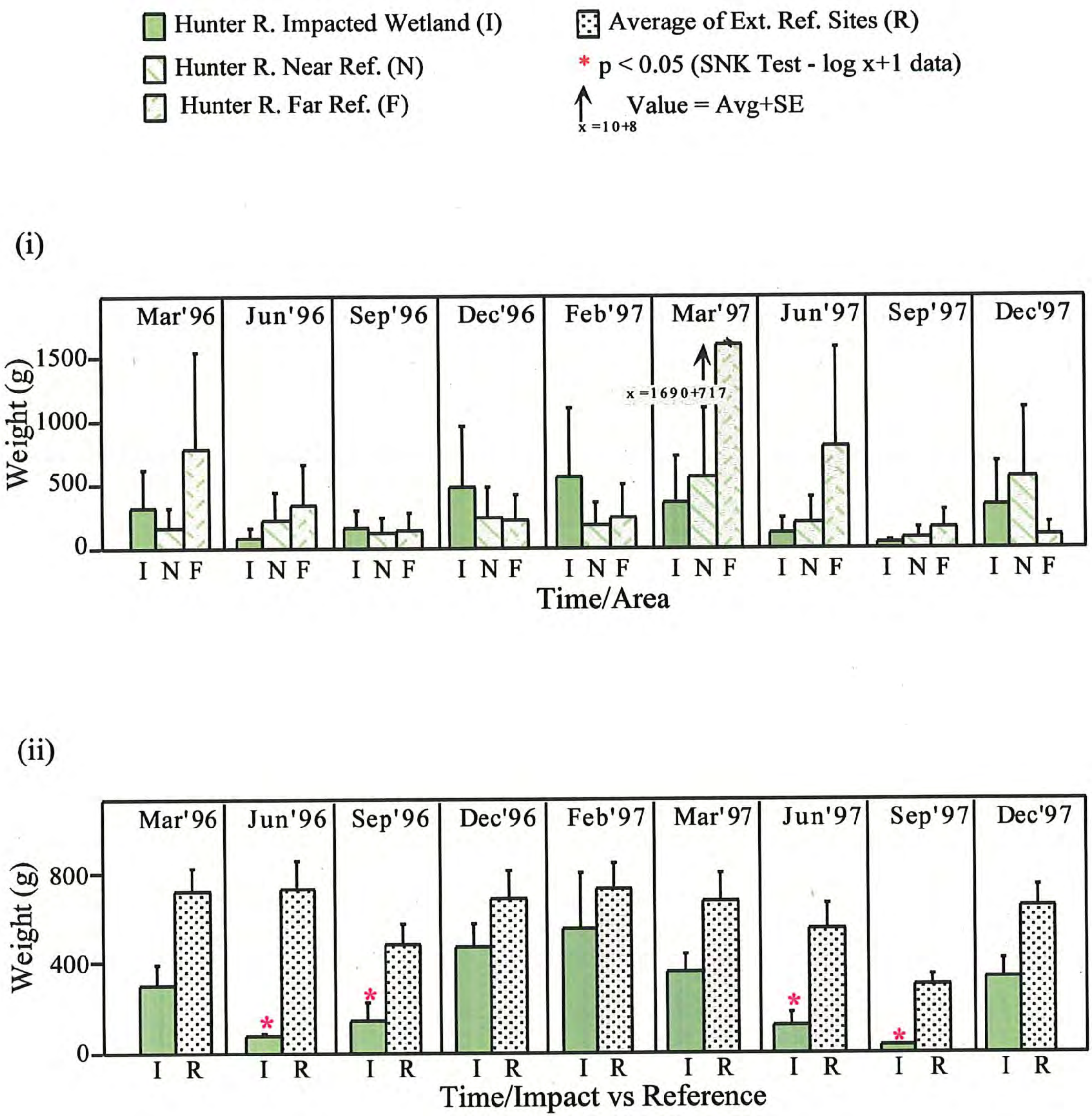

Figure 4.3.2b. Mean (+SE) biomass of fish and invertebrates collected from the Hunter River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the variation between the impacted, near reference and far reference areas through time and (ii) the variation between the impacted area and external reference estuaries through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

Abundances of selected commercial taxa

The numbers of yellowfin bream (*Acanthopagrus australis*) collected at the sites within each of the areas in the Hunter River varied significantly through time (Table 4.3.2a). Generally there were more bream collected from the sites within the impacted area and in particular there were large catches at the sites just behind the floodgates in March and September 1996 (Figure 4.3.2c). Compared with the external reference estuaries the number of bream collected from the impacted wetland area did not show any significant differences (Table 4.3.2b).

There was a significant temporal and spatial variation in the abundances of sea mullet (*Mugil cephalus*) collected from the three areas in the Hunter River (Table 4.3.2a). During six of the sampling periods there were more mullet collected from the impacted area than from the near or far reference areas and this difference was significant in September 1996 and March 1997 (Appendix 4.3, Figure 4.3.2d). However, there were fewer mullet collected at the Hunter River impacted area compared with the external reference estuaries (Figure 4.3.2d).

The number of king prawns (*Penaeus plebejus*) collected at the sites within each of the areas in the Hunter River varied significantly through time (Table 4.3.2a). During September 1996 there were more king prawns collected from the sites either side of the floodgates but during the other times there was no trend in the numbers of prawns at the different sites within the Hunter River (Figure 4.3.2e). With the exception of the September 1996 sampling period there were more king prawns collected from the external reference estuaries than from the Hunter River impacted area although the difference was only significant in June and September 1997 (Appendix 4.4, Figure 4.3.2e). September 1996 was the only time where there were significantly more king prawns collected from the impacted wetland area than from the reference estuaries (Appendix 4.4, Figure 4.3.2e).

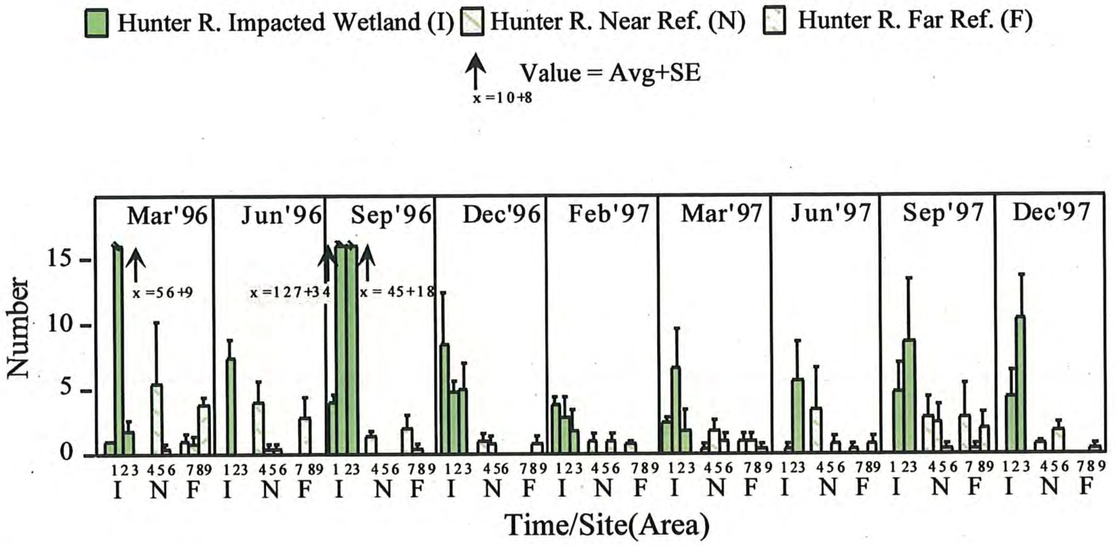

Figure 4.3.2c. Mean (+SE) number of yellowfin bream (*Acanthopagrus australis*) collected from the Hunter River.

The plot represents the significant ($p < 0.05$) term in the 3 factor analysis of variance where there is variation among sites at the impacted, near reference and far reference areas through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

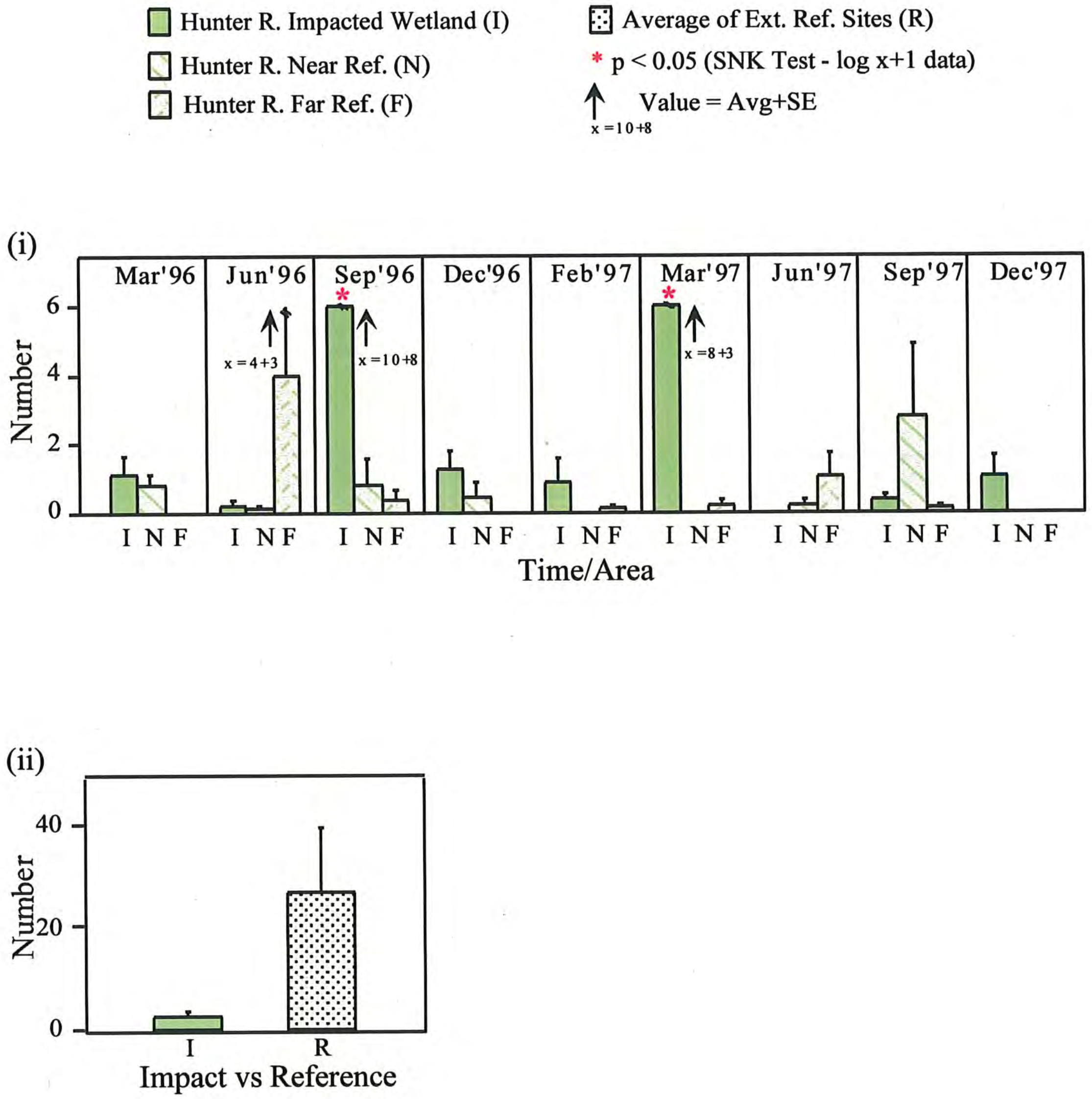

Figure 4.3.2d. Mean (+SE) number of sea mullet (*Mugil cephalus*) collected from the Hunter River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the variation between the impacted, near and far reference areas through time and (ii) the difference between the impacted area and external reference estuaries (note that the test for this term is not very powerful and no significant differences were identified). Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

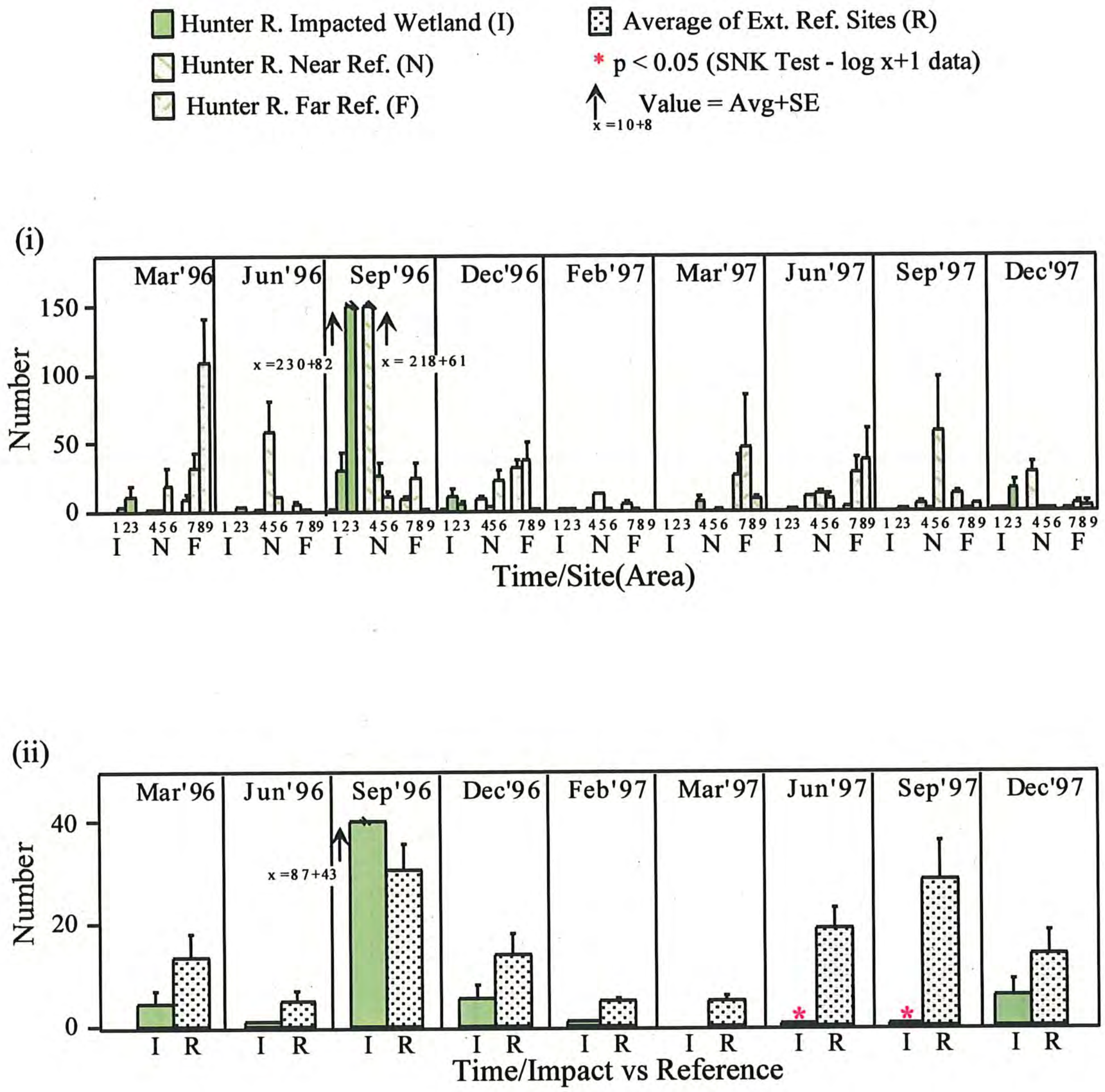

Figure 4.3.2e. Mean (+SE) number of king prawns (*Penaeus plebejus*) collected from the Hunter River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the variation between the impacted, near and far reference areas through time and (ii) the variation between the impacted area and external reference estuaries through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

Abundances of selected non-commercial taxa

There were more glassy perchlets (*Ambassis jacksoniensis*) collected from the Hunter River impacted wetland area than from the near or far reference areas for all sampling occasions except June and September 1997 (Appendix 4.3, Figure 4.3.2f). The differences were significant in March 1996, March 1997 and December 1997 (Appendix 4.3). However there were significantly fewer ambassids collected from the Hunter River impacted area than from the external reference estuaries except for December 1996 sampling period (Appendix 4.4, Figure 4.3.2f).

There was a significant variation in the numbers of glass gobies (*Gobiopterus semivestitus*) collected from the three areas in the Hunter River and in most cases there were more collected from the impacted area (Table 4.3.2a, Figure 4.3.2g) although there was also a significant variation in the numbers of glass gobies at the sites within the impacted area (Table 4.3.2a, Figure 4.3.2g).

In the Hunter River, flathead gudgeons (*Philypnodon grandiceps*) were only ever collected from the impacted wetland area except for one individual collected from the near reference area at site 4 in March 1996 (Figure 4.3.2h). Also, over time there were more flathead gudgeons collected from the Hunter River wetland area compared with the external reference estuaries and this difference was significant in March 1996 and December 1997 (Table 4.3.2b, Figure 4.3.2h).

There were significantly more blue spot gobies and large mouth gobies collected from the Hunter River impacted wetland area compared with the near and far reference areas (Table 4.3.2a, Appendix 4.3, Figure 4.3.2i, 4.3.2j). However the numbers of these gobies varied significantly at the sites within the impacted area over time and there were usually fewer gobies at the upper most site within the wetland (Table 4.3.2a, Figure 4.3.2i, 4.3.2j).

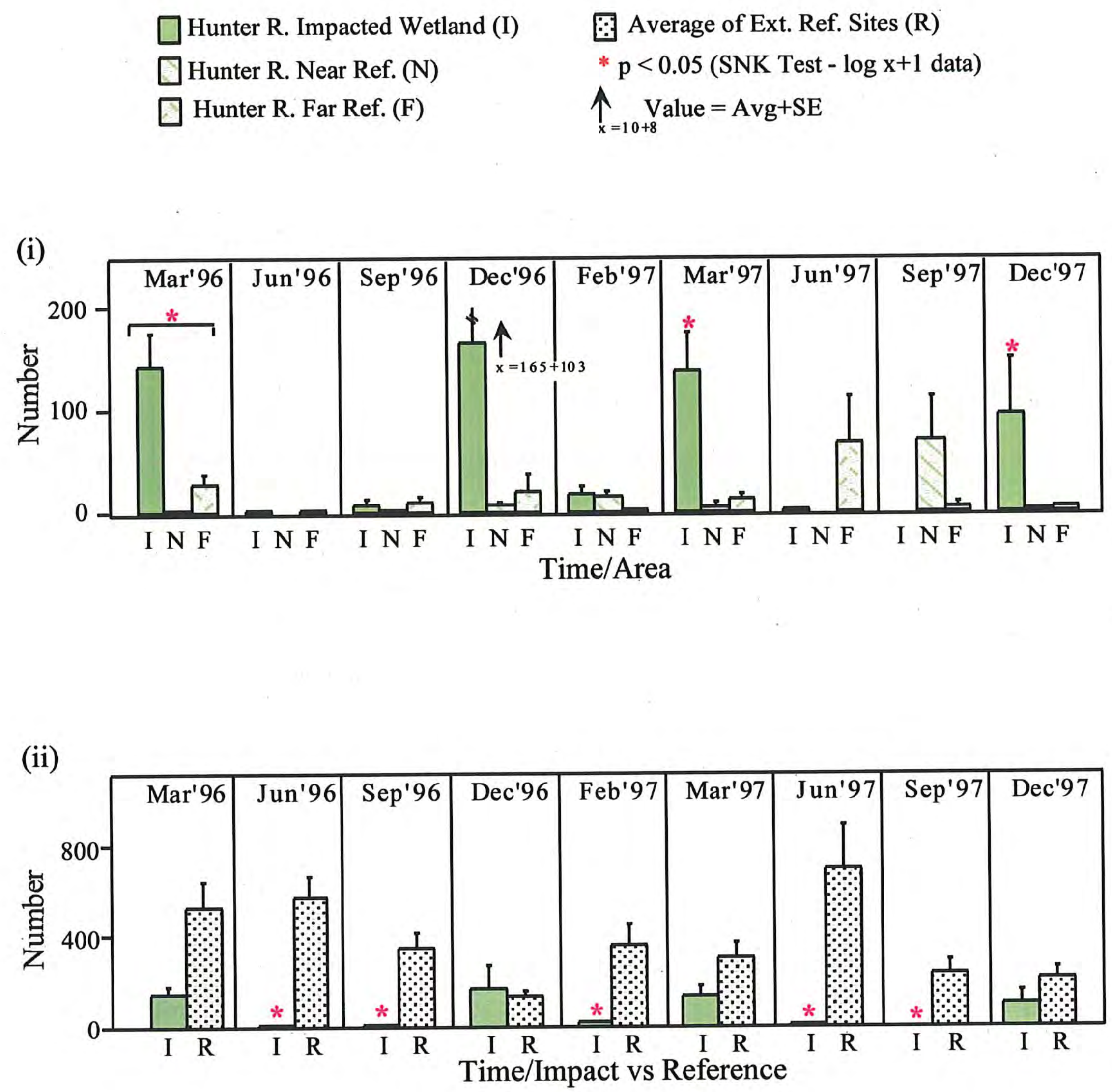

Figure 4.3.2f. Mean (+SE) number of glassy perchlets (*Ambassis jacksoniensis*) collected from the Hunter River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the variation between the impacted, near reference and far reference areas over time and (ii) the difference between the impacted area and external reference estuaries through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

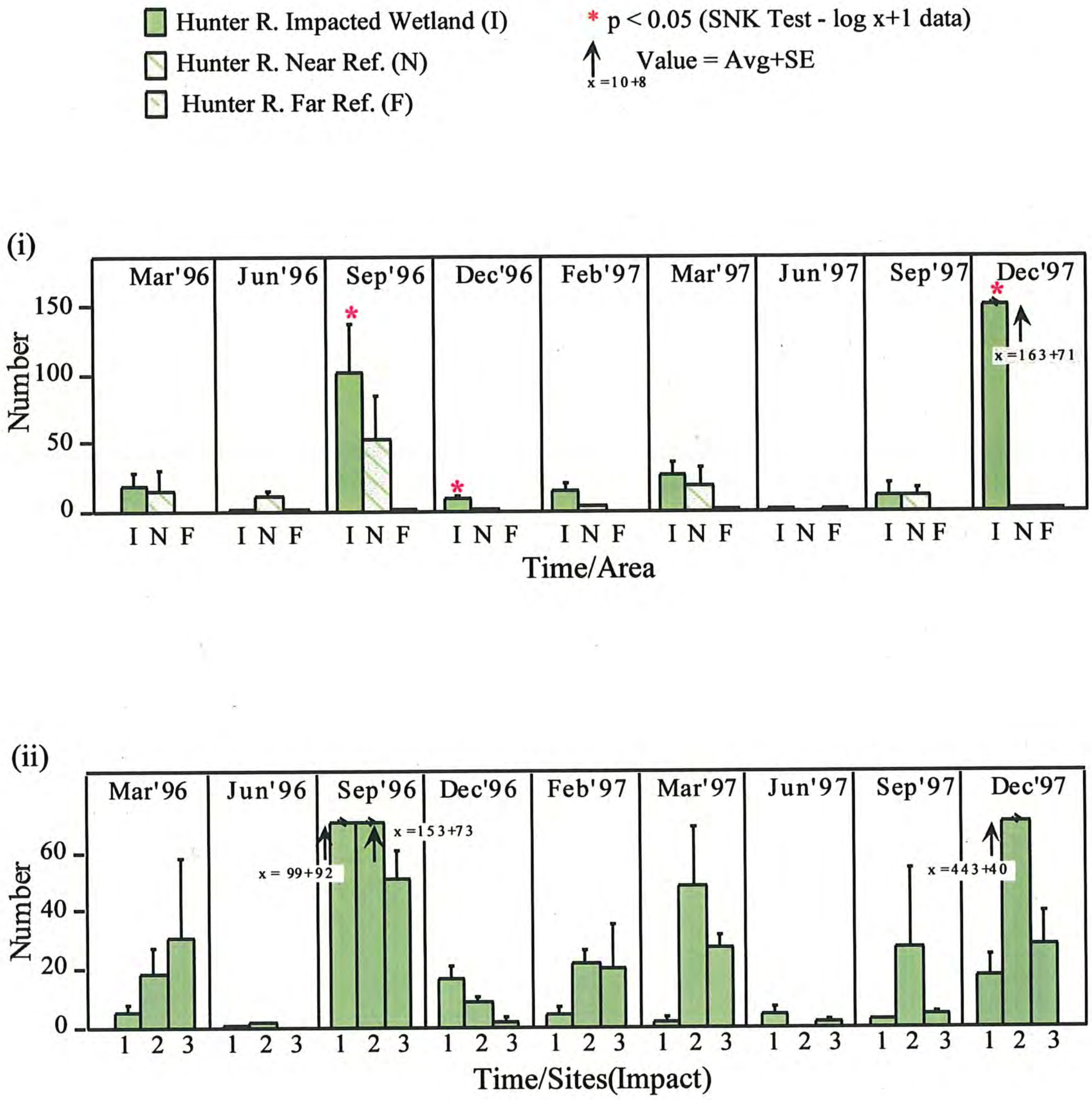

Figure 4.3.2g. Mean (+SE) number of glass gobies (*Gobiopterus semivestitus*) collected from the Hunter River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the variation between the impacted, near reference and far reference areas over time and (ii) the variation among the three sites in the impacted area through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

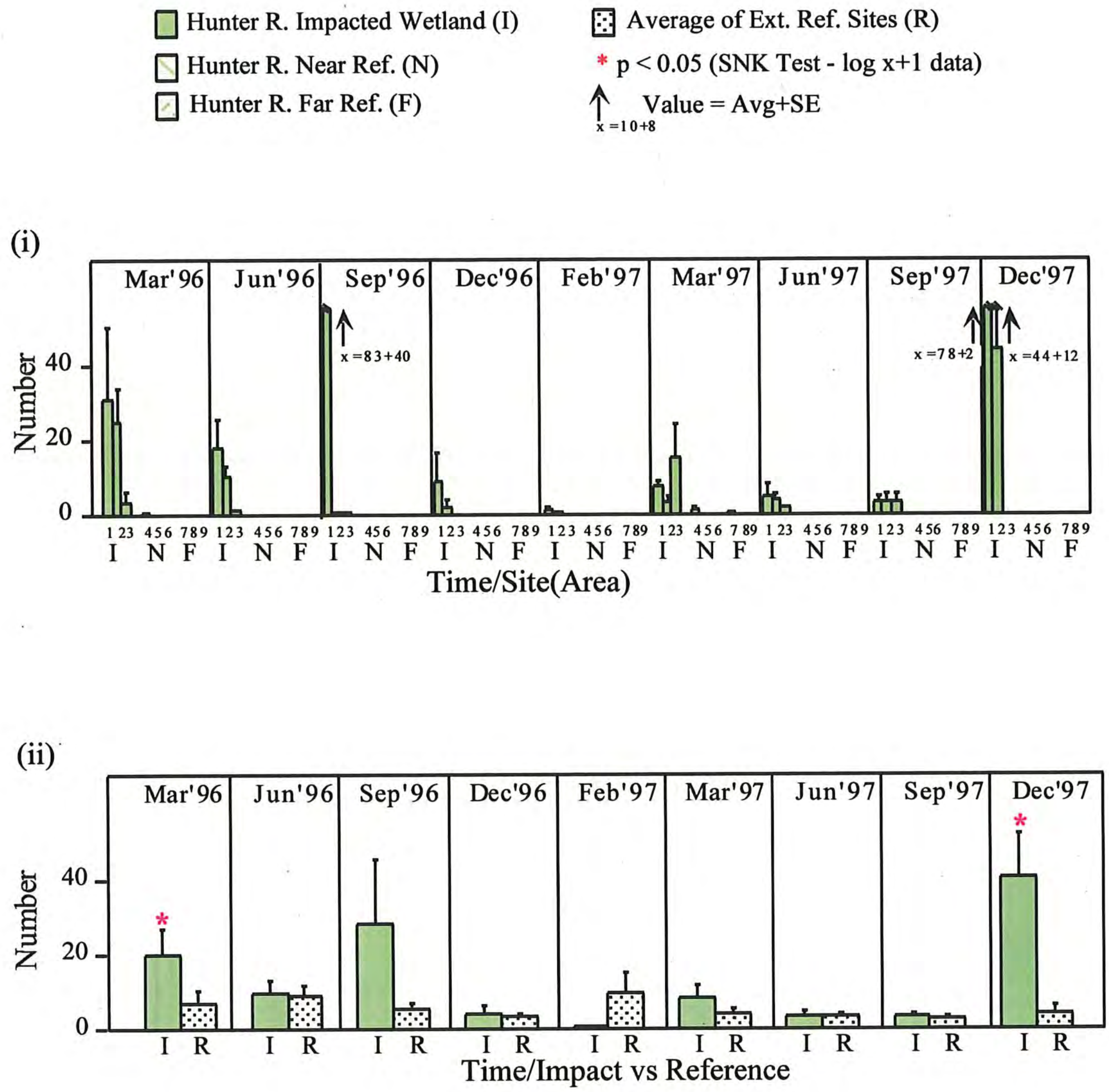

Figure 4.3.2h. Mean (+SE) number of flathead gudgeons (*Philypnodon grandiceps*) collected from the Hunter River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the variation among sites within the impacted, near reference and far reference areas through time and (ii) the variation between the impacted area and external reference through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

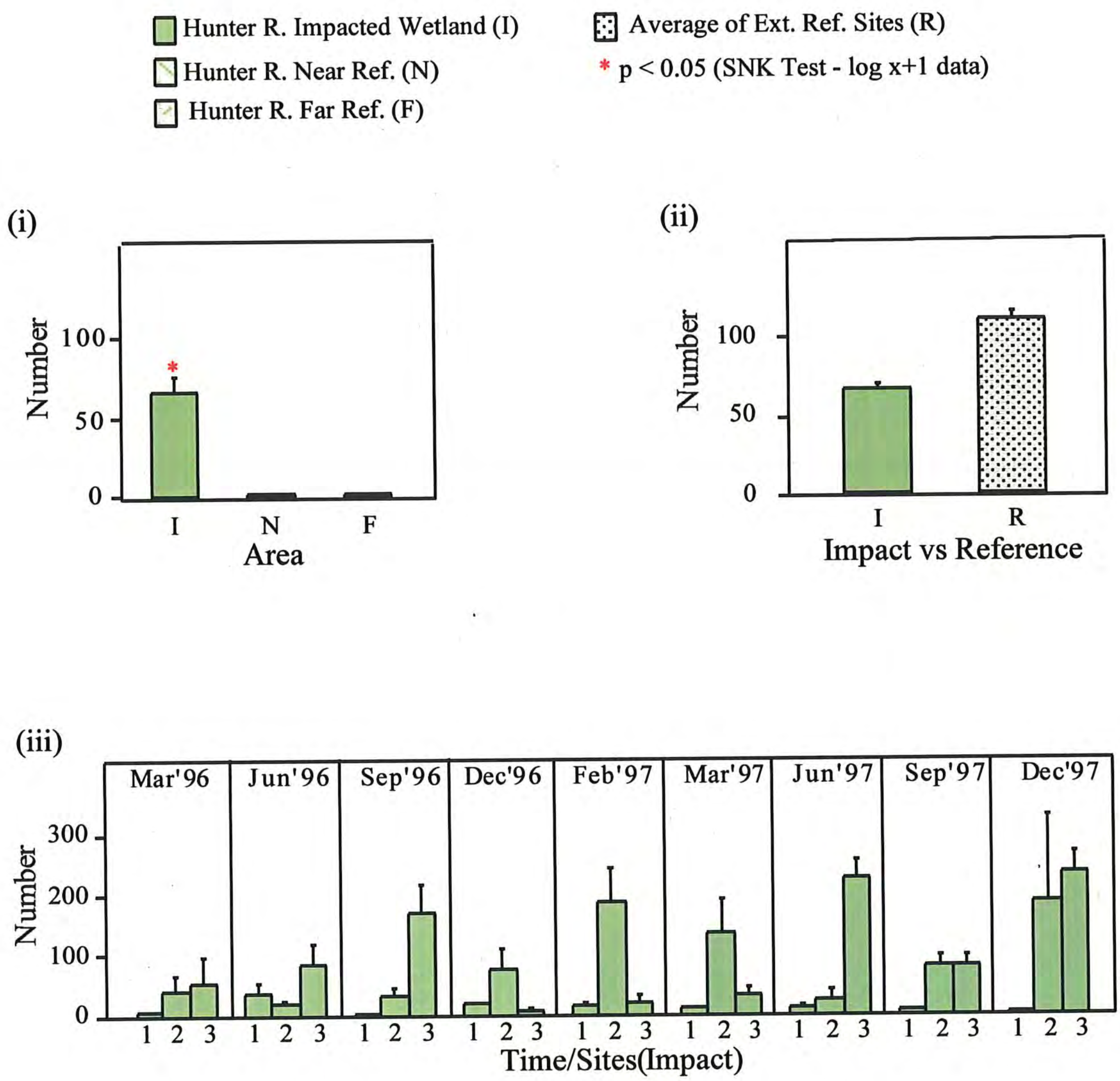

Figure 4.3.2i. Mean (+SE) number of blue spot gobies (*Pseudogobius olorum*) collected from the Hunter River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the variation between the impacted, near and far reference areas and (ii) the difference between the impacted area and the external reference estuaries (note that the test for this term is not very powerful and no significant differences were identified) and (iii) the variation among the three sites in the impacted area through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

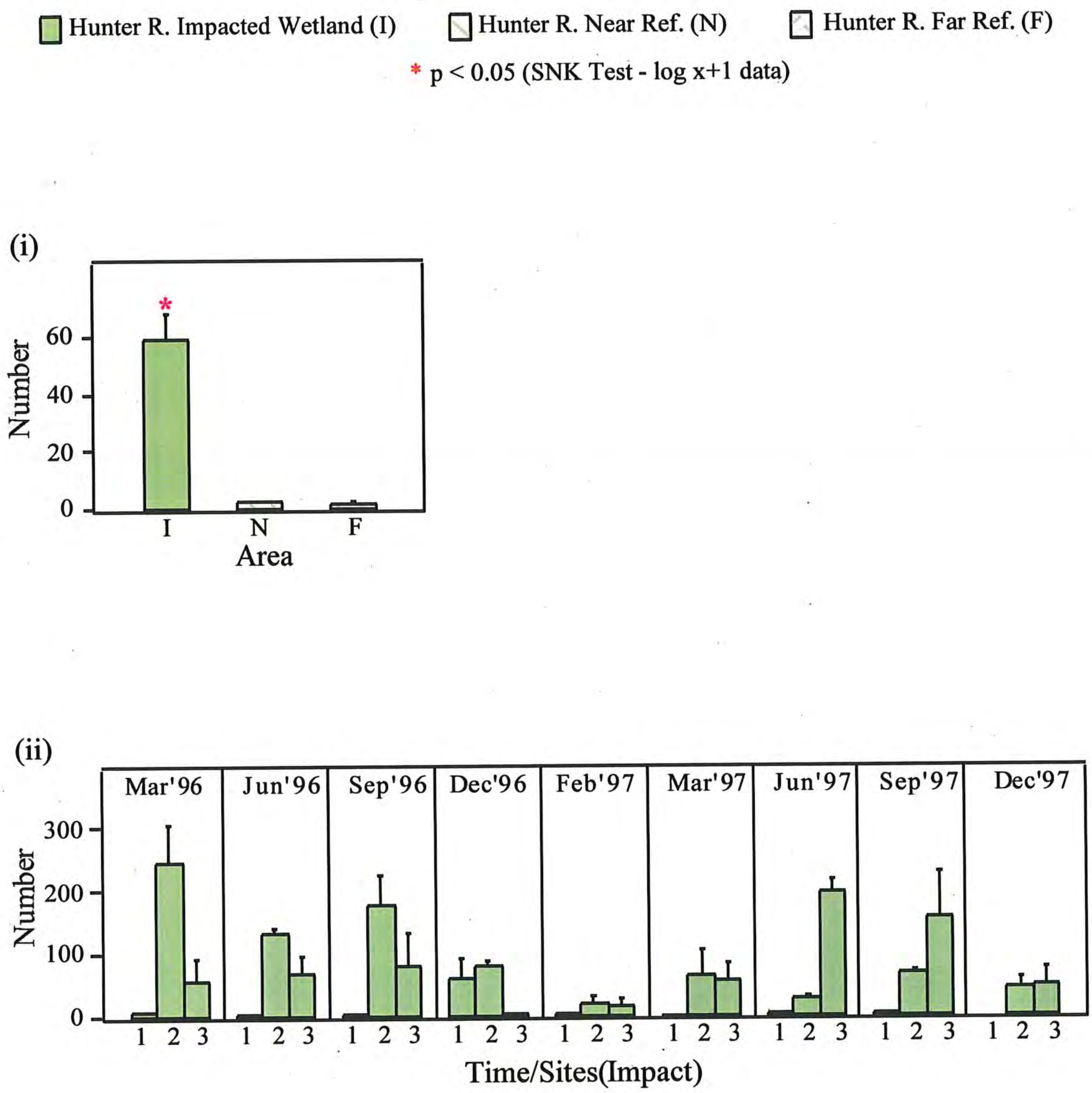

Figure 4.3.2j. Mean (+SE) number of large mouth gobies (*Redigobius macrostoma*) collected from the Hunter River and external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models (3 factor and asymmetrical) with (i) the differences between the impacted, near and far reference areas and (ii) the variation among the three sites in the impacted area through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

4.3.3. Botany Bay

As the Botany Bay near and far reference sites are significantly different to the reference estuaries (Figure 4.2.1b) only the test of the second hypothesis of no difference between the intra estuary locations is presented.

Species richness and biomass

Species richness at the three different areas in Botany Bay varied through time (Table 4.3.3). During six of the times sampled there were fewer taxa at the near reference sites and this difference was significant in September and December 1996 (Figure 4.3.3a, Appendix 4.5). In February 1997, there were significantly more taxa at the far reference area compared to the other two areas (Appendix 4.5, Figure 4.3.3a).

There was a significantly greater biomass of fish and invertebrates collected from the Botany Bay impacted wetland compared to the near and far reference areas (Table 4.3.3, Appendix 4.5, Figure 4.3.3b).

Table 4.3.3. Summary of the three factor Analysis of Variance results for the comparison of the Botany Bay impacted wetland area and the near and the far reference areas through time.

The species richness and biomass of fish and invertebrates and the abundances of selected commercial and non-commercial taxa were analysed. Only the mean square (MS) values and the significance levels for the *F*-tests (F) are shown. All data were transformed to log(x+1) and mean square values have been rounded to 3 decimal places. The results of the Cochran's test after transformation are shown at the bottom of the table (s = significant, $p > 0.05$; ns = not significant, $p < 0.05$).

Source of variation	**df**	**Species Richness**		**Biomass**		***Acanthopagrus australis***		***Mugil cephalus***		***Ambassis jacksoniensis***		***Pseudogobius olorum***		***Philypnodon grandiceps***	
		MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F
Time	7	0.326	**	2.191	**	0.326	ns	0.336	ns	2.498	ns	0.063	ns	1.007	**
Area	2	0.603	+	25.285	**	42.634	+	2.972	+	35.790	+	11.919	+	89.759	+
Time x Area	14	0.122	*	0.493	ns, E	0.317	ns	1.280	**	1.749	ns	0.063	ns	0.989	**
Site(Area)	6	0.112	ns	1.266	ns	0.028	ns	1.709	**	1.358	ns	0.177	**	0.885	**
Time x Site(Area)	42	0.058	**	0.618	**	0.182	**	0.353	**	1.273	**	0.040	ns	0.045	ns
Residual	144	0.020		0.312		0.080		0.168		0.278		0.078		0.112	
Cochran's Test		s		s		s		s		s		s		s	

ns : not significant, $p > 0.05$
* : significant, $p < 0.05$
** : significant, $p < 0.01$

+ : no valid F-ratio
ns, E : term eliminated from the original model because $p > 0.25$

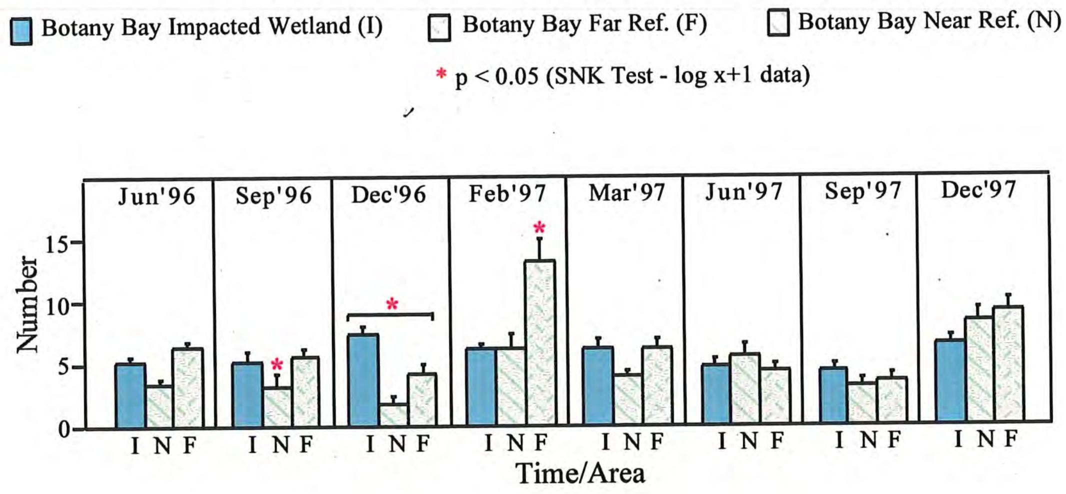

Figure 4.3.3a. Mean (+SE) number of taxa collected from Botany Bay.

Plots show the significant ($p < 0.05$) terms in the analyses of variance model and show the differences between the impacted, near reference and far reference areas through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

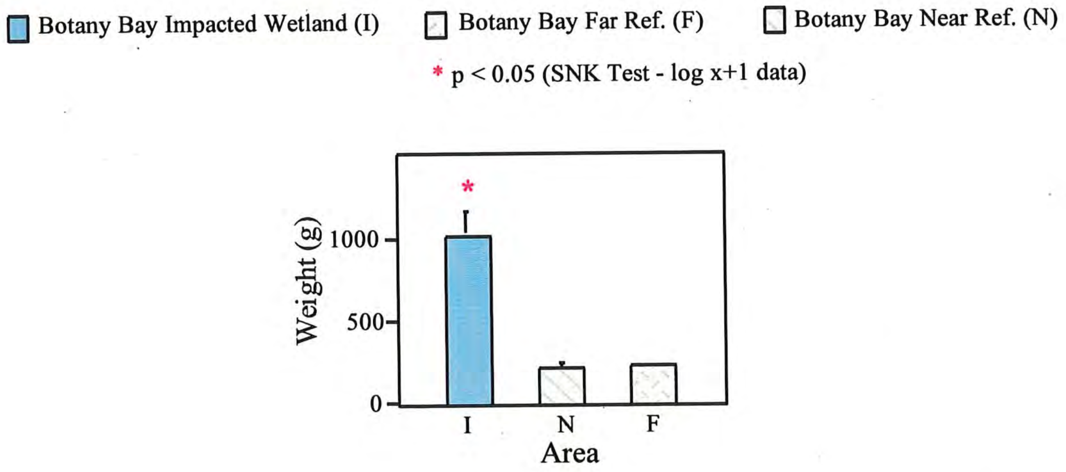

Figure 4.3.3b. Mean (+SE) biomass of fish and invertebrates collected from Botany Bay.

Plots show the significant ($p < 0.05$) terms in the analyses of variance models with the variation between the impacted, near reference and far reference areas. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

Abundances of selected commercial taxa

There was a significant temporal and spatial variation in the number of yellowfin bream (*Acanthopagrus australis*) collected from the sites in Botany Bay (Table 4.3.3). There were always more bream collected from the impacted wetland area than from the near or far reference areas (Figure 4.3.3c). In particular, there were larger catches of bream from the site furthest upstream from the pipe entrance in February and December 1997 (Figure 4.3.3c).

Except for June 1996, there were more sea mullet (*Mugil cephalus*) collected from the Botany Bay impacted wetland area compared to the near and far reference areas in the Bay (Table 4.3.3, Figure 4.3.3d). In June 1996 there was one significantly large catch of sea mullet from the near reference area (Figure 4.3.3d, Appendix 4.5). These were all small juveniles and were collected from the site directly adjacent to the entrance pipe to the Rockdale wetlands area.

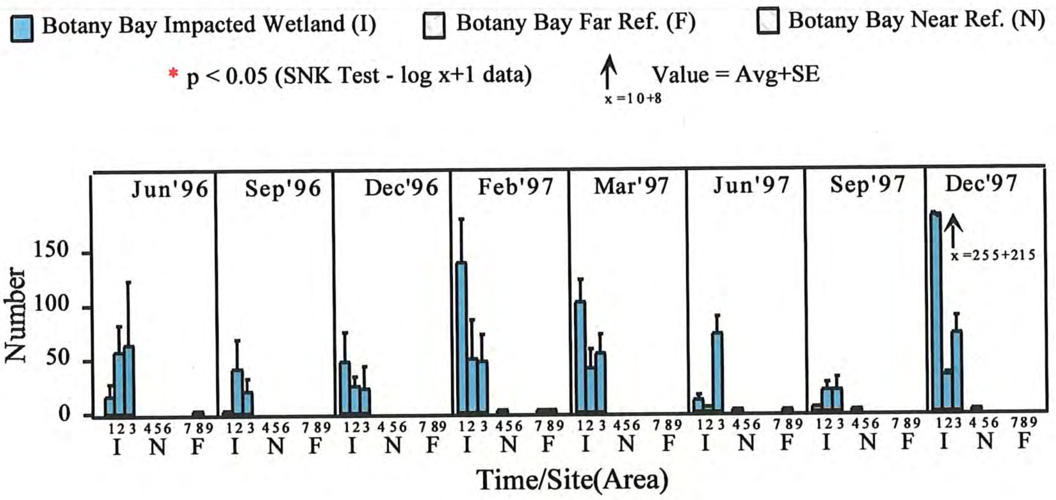

Figure 4.3.3c. Mean (+SE) number of yellowfin bream (*Acanthopagrus australis*) collected from Botany Bay.

Plots show the significant ($p < 0.05$) terms in the analyses of variance model with the variation among sites within the impacted, near reference and far reference areas over time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

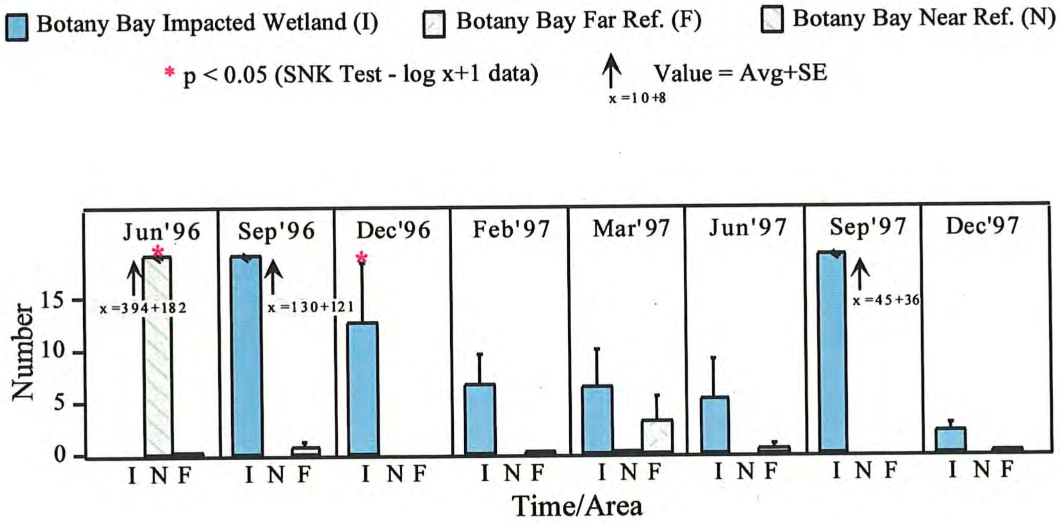

Figure 4.3.3d. Mean (+SE) number of sea mullet (*Mugil cephalus*) collected from Botany Bay.

Plots show the significant ($p < 0.05$) terms in the analyses of variance model with the variation between the impacted, near and far reference areas through time Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

Abundances of selected non-commercial taxa

The number of glassy perchlets (*Ambassis jacksoniensis*) showed significant spatial and temporal variation in Botany Bay (Table 4.3.3). In particular, the numbers of ambassids varied substantially at the far reference sites and included some very large catches (Figure 4.3.3e).

Blue spot gobies (*Pseudogobius olorum*) and flathead gudgeons (*Philypnodon grandiceps*) only occurred in the Botany Bay wetland area and were never collected from the near or far Botany Bay reference sites (Figure 4.3.3f and Figure 4.3.3g).

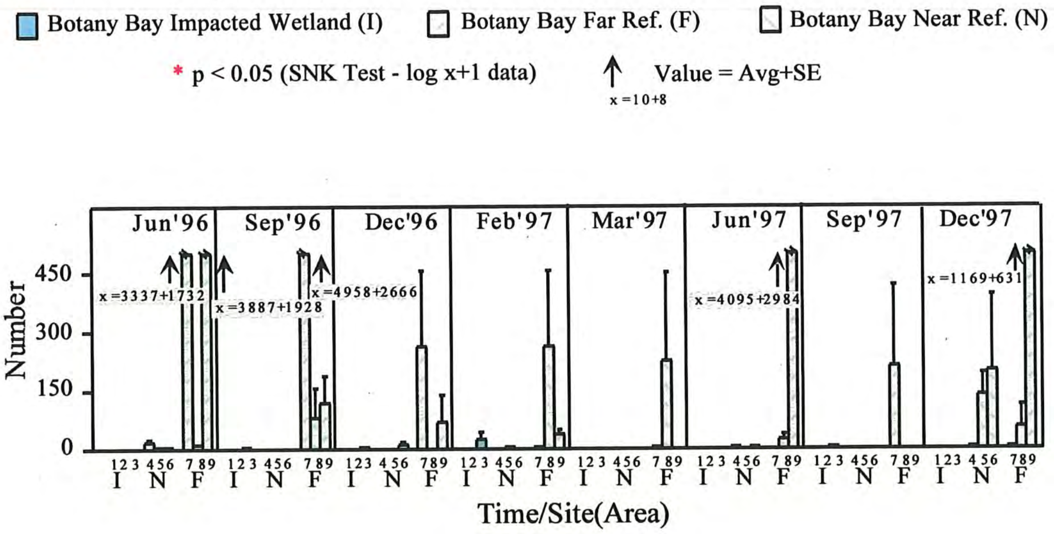

Figure 4.3.3e. Mean (+SE) number of glassy perchlets (*Ambassis jacksoniensis*) collected from Botany Bay.

Plots show the significant ($p < 0.05$) terms in the analyses of variance model with the variation among sites within the impacted, near reference and far reference areas over time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

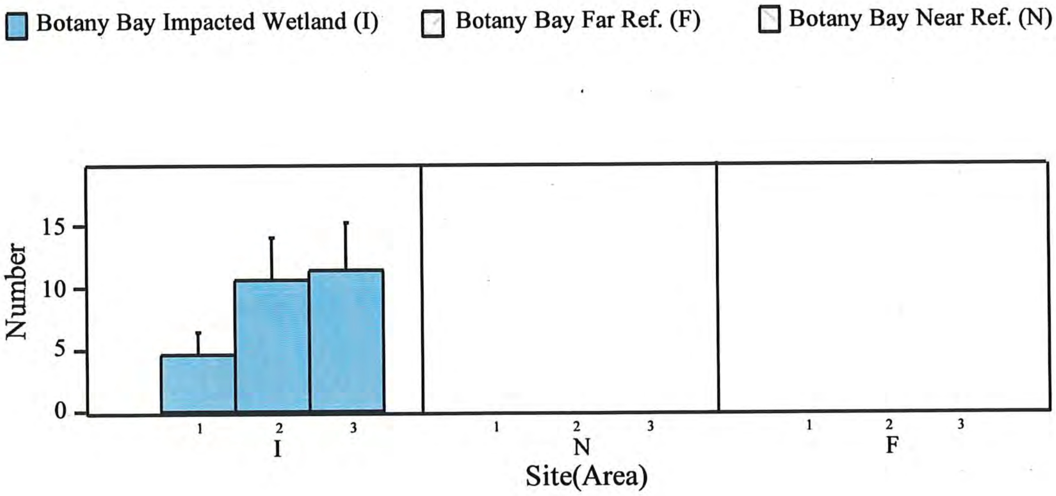

Figure 4.3.3f. Mean (+SE) number of blue spot gobies (*Pseudogobius olorum*) collected from Botany Bay.

Plots show the significant ($p < 0.05$) terms in the analyses of variance model with the variation between the impacted, near and far reference areas through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

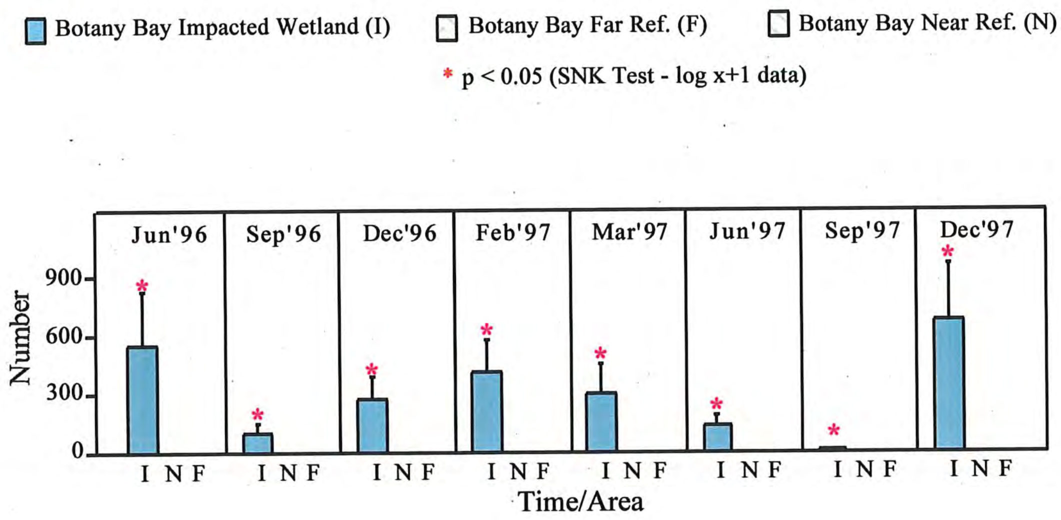

Figure 4.3.3g. Mean (+SE) number of flathead gudgeons (*Philypnodon grandiceps*) collected from Botany Bay.

Plots show the significant ($p < 0.05$) terms in the analyses of variance model with the variation among sites within the impacted, near reference and far reference areas over time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

4.3.4. External Reference Estuaries

Species richness

Species richness at the three external reference estuaries varied through time and there were slightly more species collected from the Wallamba River and the least number of taxa were collected from the Nambucca River (Table 4.3.1b, 4.3.2b, Figure 4.3.4a).

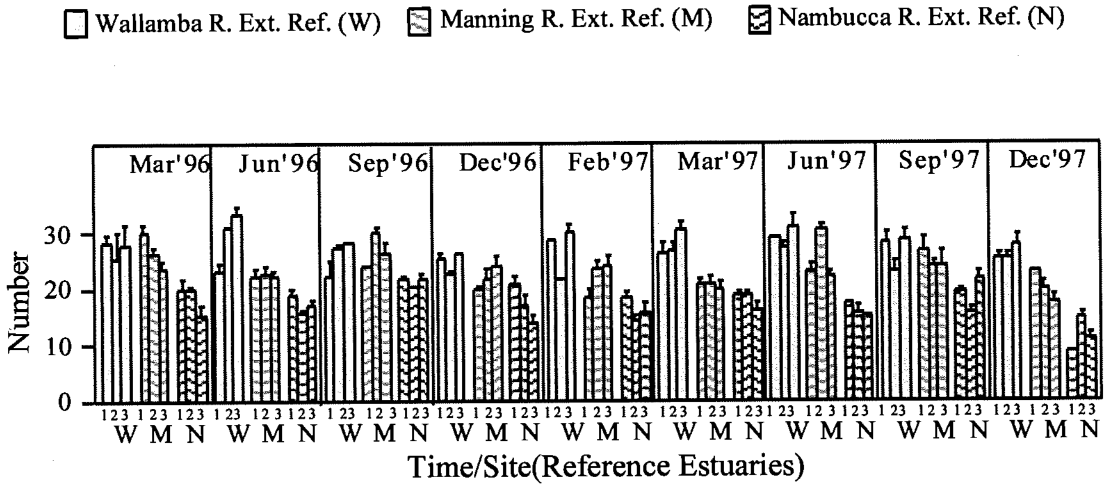

Figure 4.3.4a. Mean (+SE) <u>number of taxa</u> collected from the external reference estuaries.

The plot shows the significant ($p < 0.05$) term in the analysis of variance models for the Hunter River and shows the variation between the sites at each of the external reference estuaries through time. Raw data were used for the plot and SNK test results are only shown for non-nested terms in the analysis of variance.

Abundances of selected commercial taxa

The number of bream collected from the external reference estuaries varied through time and there were fewer bream collected during the summer/autumn months compared with the winter/spring months (Table 4.3.1b, 4.3.2b, Figure 4.3.4b). Of the three external reference estuaries the largest catches of bream were from the Manning River (Figure 4.3.4b). These differences were significant in March and September 1996 and June and September 1997 (Figure 4.3.4b, Appendix 4.6). In the Nambucca River there were significantly more bream collected in June 1996 and September 1997 (Appendix 4.6, Figure 4.3.4b).

The abundances of sea mullet at the external reference estuaries varied significantly between the sites through time (Table 4.3.1b, 4.3.2b) and there were very large catches of these mullet collected during September 1996 and 1997 from the Manning River and Nambucca River respectively (Figure 4.3.4b).

The numbers of king prawns collected from the external reference estuaries varied through time (Table 4.3.1b, 4.3.3b). The least number of prawns were collected from the Nambucca River and except for September 1996, there were more prawns collected from the Wallamba River (Figure 4.3.4c).

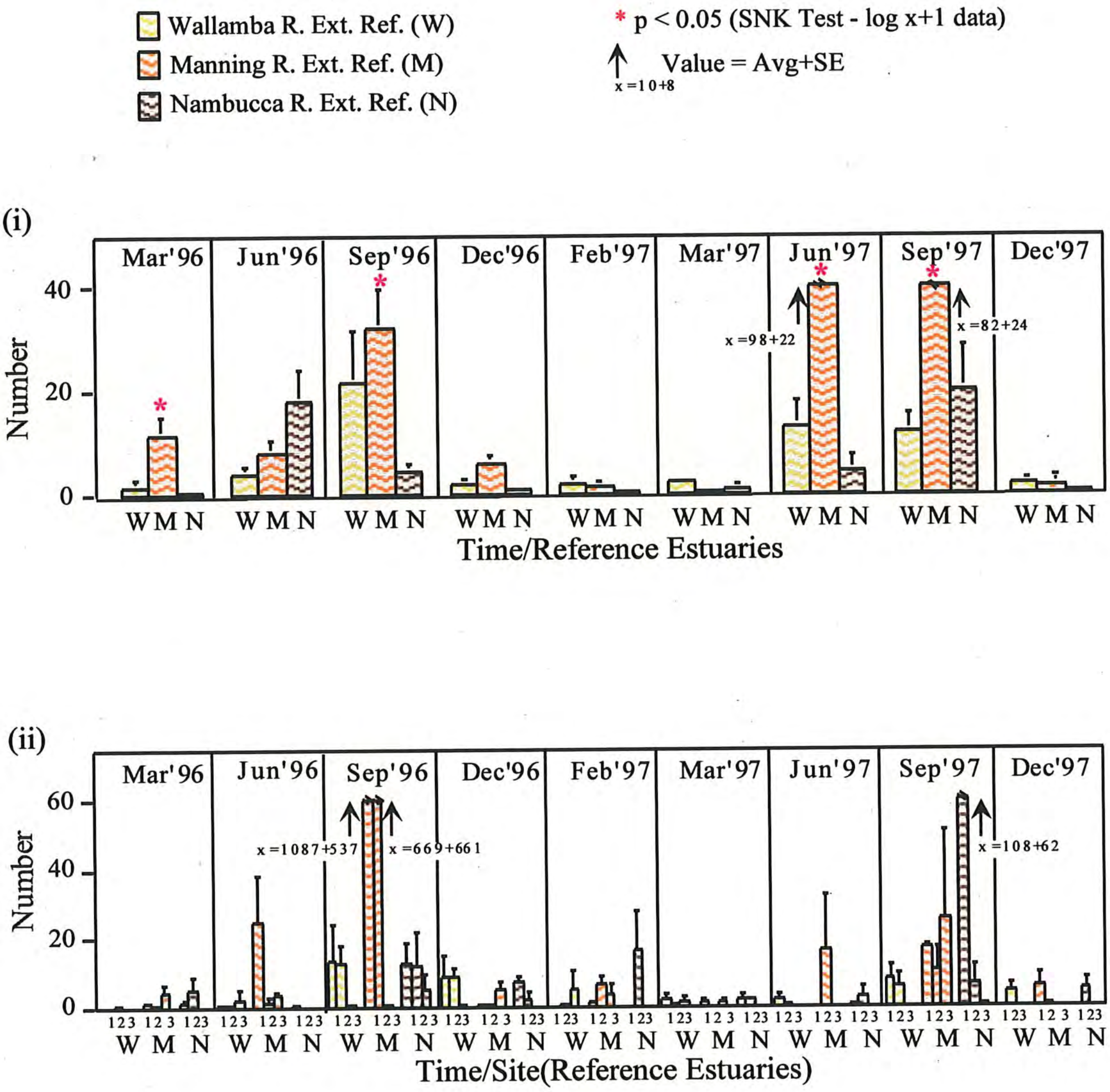

Figure 4.3.4b. Mean (+SE) number of (i) yellowfin bream (*Acanthopagrus australis*) and (ii) sea mullet (*Mugil cephalus*) collected from the external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the asymmetrical analysis of variance models for the Hunter River and the Macleay River with (i) the differences between the external reference estuaries through time and (ii) the differences between the sites at each of the external reference estuaries through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

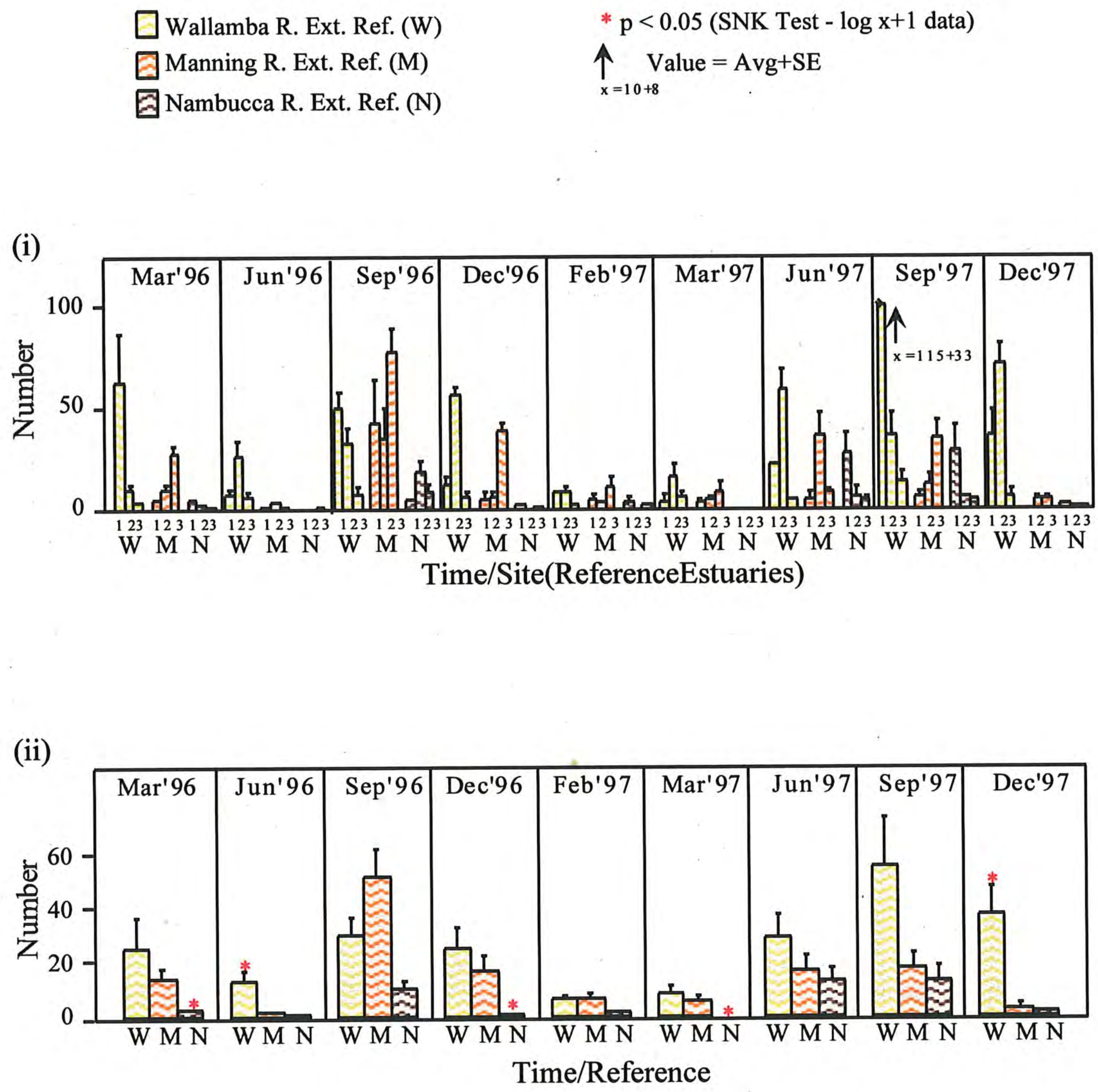

Figure 4.3.4c. Mean (+SE) number of king prawns (*Penaeus plebejus*) collected from the external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the asymmetrical analysis of variance models for (i) the Hunter River with the variation between the sites at each of the external reference estuaries through time and (ii) the Macleay River with the differences between the external reference estuaries through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

Abundances of selected non-commercial taxa

The numbers of ambassids varied significantly at the sites within each of the reference estuaries, and particularly in June 1997 when there were some large catches from the Manning River (Table 4.3.1b, 4.3.2b, Figure 4.3.4d).

The numbers of glass gobies collected from the external reference estuaries varied over time (Table 4.3.1b, 4.3.2b) and there were more glass gobies collected from the Manning River for all times except December 1997 (Figure 4.3.4e). Only 38 glass gobies were collected from the Nambucca River throughout the study which in comparison to the numbers collected from the Wallamba and Manning rivers was relatively insignificant (Appendix 2, Figure 4.3.4e).

Among the external control estuaries the numbers of blue spot gobies and flathead gudgeons varied between sites and over time and in particular at site 3 on the Wallamba River there were large catches of gudgeons in March 1996 and February and December 1997 (Table 4.3.1b, 4.3.2b, Figure 4.3.4e).

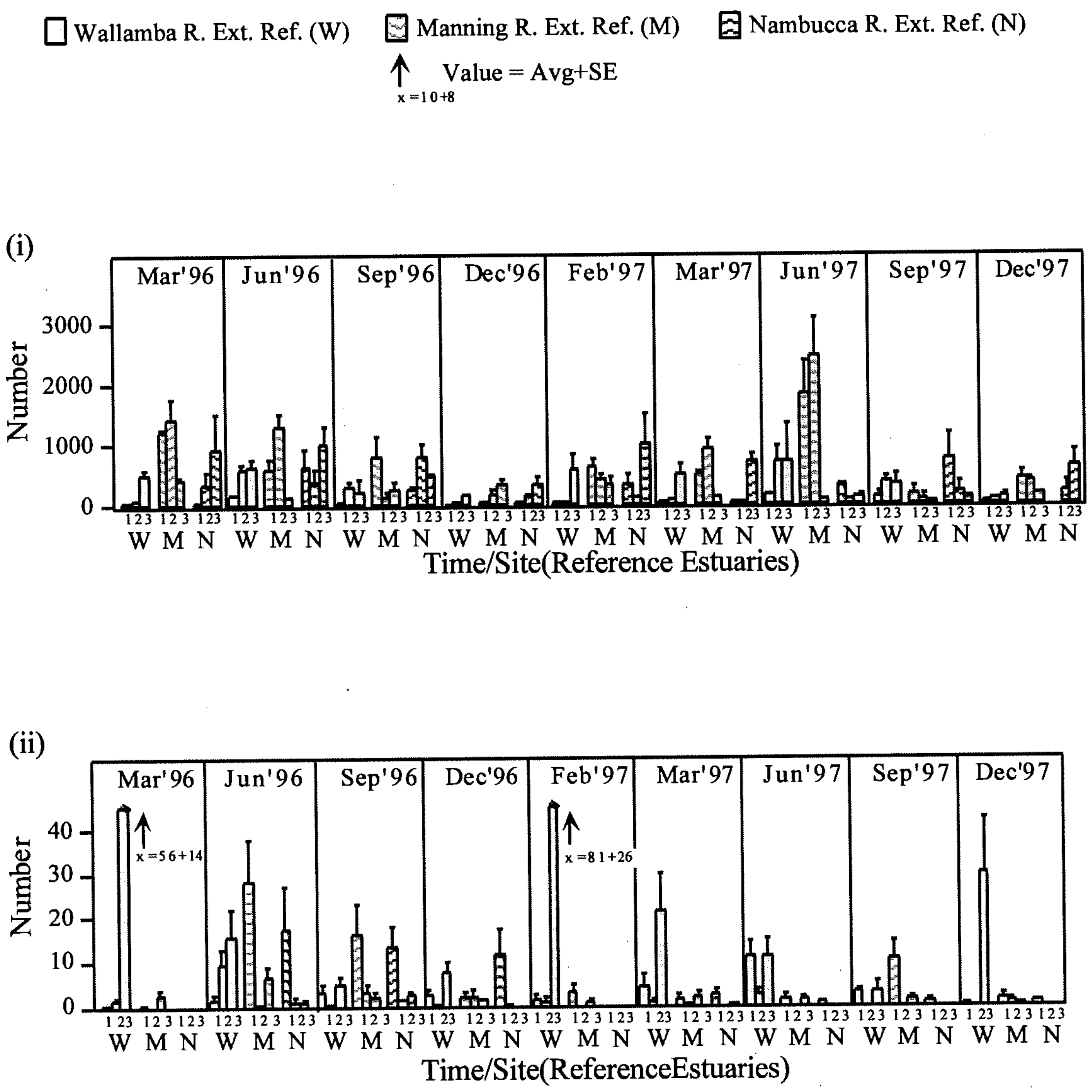

Figure 4.3.4d. Mean (+SE) number of (i) glassy perchlets (*Ambassis jacksoniensis*) and (ii) flathead gudgeons (*Philypnodon grandiceps*) collected from the external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the asymmetrical analysis of variance models for the Hunter River and Macleay River with the differences between the sites at each of the external reference estuaries through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

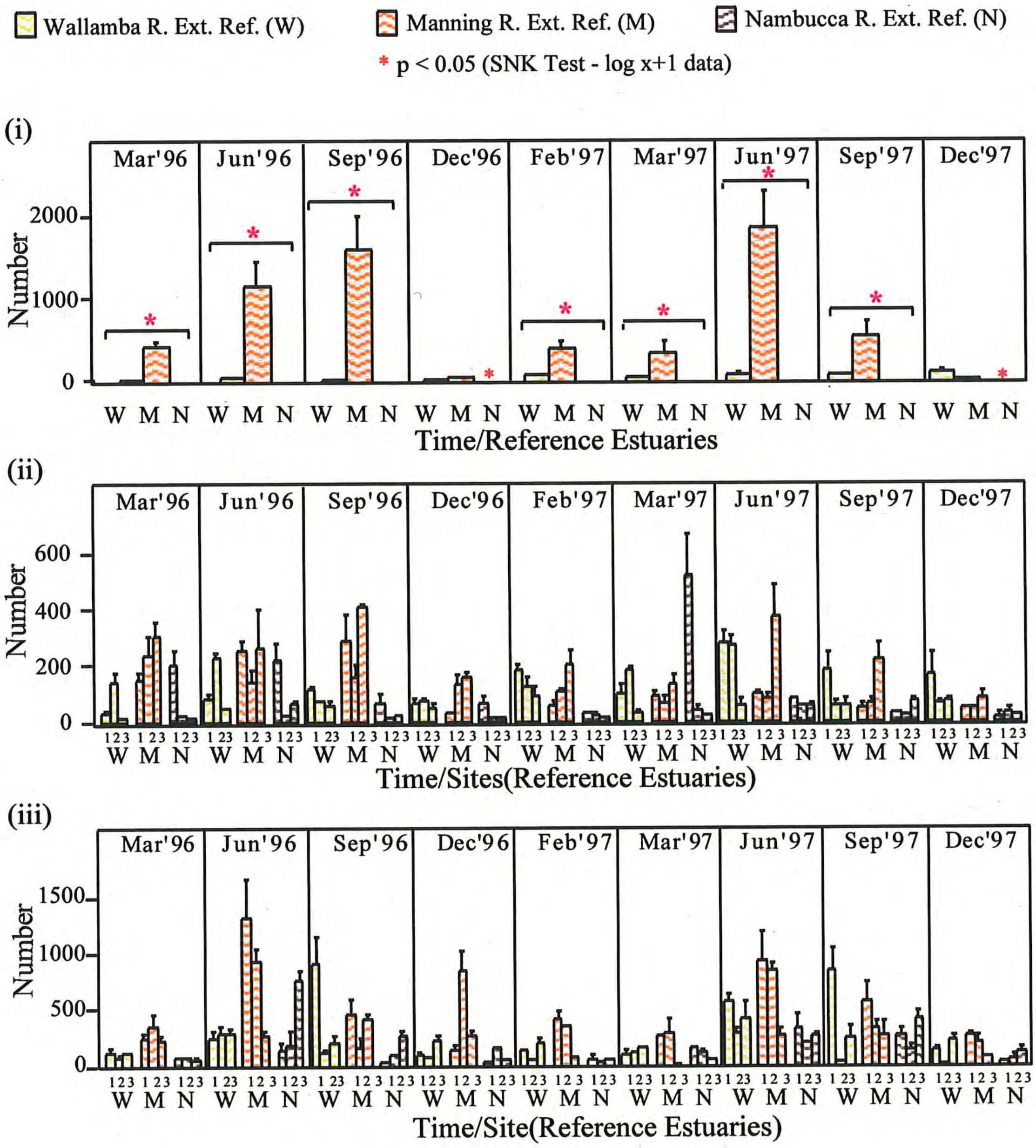

Figure 4.3.4e. Mean (+SE) number of (i) glass gobies (*Gobiopterus semivestitus*) and (ii) blue spot gobies (*Pseudogobius olorum*) and (iii) large mouth gobies (*Redigobius macrostoma*) collected from the external reference estuaries.

Plots show the significant ($p < 0.05$) terms in the asymmetrical analysis of variance models for the Hunter River and Macleay River with (i) the differences between the external reference estuaries through time and for (ii) and (iii) the differences between the sites at each of the external reference estuaries through time. Raw data were used for the plots and SNK test results are only shown for non-nested terms in the analysis of variance.

4.4. Length frequency

The seine net in this study was designed for sampling the juvenile fish community not the larger adults. Consequently, the length frequency distributions are only used to describe the abundances and recruitment of juvenile fish into an area. Only yellowfin bream (*Acanthopagrus australis*) and sand mullet (*Myxus elongatus*) from the Botany Bay impacted wetland area occurred consistently in sufficient numbers to warrant investigation of length frequency distributions. Although other commercially important species were collected at all the sample locations throughout the study period, they were never consistently abundant in any one particular area.

Two separate year classes of yellowfin bream occurred in the Rockdale wetlands area in Botany Bay throughout the study period. The smaller age class was always the most abundant. The recruitment of juveniles with a caudal length less than 50 mm occurred in the December of both sampling years (Figure 4.4a).

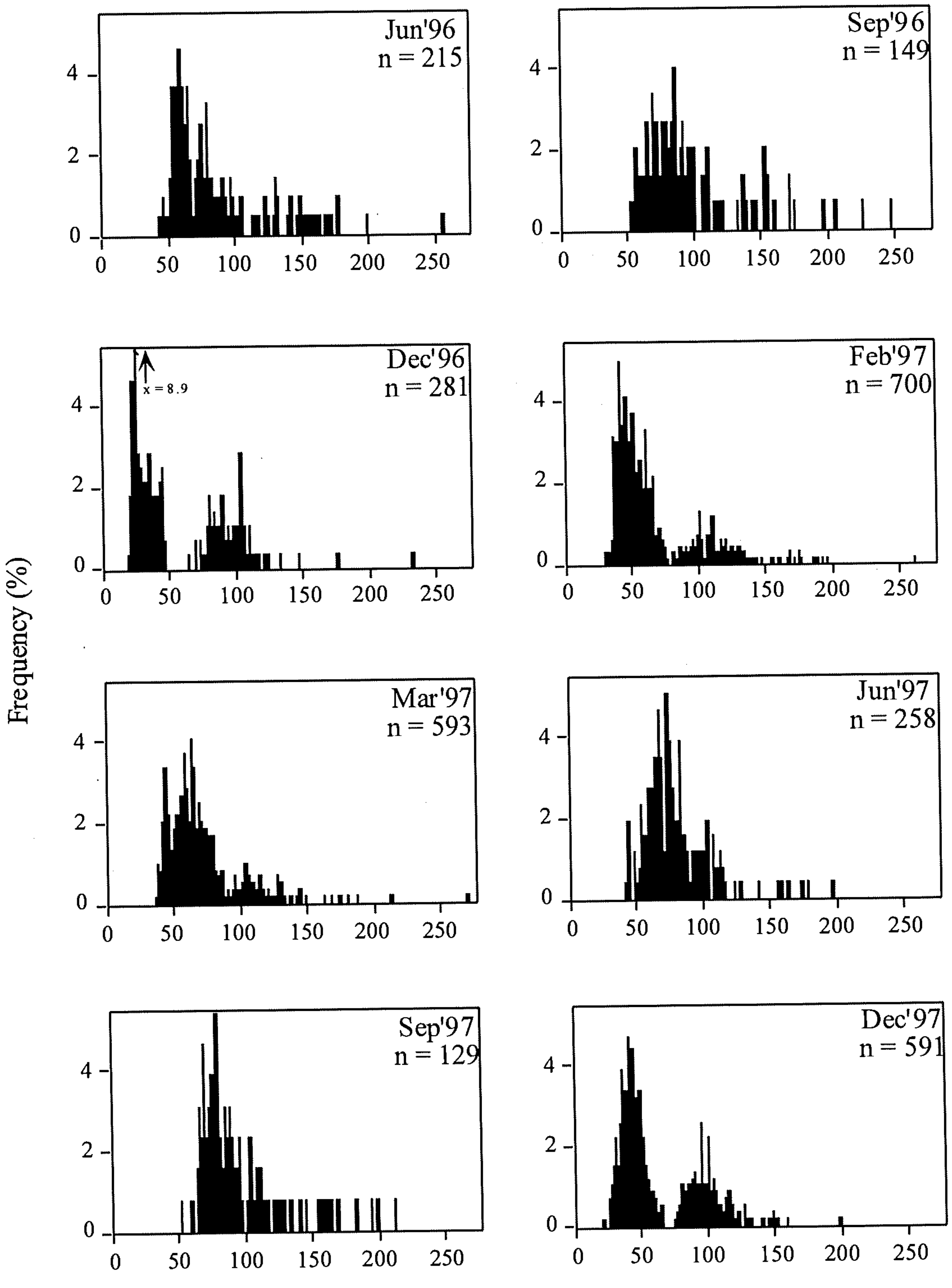

Figure 4.4a. Length frequency histograms for yellowfin bream (*Acanthopagrus australis*) collected from the Botany Bay impacted wetland area for each of the sampling periods.

Until March 1997 there was one dominant year class of sand mullet in the wetlands which grew from an average of 50 mm total length to an average total length of approximately 125 mm. The recruitment of sand mullet in the Botany Bay impacted wetland area occurred in autumn. There was a distinct small age class in March 1997 with most individuals measuring less than 50 mm total length (Figure 4.4b). The number of individuals of sand mullet collected from the Botany Bay wetlands varied from between 690 animals in March 1997 to only 15 individuals in December 1997 suggesting that there was some movement of these animals out of the wetlands. McDowall (1996) suggests that often juvenile sand mullet in their first year enter fresh water but rarely after this.

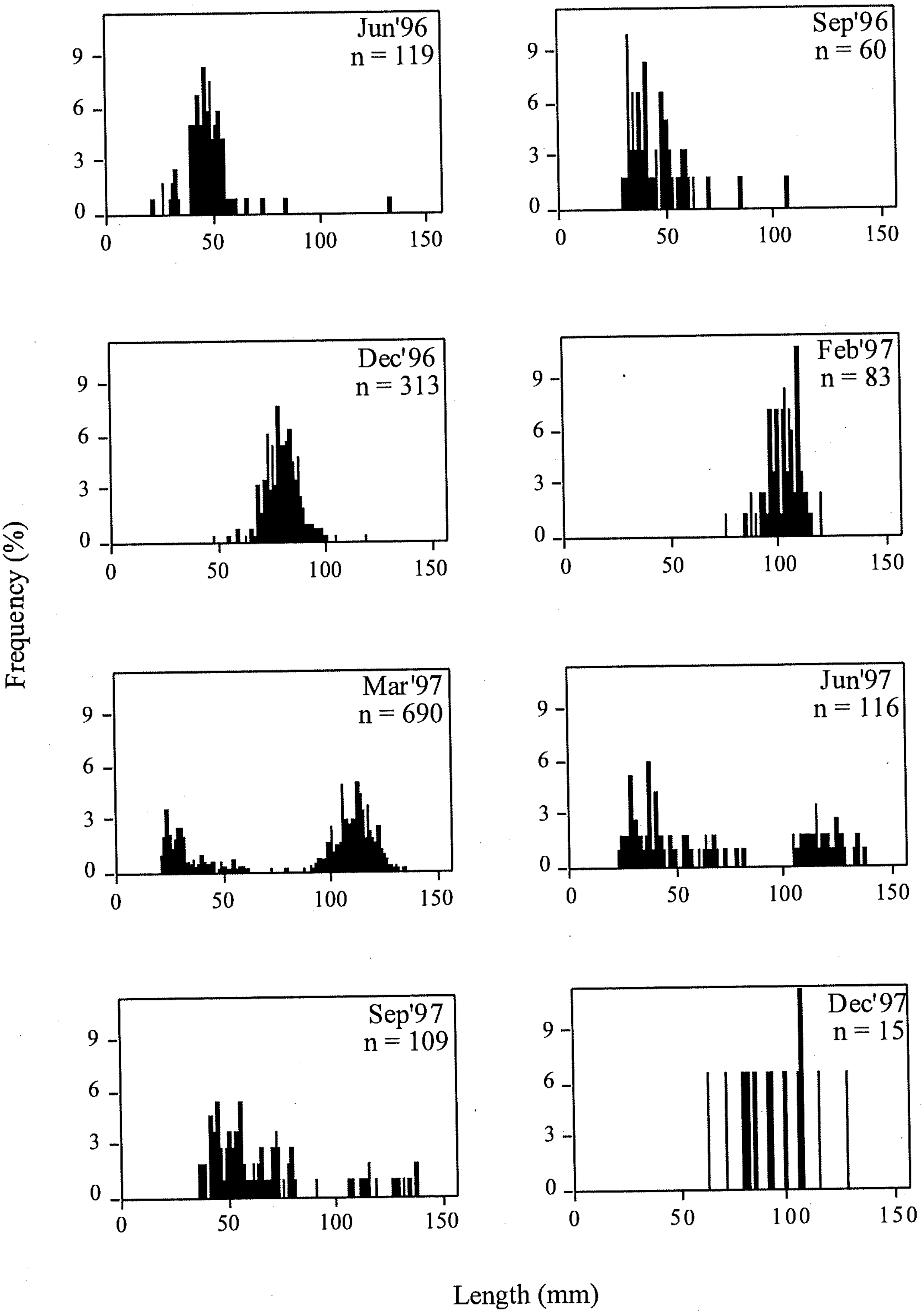

Figure 4.4b. Length frequency histograms for sand mullet (*Myxus elongatus*) collected from the Botany Bay impacted wetland area for each of the sampling periods.

4.5. Water quality

4.5.1. Physico-chemical variables

Water temperatures measured in the field ranged between 12.7°C and 34.5°C during the study period (Appendix 5). On average, the lowest temperatures were recorded from the near reference sites within Botany Bay and the highest average temperatures were recorded from the northern-most estuaries (Figure 4.5.1). In comparison to the Hunter River or Macleay River, the water temperatures in the Botany Bay impacted wetland area were greater than the near or far reference areas, however temperatures within the Macleay River impacted wetland area were more variable than the other wetland areas (Figure 4.5.1).

The salinity in the wetland estuaries followed an expected gradient, with the lowest salinities occurring upstream in the impacted wetland areas and the highest salinities closer to the mouth of the estuary at the far reference areas. The Macleay River wetland area had the lowest average salinity throughout the study period, followed by the Hunter River and Botany Bay respectively (Figure 4.5.1). The sites within the Nambucca River were always less saline than the Wallamba and Manning rivers.

The pH was always lowest in the impacted wetland areas compared to the near or far reference areas or the external reference estuaries from Botany Bay, Hunter River and the Macleay River (Figure 4.5.1). In particular, the pH of the Macleay River impacted wetland area was substantially lower than any other area and dropping as low as 3.69 in June 1996 (Appendix 6; Figure 4.5.1).

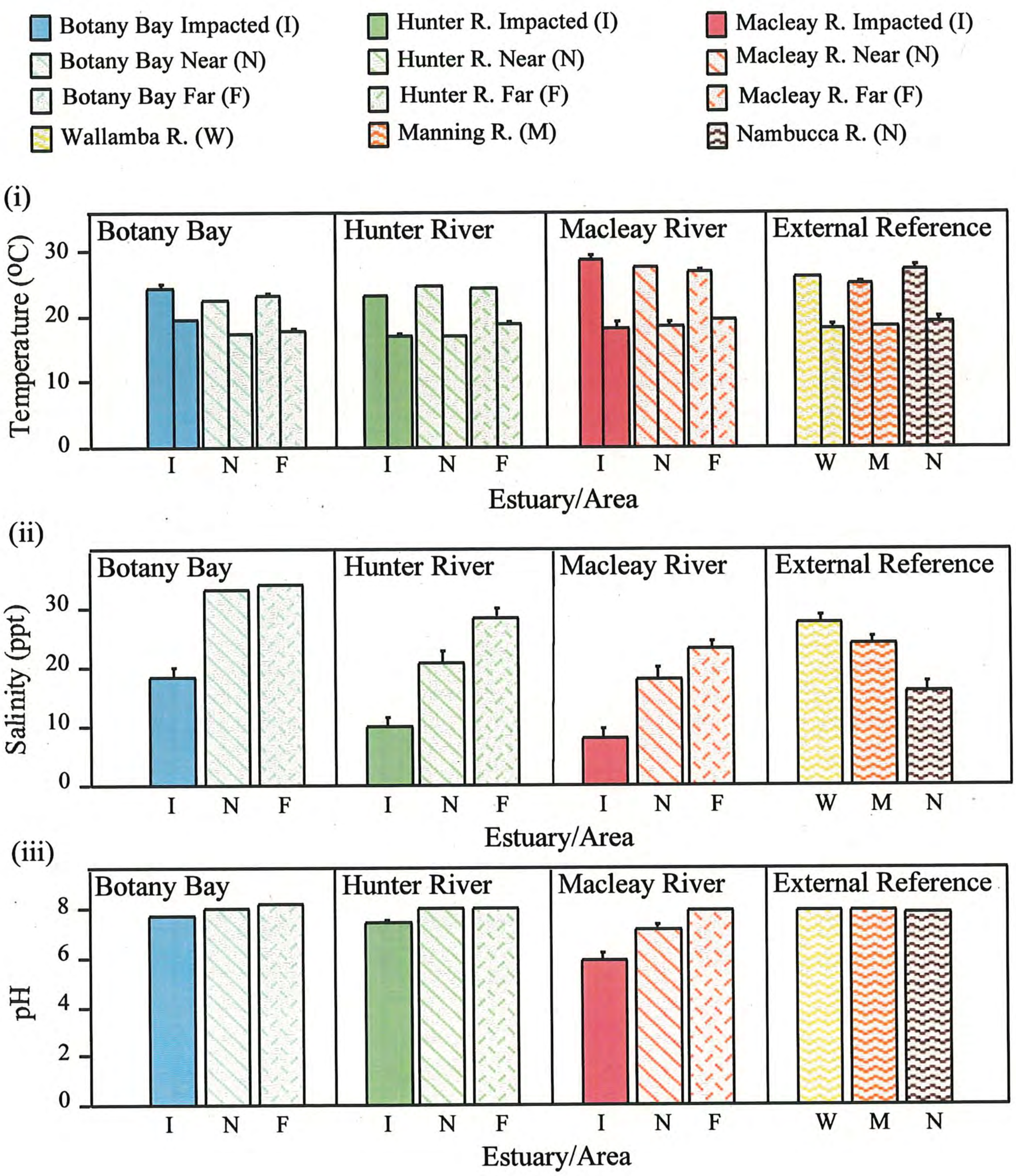

Figure 4.5.1. Mean (+SE) values for each of the physico-chemical parameters measured in the field at the impacted (I), near reference (N) and far reference (F) areas in each of the wetland estuaries and at each of the external reference estuaries.

The parameters were measured at each site prior to collecting the biological samples and are shown here for (i) temperature in summer and winter respectively, (ii) salinity and (iii) pH.

4.5.2. Macleay River rainfall and data logger information

Smokey Cape and Kempsey are the closest Bureau of Meteorology rainfall stations to our study area on the Macleay River. However, there were no data collected from the Smokey Cape station between October 1996 and July 1997 (Figure 4.5.3a). Between March 1996 to September 1996 and July 1997 to December 1997, the rainfall at Kempsey and Smokey Cape followed a similar trend although at times there were slightly heavier falls at one of the stations. The heaviest rainfalls (more than 50 mm) occurred in May, July and November 1996 and January and March 1997 (Figure 4.5.3a).

Temperature in the Macleay River followed a typical cycle with the highest temperatures in February and the lowest temperatures in July of both years. There was always a few degrees difference in the temperatures in the shallow Yarrahapinni Broadwater behind the floodgates compared to the main river channel (Figure 4.5.3a). In the wetlands area temperatures were greater in summer and lower in winter compared with the main river channel as was expected due to the much shallower waters of the wetlands area.

Conductivity in the Macleay River estuary was extremely variable (Figure 4.5.3b). There were a number of dramatic decreases in the conductivity levels and these were directly related to increased rainfall (Figure 4.5.3a and Figure 4.5.3b). Conductivity in the Yarrahapinni wetland was always lower than in the main channel of the Macleay River indicating the lack of tidal flow into the wetlands due to the presence of the floodgates.

The data logger results show the area behind the floodgates had the most variable pH levels with acidic values as low as 3.85. Downstream of the floodgates, in the main channel of the Macleay River the pH levels followed a similar trend to the levels in the Yarrahapinni wetland area except the levels were always within the ANZECC (1992) guideline limits.

Between March 1996 and December 1997 the dissolved oxygen levels in the Macleay River varied between almost zero to 24 mg/L (Figure 4.5.3c). The dissolved oxygen levels in the Macleay River channel and the Yarrahapinni wetlands fell below the 6 mg/L level recommended for the protection of aquatic ecosystems (ANZECC, 1992) for 68% and 64% of the days, respectively. The highest (24 mg/L) and the lowest (3.04 mg/L) levels of dissolved oxygen were both recorded from the main channel of the Macleay River.

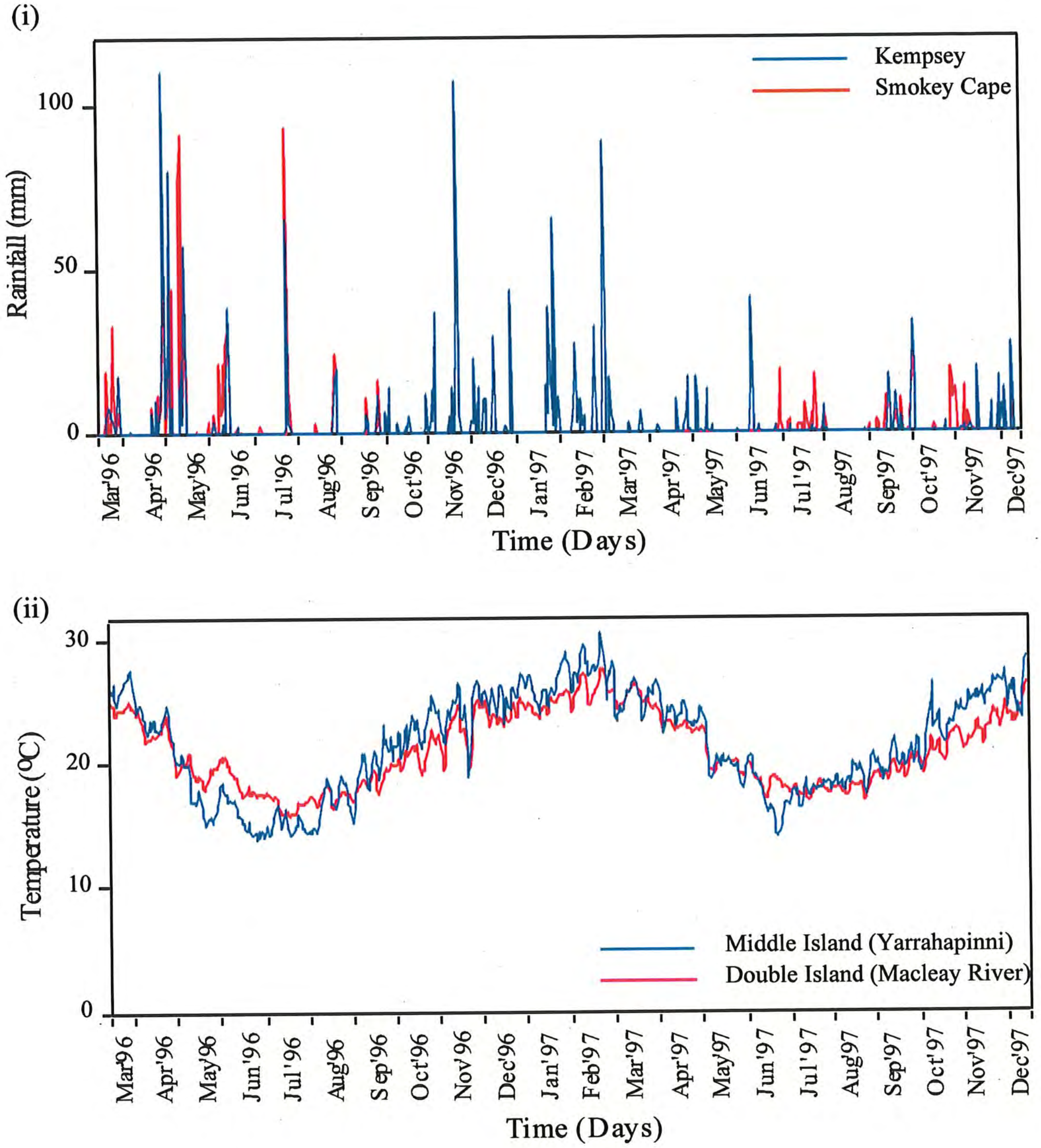

Figure 4.5.3a. Graph of (i) the mean daily rainfall at Kempsey and Smokey Cape and (ii) the mean daily temperatures recorded at Double Island and Middle Island.

Data are for the period between March 19th, 1996 and December 18th, 1997. Rainfall was recorded by the Bureau of Meteorology and temperatures were recorded by the Department of Public Works and Services data loggers in the main channel of the Macleay River, downstream of the Yarrahapinni wetlands area and in the Yarrahapinni wetlands area.

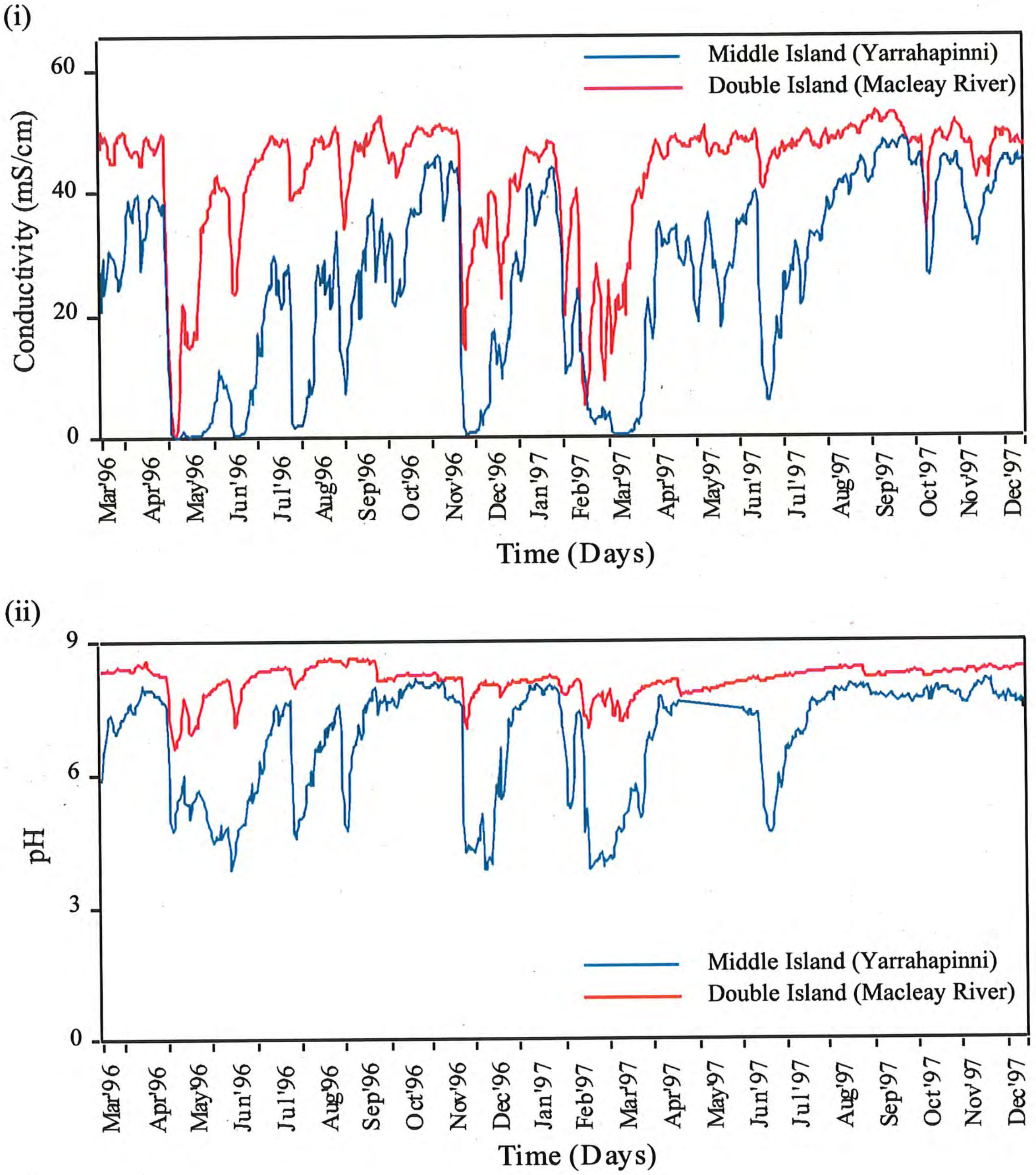

Figure 4.5.3b. Graph of (i) the mean daily conductivity and (ii) the mean daily pH at Double Island and Middle Island

Data are for the period between March 19th, 1996 and December 18th, 1997 and was recorded by the Department of Public Works and Services data loggers in the main channel of the Macleay River, downstream of the Yarrahapinni wetlands area and in the Yarrahapinni wetlands area.

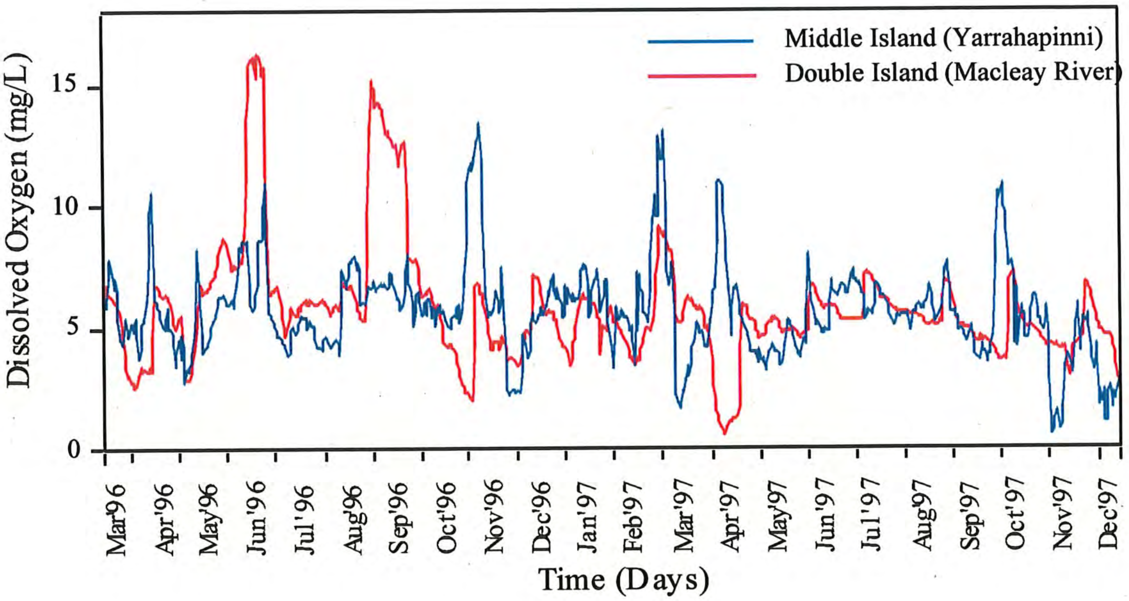

Figure 4.5.3c. Graph of the mean daily dissolved oxygen at Double Island and at Middle Island.

Data are for the period between March 19th, 1996 and December 18th, 1997 and was recorded by the Department of Public Works and Services data loggers in the main channel of the Macleay River, downstream of the Yarrahapinni wetlands area and in the Yarrahapinni wetlands area.

5. Discussion

The often negative effects on the ichthyofauna of freshwater rivers of river modification, channelisation, flow regulation and barriers to passage are well documented (Swales, 1982; Ward and Stanford, 1989; Harris and Mallen-Cooper, 1994; Jurajda, 1995; Gehrke *et al.*, 1995; Pethebridge *et al.*, 1998). The impacts of reduced freshwater flow due to river regulation and diversion on estuarine and marine fish and invertebrates have been reviewed by Drinkwater and Frank (1994). These impacts include effects on migration patterns, spawning habitat, species diversity, water quality and distribution, and production of lower trophic levels.

The impact of tidal floodgate structures on the marine and estuarine ichthyofauna of rivers is less well understood (Rey *et al.*, 1990; Pollard and Hannan, 1994; Vose and Bell, 1994). All studies demonstrate a degradation in the quality of fish habitat and a significant reduction in the abundance and species composition of the fish community above as compared to below barriers. The importance of tidal exchange as a key factor regulating fish in estuarine wetland restoration projects has also been demonstrated (Gilmore, 1986; Rey *et al.*, 1990 and Vose and Bell, 1994).

This study shows the fish community structure above and below three tidal barriers to estuarine wetlands varied considerably. Where floodgates are completely closed (Yarrahapinni wetlands Macleay River), the upstream community is dominated by freshwater species such as gudgeons (*Philypnodon* sp., *Philypnodon grandiceps* and *Gobiomorphus* spp.), gobies (*Pseudogobius olorum*), southern blue-eyes (*Pseudomugil signifer*), mosquitofish *(Gambusia holbrookii*) and aquatic insects such as dragonfly nymphs, damselfly nymphs and water boatman. There were very few commercially or recreationally important fish and invertebrate species collected from this area. At the site furthest upstream in these wetlands there were two of the three samples collected in March 1996 that contained no fish or invertebrates. During the study another five samples were collected from this site which contained no fish. The below floodgate community was diverse and dominated by flat tailed mullet (*Liza argentea*), sea mullet (*Mugil cephalus*), yellowfin bream (*Acanthopagrus australis*), tarwhine (*Rhabdosargus sarba*), striped trumpeter (*Pelates sexlineatus*), glass perch (*Ambassis jacksoniensis*), school prawns (*Metapenaeus macleayi*), king prawns (*Penaeus plebejus*) and a variety of gobies and non commercial shrimps.

In comparison, the community in the wetland area on Ironbark Creek in the Hunter River where the floodgates were partially open, was very diverse and included juveniles of several species of economic importance and few of the freshwater species similar to the Yarrahapinni wetlands. Overall, the community structure in Ironbark Creek was comparable to the main channel of the Hunter River but actually supported a greater number of juvenile sea mullet (*Mugil cephalus*), yellowfin bream (*Acanthopagrus australis*) and school prawns (*Metapenaeus macleayi*) than the main channel. Species richness, biomass and the data presented for the major commercial and non-commercial species show no long term trends distinguishable from seasonal patterns indicative of a significant ongoing response to the partial floodgate opening.

Commercial fish species dominated the samples collected from the Rockdale wetlands area in Botany Bay. This area supported a significantly greater local abundance and biomass of commercial fish than the Bay itself. It appears that the Rockdale wetlands provides an important nursery area especially for yellowfin bream and mullet of Botany Bay which are able to move through the permanently open 700 m long pipe into the modified wetlands.

At the community level, the spatial differences between the sampled estuaries/areas was consistent through time. When the site data were combined to obtain a single MDS ordination point for each time, it was found that the community structure had a seasonal trend and sites were most different during the warmer months. There was virtually no difference between the winter samples for the two years that were sampled. However, there were not enough data points (i.e. seasons/years) to do an ANOSIM to test the significance of these differences and a SIMPER analysis was not able to determine any taxa that unequivocally discriminated the seasons.

The spatial MDS analysis of the data clearly demonstrates the intra estuary and external reference estuary similarity of below barrier sites and their similarity to the Ironbark Creek, Hunter River above floodgate sites. The analysis shows Ironbark Creek with a moderate tidal exchange is functioning as a nursery habitat and has a sustainable fish community especially of bream, mullet and school prawns. The spatial analysis also shows Botany Bay was different from all other sampled estuaries.

The exchange and transformation of water, nutrients, sediments and biota are processes that link fisheries habitats. Habitat integrity and diversity and natural physico- chemical and biological linkages between habitats are critical to maintaining fish species diversity, trophic structures, integrity of important fishery stocks and sustainable fisheries (Zeller, 1998).

Therefore, in the context of the three different 'restored/modified' wetlands we studied:- " What's a wetland worth?". This vexing question can be addressed at the economic and ecological levels. The economic valuation of wetlands aims to place a $ value on the ecological system using the observed consumer choices to infer the marginal value of changes in environmental amenity (hedonic property value models and travel cost methods). However, if the community do not 'use' the environmental amenity directly the use of choice survey techniques or the contingent valuation method is applied. (Bell, 1997; Blomquist and Whitehead, 1998; Pate and Loomis, 1997; Freeman, 1993). Unfortunately these economic valuations are an anthropogenic summation of habitat quality rather than the natural ecological summation and only partially answer the question.

The ecological issues can be summarised into the broad categories of predicability, structure and function, limiting factors and landscape issues (Zedler, 1996). Clearly the functional or process attributes of the wetland or any other habitat are difficult to measure and define. However, no environmental factor operates in isolation and the quality of the habitat is the summation of a range of factors, processes and conditions. If the habitat is restored, created or enhanced the functional equivalence of the modified habitat must be considered (Simenstad and Thom, 1996). The critical issue is sustainability and the two most fundamental principals are integration of economic, environmental and social value systems and maintenance of intergenerational equitability (McCormick, 1999).

Are the restored wetlands functionally equivalent? The distribution of juvenile fish in estuaries has been partially explained in relation to shelter, calm water, suitable food, predators and turbidity (Blaber and Blaber, 1980). Many studies have demonstrated the high proportion of temporary resident fish occurring as juveniles in shallow tidal wetlands containing seagrass, mangroves or salt marsh (Morton *et al.*, 1987; Bell and Pollard, 1989; Ferrell and Bell, 1991; Bell and Worthington, 1992; West and King, 1996; Gray *et al.*, 1996 and 1998 and Hannan and Williams, 1998). Many of these fishes move between habitats on seasonal and/or inter annual cycles and an appropriate surrogate for the functional equivalence and sustainability of the 'restored' habitat is it's utilisation by fish and invertebrates in a similar way to the external reference sites and estuaries.

From previous studies in Botany Bay (Bell *et al.*, 1984) we know that many juvenile fish use the Towra Point Reserve as a nursery ground. From our study, we have identified the highly modified Rockdale wetlands area with a significant tidal exchange, as another important nursery ground for juvenile bream and mullet which appears to be functioning in a sustainable manner. Repeated recruitment of juvenile fish, based on length frequency data is occurring. The development of Botany Bay as a major shipping and industrial port including significant reclamation of the natural habitats has limited the available juvenile fish habitat in the Bay especially on the northern and western shores and this may have accentuated the importance and utilisation of the Rockdale wetlands.

A further indicator of the functional equivalency of the 'restored' wetlands in Ironbark Creek, Hunter River and Rockdale wetlands, Botany Bay is the presence of small numbers (8) of glass eels, *Anguilla* sp. collected in winter through to summer in both years and (18) common jollytails, *Galaxias maculatus* collected in the spring of both years. These migratory species are normally excluded by tidal barriers due to both the physical barrier and the habitat and water quality alterations above the barrier.

Anguilla australis occurs in a wide variety of wetland habitats including rivers, creeks, lakes and swamps while *A. reinhardtii* tends to occur more often in rivers rather than lakes. Eels migrate downstream to spawn in the sea when sexually mature. Larval eels (leptocephali) are carried back from the spawning grounds by the East Australian Current. When near the coast they metamorphose into glass eels. Young eels enter the estuaries often in winter and spring and migrate to freshwater during spring and summer. They may take 10-20 years to reach maturity and then begin their downstream migration to the sea to spawn (McDowall, 1996).

Galaxias maculatus tolerates a wide range of habitat conditions including salinities well in excess of full seawater. Adults migrate downstream on new or full moons, mostly during autumn. They spawn among the terrestrial vegetation on the margins of river estuaries when inundated at high spring tides. The larvae (~7mm long) go to sea, spend the winter there and migrate back to the estuaries as slender, transparent juveniles (45-50mm long after ~5-6 months). They enter estuaries often in shoals on the rising tide and move upstream into adult habitats to feed and grow. Their usual adult size is ~100mm but they can reach up to 190mm (McDowall, 1996).

Utilisation of restored areas by key species

Acanthopagrus australis is found on the east-coast from central Queensland to eastern Victoria. They occur on coastal reefs and in rocky or muddy estuaries and are usually found in small to large schools. Yellowfin bream spawn mostly during winter, but this can vary considerably between estuaries and years (Kuiter, 1993). Spawning occurs near the river entrances either over river bars or in the surf zone. The adults migrate from their feeding grounds to the spawning site. After one month the post-larvae enter estuaries on the flood tide and settle out of the plankton when they are about 13mm total length. Post-larvae and juveniles mainly inhabit seagrass beds in shallow estuarine waters. Growth is rapid prior to maturity. In Tuggerah Lakes juveniles reach 130 mm FL at 1 year, 18cm at 2 years and 23cm at 3 years. In Botany Bay, male fish reach maturity from 3 years and females at 4 years and approx. 24cm FL (Kailola *et al.,* 1993).

Bream were found in all the estuaries sampled. The greatest abundances were collected from the Rockdale wetlands area and ranged in length between 18 and 375mm (84% of these were less than 100mm and less than 1% were greater than 200mm). There were only 14 individuals collected from outside the wetlands area in the Bay itself and were these were collected in September 1996 and March and June 1997. Twelve of these individuals measured between 7 and 19mm. Bream were also very abundant in the Macleay River but were never collected from the area behind the floodgates. In comparison, the area behind the floodgates in the Hunter River supported more bream than the areas outside the floodgates. The Macleay River bream measured between 7 and 187mm, with 97% of those measured being under 100mm fork length. The bream collected from Ironbark Creek ranged in size between 9 and 265mm with 94% of measurements under 100mm. In the main channel of the Hunter River, 78% of the measured bream were under 100mm and ranged between 8 and 180mm.

Mugil cephalus occurs in coastal waters and estuaries in tropical and temperate waters of all seas in the world. They inhabit fresh, estuarine and coastal waters in all states of Australia. Adult sea mullet typically inhabit freshwater reaches of coastal rivers except during the spawning season when they migrate through the estuaries to inshore waters. Also, a small proportion (approx. 5%) of older juveniles may leave the estuaries and migrate along the beaches in early summer. This migration may be associated with flooding rivers (they are referred to as 'Hard-gut' mullet, because their guts are empty). Sea mullet often school as juveniles and during the spawning season as adults. Feeding schools of juveniles commonly disperse over sand and mud flats of estuaries during high tide and reform on the ebb tide. The highest catches of sea mullet caught by commercial fishermen in estuaries occurs during late summer and autumn when movement of mature fish through the estuaries is greatest (Kailola *et al.*, 1993).

Sea mullet were collected from all areas and estuaries that were sampled during the study period. This species was the second most abundant commercially important species collected, but more than 50% of the total abundance was contributed by 5 samples from June and September 1996 (3 samples from Botany Bay and 2 samples from the Manning River).

The greatest numbers of sea mullet were collected from the Manning River, however, 4112 individuals of the 5668 collected (i.e. 73%) were caught in September 1996 from only two replicates and most measured between 22 and 37mm.

Except for 9 individuals, all of the sea mullet (3545 individuals) collected from the near reference area in Botany Bay were collected in June 1996 and 3082 of these were collected from the site directly outside the entrance to the Rockdale wetlands. The remaining 454 individuals were collected from the Bay site upstream of the entrance site. All individuals from this area (i.e. the Bay) measured between 22 and 32mm fork length.

In June 1996, sea mullet were <u>only</u> collected from the site directly outside the wetlands area in the Bay and none were collected from the Rockdale wetlands area. Sea mullet were never collected from the Bay in such abundances after June 1996, yet they were present in large abundances in the wetlands area for all sampling occasions after June 1996. This may suggest a substantial recruitment of these mullet into the wetlands area sometime soon after the June 1996 sampling period.

Sea mullet were never collected from the site furthest upstream in the wetlands. The sea mullet from the wetlands area measured between 22 and 152mm (15% were $\leq$ 32mm, 72% were $<$ 50mm).

Myxus elongatus is found in southern Australia waters from Queensland to West Australia and also at Lord Howe Island. They mostly occur in shallow waters in coastal bays and in estuaries and harbours. They are found in small to large schools over sandy flats (Kuiter, 1993). Spawning probably occurs near the mouths of estuaries. Fish in their first year often enter fresh water but seldom thereafter. They are more commonly found in brackish water (McDowall, 1996).

Most of the sand mullet collected during the study were from the Botany Bay wetland area and measured 20 to 156mm fork length. Of the 2,647 individuals collected from this area, 1,768 individuals were collected from the site just inside the pipe entrance and were collected in March 1996, June 1996, February 1997 and September 1996 and 1997. There were no sand mullet collected from the Yarrahapinni wetland and relatively few of these mullet were collected from the Ironbark Creek wetland area compared with the main channel of the Hunter River.

Ambassis jacksoniensis is found in east coast estuaries from southern Queensland to southern NSW. They school in lakes and along the tidal channels from the sea to estuaries, along breakwaters and under jetties which offer shelter from the strong currents. They feed on zooplankton from near the surface to the substrate (Kuiter, 1993).

Ambassids were common in all estuaries that we sampled. In the Hunter River there were almost five times as many ambassids in the area behind the floodgates (Ironbark Creek) than there were in the main channel of the river. In comparison, there were far more individuals of ambassids collected from the main channel of the Macleay River compared with only four specimens that were collected from the area behind the floodgates in the Yarrahapinni Broadwater. The most ambassids collected from any one area was from the far reference area in Botany Bay but 74% of these were from 2 samples collected in September 1996 and June 1997.

Gobiopterus semivestitus occurs on the south-east coast from Queensland to South Australia. Usually occur in quiet coastal estuaries and they commonly enter fresh water (Kuiter, 1993).

During this study the glass gobies often occurred in the samples in large numbers and particularly in the Manning River where more than a thousand individuals was not uncommon for any one sample. In comparison, there were only 17 individuals collected from Botany Bay although these were not confined to any one area of the Bay. Glass gobies were commonly found in the samples collected from behind the Hunter River floodgates and the numbers there were three times more abundant than in the main channel of the Hunter River. However, in the area behind the floodgates in the Macleay River, glass gobies were rarely collected (only 7 individuals behind the floodgates compared to 1,717 individuals in the main channel of the Macleay River).

Pseudogobius olorum populations extend from Moreton Bay, Queensland to western Victoria and northern Tasmania (Kuiter, 1993) They probably spawn in the upper reaches of estuaries where the salinity is lower than in the marine environment (McDowall, 1996).

Blue spot gobies were always more abundant in the wetland areas than in the main channel of the connecting river. They were also very abundant in the external reference estuaries and particularly in the Manning River where a total of 12,726 individuals were collected during the study.

Redigobius macrostoma are found from southern Queensland to Victoria and west to Glenelg River, and north-eastern Tasmania. They occur in estuaries and harbours mostly in muddy, weedy or seagrass estuaries entering the lower reaches of freshwater streams (Kuiter, 1993 and McDowall, 1996).

Large mouth gobies were the most abundant goby collected during the study period. They were abundant in all estuaries except Botany Bay where only one individual was ever collected. The lack of large mouth gobies in Botany Bay is probably due to the sandy nature of the bay compared to the muddy nature of the other estuaries. There were more of these gobies collected from Ironbark Creek than from the main channel of the Hunter River but in the Macleay River there fewer large mouth gobies in the wetland area. Overall there were more than double the number of large mouth gobies collected from the Macleay River compared to the Hunter River, but the greatest abundances were collected from the Manning River.

Philypnodon grandiceps occurs in coastal drainage's from the MacKenzie River in Queensland to South Australia. They prefer quiet waters, particularly lakes and dams, usually on weedy or mud bottoms; they frequently occur in estuaries. They breed in the spring and summer in inland drainages, apparently over a longer period (through to winter) in northern coastal rivers. They feed on small fishes, crustaceans and insects (McDowall, 1996).

The flathead gudgeon was the most abundant gudgeon collected during the study period, and they were collected in the greatest abundance from the wetland areas and particularly in the Rockdale wetlands. Among the external reference estuaries, the Wallamba River had the most flathead gudgeons.

Metapenaeus macleayi is distributed from Moreton Bay in Queensland to northern Victoria. They occur in sandy and sandy mud-bottomed rivers, estuaries and inshore waters to a depth of 50m (Jones and Morgan, 1994).

School prawns were abundant in all estuaries that we sampled except for Botany Bay where there were only 5 individuals collected during the study period. There were more school prawns collected from the Hunter River wetlands area than from the main channel of the Hunter River, but there were more school prawns collected from the main channel of the Macleay River than there were from the Macleay River wetlands area. Overall there were more school prawns collected from the Macleay River than from any of the other estuaries.

Macrobrachium intermedium and *Palaemon debilis* occur in the south of Australia inhabiting estuaries and shallow inshore waters, often in seagrass beds. *M. intermedium* occurs in very high densities in coastal and estuarine seagrass beds and also among seaweeds on sheltered reefs (Jones and Morgan, 1994).

There were far more *Palaemon debilis* collected than *Macrobrachium intermedium* (237,879 individuals compared with 70,534 individuals) but they were both ranked amongst the top 5 most abundant taxa collected during the study period. The greatest abundances of *M. intermedium* and *P. debilis* were collected from the external reference estuaries and from the far reference area on the Macleay River. These species were collected from each of the wetland areas but there were only six individuals of *M. intermedium* and 4 individuals of *P. debilis* collected from the Rockdale wetlands. There were substantially more *P. debilis* collected from Ironbark Creek compared to the main channel of the Hunter River.

Acetes sibogae australis was the most abundant species collected during the study and they were abundant in all estuaries except Botany Bay and the Nambucca River. For fourteen of the samples collected, there were more than 10,000 individuals in the sample. These shrimps were most abundant in June of both years sampled and are a major food of yellowfin bream and other carnivorous fish species.

Effects of acid sulphate soil runoff

The catchment of the Yarrahapinni wetlands area is dominated by drained estuarine soils rich in pyrite and as expected the lowest pH values were recorded from this area, especially after heavy rain. However, even when the pH fell to as low as 3.7 in 1996, the water in the Yarrahapinni wetlands recovered quickly during dry periods increasing to values of 6 and 7. During the sampling times in 1997 pH ranged from 5.2 to 8.8. The periods of low pH in the Yarrahapinni wetlands were of a shorter duration and the pH did not drop as low as in wetter climatic years as recorded in a variety of northern NSW estuaries (Richardson, 1981; Sammut *et al.,* 1995; Sammut *et al.,* 1996; White *et al.,* 1997).

During this study, Ironbark Creek with partial floodgate opening, had a pH range of 6.5 – 8.5 and showed no detectable effect of acid drainage.

Throughout our sampling in 1996 and 1997 no occurrences of epizootic ulcerative syndrome (EUS) were observed on fish at any study site. Based on the studies of Sammut *et al.,* (1993); Sammut *et al.,* (1995) and Roach, (1997) in wetter years we would predict fish kills and the occurrence of epizootic ulcerative syndrome. In addition the impacts of inorganic monomeric aluminium and iron flocs on fish, crustaceans and bivalves causing morbidity and at sub lethal chronic levels causing a reduction in benthic invertebrate species diversity and abundance.

This study was conducted during a significant El Nino event when below average rainfall occurred. As a consequence the impacts of acid sulphate soil runoff on the fish and invertebrate communities was not as evident as in normal rainfall years.

6. Conclusion

Relative to our objectives we have demonstrated that fish and invertebrates use 'restored' or highly modified wetlands. Dependent on the degree of tidal exchange, the faunal communities are in general similar to sites within the parent estuary and at sites in external reference estuaries.

The species found in the impacted wetland without tidal exchange are predominantly insects and fish species normally found in fresh or brackish water. In the restored wetlands juvenile bream, sea mullet and sand mullet were very abundant, while the larger individuals were often sampled outside the restored areas. School prawns were very abundant in the Ironbark creek partially restored wetland and in the Macleay River below the floodgates. The high abundance of the small non-commercial Gobiidae, Atherinidae and Eleotrididae species in all the 'restored' wetland areas results from their habitat preference and ability to complete their life cycle in estuaries. These species also dominate in estuaries of south-western Australia with restricted tidal access or periodic closure (Potter and Hyndes, 1999). Species absent or in very low densities inside the restored wetlands compared to other locations in the parent estuary or the reference estuaries were silver biddies, tarwhine, blackfish, striped trumpeter and king prawns.

Based on the results from Ironbark Creek and the Rockdale Wetlands if tidal exchange was increased and acid sulphate soil runoff minimised the occurrence of significant numbers of commercially and recreationally important bream, mullet and school prawns would be predicted to occur in the area behind the Yarrahappini floodgates.

Even though the Rockdale wetlands are open to Botany Bay via a 700m pipe, we would not expect the same faunal community structure at the Yarrahapini Broadwater, Macleay River and Ironbark Creek, Hunter River wetlands if the gates at these sites were completely removed/opened because of the obvious physical differences of these estuaries compared to Botany Bay. The data collected for the Rockdale wetlands area does show fish are capable of recruiting into highly modified wetland areas especially if suitable juvenile habitat is limited as in the Bay where significant reclamation and industrial foreshore development has occurred.

Studies by Neira and Potter (1992) show the influence of seasonal or periodic estuary closures results in the low occurrence of marine spawned larvae in the estuary and reflects the lack of tidal water movement in the system and hence the lack of a mechanism to facilitate the transport and dispersion of ichthyoplankton larvae in an estuary in south west Australia. Potter and Hyndes (1999) in their review of the ichthyofauna of Australian estuaries show the juveniles of marine spawning species like bream and mullet are at a recruitment disadvantage when seasonal closure of an estuary occurs. This is also true when there is a partial tidal barrier to the preferred wetland habitat as in many restoration projects. The timing of floodgate opening is thus a critical factor in management of tidal barriers.

The functional equivalency of a restored wetland compared to a natural wetland is an important performance criteria. We have shown that based on the fish and invertebrate community composition and presence of migratory *Anguilla spp.*, eels and *Galaxias maculatus,* common jollytails the restored wetlands with tidal exchange are similar to the external reference sites and estuaries.

7. Recommendations and Implications

7.1. Benefits

Primary beneficiaries of this research are the commercial and recreational sectors of the fishing industry. When the floodgates are opened they benefit from the increase in the level of restoration and total area of fish habitat available. They also benefit from the increased knowledge of the functioning of the complex of fish and invertebrate habitats in coastal wetlands and the development of procedures to mitigate the negative impact of acid sulphate soil drainage.

Secondary beneficiaries are the community and other user groups who gain increased amenity from the restored coastal wetlands. This project further builds on previous FRDC funded studies of tidal impediments in estuaries (Williams and Watford, 1997) and provides valuable input to NSW Fisheries studies on the NSW north coast aimed at collating operational data on floodgates (National Heritage Trust funded).

Outcomes from this research were a significant issue at the August 1997 workshops on 'Floodgate management from a fisheries perspective" held on the NSW north coast and attended by local councils, state agencies and industry.

In addition the Clarence Floodplain Project managed by Clarence River County Council (CRCC) has a major focus on floodgates and involves landowner education activities. Outcomes of this study and the indicated further research are part of the floodgate management program to improve water quality, particularly pH and reduce the discharge of acid water from drains and creek systems and to allow fish passage to habitat behind flood mitigation structures during non flood conditions.

The management of floodgates to allow passage of fish and invertebrates and the development of estuarine faunal communities in previously alienated habitat above the structures significantly enhances fish and invertebrate stocks. The consequent protection of fish habitats and fish and invertebrate species supports biodiversity conservation and the habitat restoration can assist in the development of management plans under the relevant Threatened Species Legislation.

This active management can lead to significant improvements in habitat restoration, water quality and management of acid sulphate soils. The latter is especially relevant during dry weather and minor flood periods when brackish estuarine water can have up to three times the acid neutralisation capacity of fresh water.

7.2. Intellectual Property

No patents emerged from this research. All results will be published by NSW Fisheries in reports, public domain scientific journals and presented at industry workshops and seminars.

7.3. Further Development

The need to modify the management of floodgate structures to allow tidal water exchange is being increasingly recognised by many decision making agencies. However, landholders will not change current management practises unless as a minimum, there will be no adverse affects on their productivity. Guidelines for change must be developed in an integrated manner with a focus on land, water, agriculture and fisheries.

The times at which gates are opened, the size of the cells in any gate and the availability of larvae and juveniles to recruit to a 'restored' area was not investigated in this study. We have demonstrated that fish and invertebrates use 'restored' wetlands and clearly the above parameters should be investigated. This would help to develop detailed guidelines for resource managers implementing estuary and tidal barrier/floodgate management plans.

A second issue for further study is the long term impact of chronic acid drainage, which does not cause major fish kills but which may have less obvious effects on the recruitment of migratory and catadromous fish such as Australian bass, sea mullet, freshwater herring, eels and school prawns. The life history, behaviour and demography of the catadromous Australian bass shows it is susceptible to such an impact (Harris, 1988 and 1989). The Basscatch program (Harris, 1989) has expanded in recent years and the population collapse through recruitment failure of Australian bass in NSW rivers such as the Hastings and Manning is partially attributed to acid drainage (Harris, pers. comm.).

7.4. Staff

The following NSW Fisheries staff were directly employed on this project with FRDC funds:

Tracey McVea	Fisheries Technician
Brett Louden	Fisheries Technician
Lesley Diver	Casual Fisheries Technician

Other NSW Fisheries staff, contributing to the project but not directly funded were:

Philip Gibbs	Principal Investigator
Nick Otway	Senior Research Scientist
Will Macbeth	Fisheries Technician
Judy Upston	Fisheries Technician

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9. Appendices

Appendix 1. Latitude and longitude of each of the sampling sites as measured with a hand held GPS (± 100m).

Estuary	Site	Latitude	Longitude
Nambucca River	1	30 42' 931"	152 58' 846"
	2	30 42' 008"	152 59' 170"
	3	30 41' 503"	152 59' 230"
Macleay River	1	30 52' 363"	152 59' 135"
	2	30 53' 913"	152 59' 144"
	3	30 52' 912"	152 59' 912"
	4	30 54' 010"	152 59' 220"
	5	30 54' 089"	152 59' 687"
	6	30 54' 133"	152 59' 863"
	7	30 52' 334"	152 59' 818"
	8	30 52' 112"	152 59' 562"
	9	30 51' 364"	152 59' 993"
Manning River	1	31 52' 725"	152 37' 328"
	2	31 53' 117"	152 38' 730"
	3	31 52' 834"	152 40' 595"
Wallamba River	1	32 09' 728"	152 28' 296"
	2	32 10' 666"	152 28' 172"
	3	32 10' 753"	152 28' 818"
Hunter River	1	32 52' 225"	151 41' 130"
	2	32 51' 408"	151 41' 713"
	3	32 51' 295"	151 42' 019"
	4	32 49' 960"	151 41' 745"
	5	32 51' 456"	151 42' 615"
	6	32 52' 777"	151 43' 664"
	7	32 52' 797"	151 45' 067"
	8	32 53' 843"	151 46' 783"
	9	32 53' 085"	151 47' 374"
Botany Bay	1	33 58' 315"	151 08' 707"
	2	33 58' 403"	151 08' 551"
	3	33 58' 974"	151 08' 571"
	4	33 58' 925"	151 08' 896"
	5	33 59' 735"	151 08' 941"
	6	34 00' 094"	151 08' 425"
	7	33 57' 313"	151 11' 734"
	8	33 57' 586"	151 12' 229"
	9	33 57' 932"	151 12' 364"

Appendix 2. Total abundance of all fish and invertebrate species collected from the impacted wetland, near reference and far reference areas in Botany Bay, Hunter River, Macleay River and each of the external reference estuaries.

Data are for the study period March 1996 to December 1997.

Class/Order/Family/Species		Common name	Minimum Length (mm)	Maximum Length (mm)	Total Number	Botany Bay			Hunter River			Macleay River			External Reference Estuaries		
						Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Wallamba River	Manning River	Nambucca River
CLASS CHONDRICHTHYES																	
Order Rajiformes Dasyatididae	*Dasyatis fluviorum*	Estuary stingray	280	510	9				1	1	2		1	1	2	1	
CLASS ACTINOPTERYGII																	
Order Anguilliformes Anguillidae	*Anguilla australis**	Short-fin eel	52	700	5	1			4								
	*Anguilla reinhardtii**	Long-fin eel	50	800	8	3			3			1			1		
Order Clupeiformes Engraulidae	*Engraulis australis**	Australian anchovy	16	91	306					212	87		2	1	3	1	
Clupeidae	*Herklotsichthys castelnaui**	Southern herring	70	142	20								14	4	2		
	*Hyperlophus translucidus**	Sprat	18		1					1							
	*Hyperlophus vittatus**	Sandy sprat	10	80	28312	1	120	6	45	3363	17884		2471	204	151	4060	7
	Potamalosa richmondia	Freshwater herring	33	41	15							12	3				
Order Siluriformes Plotosidae	*Cnidoglanis macrocephala**	Estuary catfish	39	329	5		1	3			1						
Order Osmeriformes Galaxiidae	*Galaxias maculatus*	Common jollytail	22	44	18	3	1				2		1	3	4	4	
Order Aulopiformes Synodontidae	*Trachinocephalus myops*	Painted lizardfish	68		1		1										
	Saurida nebulosa	Blotched saury	48	71	2									1		1	
Order Mugiliformes Mugilidae	*Liza argentea**	Flat-tail mullet	4	315	7189	330		5	27	121	44	4	1900	541	1431	2270	516
	*Mugil cephalus**	Sea mullet	9	424	13900	1868	3545	40	203	46	52	17	433	1230	236	5668	562
	*Myxus elongatus**	Sand mullet	12	221	4125	2647	36	211	36	149	286		147	26	126	273	188
	*Valamugil georgii**	Fantail mullet	27	143	12					3			8	1			
Order Lophiiformes Antennariidae	Unknown Antennariidae	Anglerfish	50	77	2				1	1							
	Juvenile Antenariidae	Anglerfish	11	11	2											2	
Order Atheriniformes Atherinidae	*Atherinason hepsetoides*	Small-scale hardy head	25	68	5			5									
	Atherinomorus ogilbyi	Ogilby's hardyhead	18	135	574		381	189			2				2		
	Leptatherina presbyteroides	Silverfish	16	31	7			7									
	Pseudomugil signifer	Southern blue-eye	8	40	9443		1		106	4		3862	280	194	3855	145	996

Appendix 2. Continued

Class/Order/Family/Species		Common name	Minimum Length (mm)	Maximum Length (mm)	Total Number	Botany Bay			Hunter River			Macleay River			External Reference Estuaries		
						Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Wallamba River	Manning River	Nambucca River
Order Beloniformes																	
Belonidae	*Tylosurus gavialoides* *	Stout longtom	74	600	6										5		1
Hemiramphidae	*Hyporhamphus regulatus* *	River garfish	26	230	62		32	2		1	1		17	4	2	2	1
Order Cyprinodontiformes																	
Poeciliidae	*Gambusia holbrookii*	Mosquitofish	7	48	1688	134			43			1399	9	1	2	26	74
Order Beryciformes																	
Trachichthyidae	Juvenile Trachichthyidae*	Roughie	10		1			1									
Order Gasterosteiformes																	
Syngnathidae	Juvenile Syngnathidae	Pipefish	15		1											1	
	Hippocampus whitei	White's seahorse	38		1		1										
	Pegasus volitans	Slender seamoth	99		1										1		
	Stigmatopora argus	Spotted pipefish	31	150	29		1	28									
	Stigmatopora nigara	Wide-body pipefish	31	137	98		17	65								16	
	Syngnathoides biaculeatus	Pipefish	157	208	3											3	
	Urocampus carnirostrus	Hairy pipefish	26	90	422		1							19	209	175	18
	Vanacampus margaritifer	Mother-of-pearl pipefish	80	162	11									4	4	2	1
Fistulariidae	*Fistularia commersonii*	Smooth flutemouth	195	305	3			2								1	
Order Scorpaeniformes																	
Dactylopteridae	*Dactyloptera orientalis*	Flying gurnard	55		1						1						
Scorpaenidae	*Centropogon australis*	Fortescue	7	64	2125	6	26	32	136	42	21	2	158	700	710	213	79
	Notesthes robusta	Bullrout	64	280	8				3					2	1	2	
Triglidae	*Chelidonichthys kumu* *	Red gurnard	23	45	3			1			1				1		
Platycephalidae	Juvenile Platycephalidae*	Flathead	9	17	7		1	2	1	2	1						
	*Platycephalus arenarius**	Flag-tail flathead	42	186	25		18	5			2						
	*Platycephalus bassensis**	Sand flathead	16	127	40		2	38									
	Platycephalus fuscus *	Dusky flathead	13	690	141			2	12	20	46		25	17	16	2	1
Order Perciformes																	
Chandidae	*Ambassis jacksoniensis*	Port Jackson glassfish	5	61	273898	84	1099	141849	5117	883	1319	4	12859	18762	18644	44718	28560
	Ambassis marianus	Ramsey's glassfish	7	101	3228	4	7		11	4	13	7	725	1061	93	69	1234
Percichthyidae	*Macquaria novemaculeata**	Australian bass	278		1					1							
Priacanthidae	*Priacanthus macracanthus*	Spotted big-eye	30		1					1							
Apogonidae	Unknown Apogonidae	Siphonfish	17		1									1			
	Siphamia cephalotes	Little siphonfish	9	20	6		4									2	
	Siphamia roseigaster	Silver siphonfish	12	64	1115									117	968	29	1
Sillaginidae	*Sillago ciliata**	Sand whiting	8	278	2446		127	802	13	369	530		386	102	41	36	40
	*Sillago maculata**	Trumpeter whiting	27	158	16		11	3			1				1		
Pomatomidae	*Pomatomus saltatrix**	Tailor	26	162	235		8		1	34	74		7	73	6	32	
Carangidae	*Caranx spp.* *	Trevally	23	61	16									6	2	6	2
	*Pseudocaranx dentex**	White trevally	56	273	10		4				1		2	3			
	Scomberoides lysan *	Queenfish	35	111	16		11						1	1	1	1	1

Appendix 2. Continued

Class/Order/Family/Species		Common name	Minimum Length (mm)	Maximum Length (mm)	Total Number	Botany Bay			Hunter River			Macleay River			External Reference Estuaries		
						Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Wallamba River	Manning River	Nambucca River
Lutjanidae	*Lutjanus argentimaculatus*	Mangrove jack	24		1									1			
	Lutjanus fulviflammus	Black spot snapper	27	41	3										1	2	
	Lutjanus russelli	Moses perch	23	24	2								1				1
Gerreidae	*Gerres subfasciatus* *	Common silver biddy	6	355	4130		14	17	355	472	108		815	688	795	584	282
Haemulidae	*Plectorhinchus gibbosus*	Brown sweetlips	65		1			1									
Sparidae	*Acanthopagrus australis**	Yellow-finned bream	7	375	13700	3623	5	9	936	90	61		2651	3193	532	2162	438
	Chrysophrys auratus *	Snapper	12	112	15		10							2		1	2
	*Rhabdosargus sarba**	Tarwhine	7	130	2937		9	82	16	4	30		138	1035	216	1114	293
Lethrinidae	*Lethrinus genivittatus*	Lancer	25		1									1			
Mullidae	*Parupeneus signatus*	Black-spot goatfish	45	53	2											2	
	Upeneus spp.	Bar-tail goatfish	34	42	3		1	1						1			
Monodactylidae	*Monodactylus argenteus*	Silver batfish	7	100	441									103	47	141	150
Enoplosidae	*Enoplosus armatus* *	Old wife	14	63	5		1	4									
Kyphosidae	*Girella tricuspidata**	Blackfish	9	700	2887		1	4	1		3		50	167	90	2340	231
	Microcanthus strigatus	Stripey	11	23	238		1	1						9		216	11
Arripidae	*Arripis georgiana**	Tommy rough	45	69	6		6										
Terapontidae	*Pelates quadrilineatus**	Four-lined trumpeter	15	50	23												23
	*Pelates sexlineatus**	Eastern striped trumpeter	6	135	11202		3	46	1	12	2	1	15	1967	2089	5921	1145
	Terapon jarbua	Crescent perch	14	111	21	2		1	1				8			3	6
Labridae	Unknown Labridae*	Groper	17	43	3												3
	Achoerodus viridis *	Eastern blue groper	11	48	60			2						12		42	4
Leptoscopidae	Juvenile Leptoscopidae	Stargazer	12		1			1									
	Lesueurina platycephala	Flathead pygmy-stargazer	20	39	5		4	1									
Uranoscopidae	*Kathetostoma laeve*	Stargazer	44	86	4		4										
Clinidae	*Heteroclinus* spp.	Weedfish	21	68	10		1	9									
Blenniidae	*Omobranchus anolius*	Oyster blenny	8	14	9					1	6			1		1	
	Petroscirtes lupus	Brown sabretooth blenny	12	65	137									27	13	96	1
Callionymidae	Juvenile Callionymidae	Stinkfish	22		1		1										
	Callionymus limiceps	Rough headed dragonet	17	112	5			1			2				2		
	Eocallionymus papilio	Painted stinkfish	17	50	3			3									
	Repomucenus limiceps	Rough-head dragonet	21	84	2		1	1									
Eleotrididae	Juvenile Eleotrididae	Gudgeon	9	14	13				12				1				
	Butis butis	Bony-snouted gudgeon	27	70	10								1	5	3		1
	Gobiomorphus australis	Striped gudgeon	14	55	10												10
	Gobiomorpus spp.	Gudgeon	7	75	1161				298			457	276			6	124
	Hyperseleotris compressus	Empirefish	7	75	2021				963	2		214	99	9		1	733
	Hypseleotris galii	Firetailed gudgeon	11	52	81							76					5
	Philypnodon grandiceps	Flathead gudgeon	8	94	25712	22059		1	1050	4	1	1324	18		825	270	160
	Philypnodon sp.	Dwarf flathead gudgeon	7	63	4886	121			543			4193	8	6			15

Appendix 2. Continued

Class/Order/Family/Species		Common name	Minimum Length (mm)	Maximum Length (mm)	Total Number	Botany Bay			Hunter River			Macleay River			External Reference Estuaries		
						Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Wallamba River	Manning River	Nambucca River
Gobiidae	Juvenile Gobiidae	Juvenile goby	8	18	21				10	2	7				1	1	
	Taenioides Type 1	Goby	23		1					1							
	Acanthigobius flaviomonius	Oriental goby	28	155	53				18	11	24						
	Amblygobius phalaena	White-bar goby	31		1											1	
	Arenigobius bifrenatus	Bridled goby	7	143	3061	6			945	207	813		72	91	205	714	8
	Arenigobius frenatus	Half bridled goby	18	95	347				8	3	1			6	317	12	
	Arenigobius spp.	Goby	51	57	4									4			
	Bathygobius kreffti	Frayed-fin goby	15	57	79			3	2	1	2			18	48	5	
	Cryptocentrus critatus	Oyster goby	14	93	32				7	6			2	2	15		
	Favonigobius exquisitus	Exquisite sand goby	6	61	11115		5	389	277	2456	1656	2	1994	1993	731	787	825
	Favonigobius lateralis	Long finned goby	11	67	2812	5	1	2561	2	30	73		2	18	116	4	
	Favonigobius tamarensis	Tamar River goby	7	65	11292	7		1	2965	830	194	14	1871	948	2592	1308	562
	Glossogobius biocellatus	Goby	12	79	30					1			1	16	7	5	
	Gobiopterus semivestitus	Glass goby	7	62	66756	2	8	7	3097	980	46	7	441	1276	3897	56957	38
	Mugilogobius paludis	Mangrove goby	8	48	315		3		178	1		1	2		9	62	59
	Mugilogobius spp.	Mangrove goby	39	39	2										2		
	Pandaculus lidwilla	Dwarf goby	10	18	293									28	7	34	224
	Parkraemeria ornata	Goby	13	39	17								3		1		13
	Pseudogobius olorum	Blue-spot goby	6	58	43636	640			5389	76	105	7433	1406	1816	8704	12726	5341
	Redigobius macrostoma	Largemouth goby	5	49	82432	1			4794	182	141	37	543	12153	19183	32708	12690
Scatophagidae	*Scatophagus argus*	Spotted scat	11	21	17									2	2	12	1
Siganidae	*Siganus nebulosus*	Happy moments	8	112	34			1						24		9	
Sphyraenidae	*Sphyraena obtusata**	Striped sea pike	24	98	27			1			1		1	4	10	10	
Nomeidae	*Psenes arafurensis*	Banded driftfish	18		1												1
Order Pleuronectiformes																	
Paralichthyidae	*Pseudorhombus arsius**	Large-tooth flounder	11	273	163			3	6	37	62		28	11	15	1	
	*Pseudorhombus jenynsii**	Small-tooth flounder	28	246	49					16	22			3	7	1	
	Pseudorhombus spp. *	Flounder	11		1										1		
Pleuronectidae	*Ammotretis rostratus**	Long-snout flounder	17	128	94		5	87			2						
Soleidae	*Synaptura nigra**	Black sole	11	137	29				3				2	8	8	8	
Cynoglossidae	*Paraplagusia unicolor**	Lemon tongue sole	43	83	1		1										
Order Tetraodontiformes																	
Balistidae	Juvenile Balistidae	Triggerfish	7	12	3		3										
Monacanthidae	Juvenile Monacanthidae*	Leatherjacket	7	27	156		1	4						1	22	56	72
	*Meuschenia freycineti**	Six spine leatherjacket	14	65	27			2						1	3	16	5
	*Meuschenia trachylepis**	Yellow-finned leatherjacket	8	220	1037		1	2	2				4	115	187	564	162
	Paramonacanthus otisensis	Dusky leatherjacket	12	100	32			1						14	7	8	2

Appendix 2. Continued

Class/Order/Family/Species		Common name	Minimum Length (mm)	Maximum Length (mm)	Total Number	Botany Bay			Hunter River			Macleay River			External Reference Estuaries		
						Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Wallamba River	Manning River	Nambucca River
Tetraodontidae	Juvenile Tetraodontidae	Juvenile toadfish	8	41	27			5	3	12	3				4		
	Arothron hispidus	Stars and stripes toadfish	32		1									1			
	Marilyna pleurosticta	Toadfish	62	177	74						1		5	7	6	51	4
	Tetractenos glaber	Smooth toadfish	34	118	9			1		1	3				1	3	
	Tetractenos hamiltoni	Common toadfish	8	143	368		15	4	5	24	69		15	30	115	89	2
	Torquigener pleurogramma	Weeping toado	11	120	69		6	59			4						
	Torquigener squamicauda	Brush-tail toadfish	12	91	28	1	19	6			2						
Diodontidae	Unknown Diodontidae	Porcupine fish	14		4											4	
	Dicotylichthys punctulatus	Three-bar porcupinefish	87	250	10									4	1	5	
Unknown	Unknown juvenile fish		8	31	32		7	4	1	2	2	2		1	7	6	
CLASS MALACOSTRACA																	
Order Mysidacea																	
Mysidae		Opossum shrimp				P	P	P	P	P	P	P	P	P	P	P	P
Order Decapoda																	
Infraorder Penaeidea																	
Penaeidae	Unknown Penaeidae*				1												1
	*Metapenaeus bennettae**	Greasyback prawn			156				42	1	36	2	11	2	40	15	7
	*Metapenaeus ensis**	Penaeid prawn			62											18	44
	*Metapenaeus macleayi**	School prawn			9425		1	4	2398	453	17	40	3205	1297	772	1051	187
	*Penaeus esculentus**	Tiger prawn			254				5				5	133	62	27	22
	*Penaeus plebejus**	King prawn			11197	1	2	421	942	1568	1319	8	2066	1253	2057	1185	375
	Penaeus spp.*				10						10						
Infraorder Caridae		Shrimps															
	Carid Type 1				4											4	
Sergestidae	*Acetes sibogae australis*				514794	1	21	6	22384	73178	183998	112	8127	161770	4654	60492	51
Alpheidae	*Alpheus richardsoni*	Snapping shrimps			914		2		77	206	293	1	30	247	39	17	2
Palaemonidae	*Chlorotocella leptorhynchus*				5079									12	5049	14	4
	Macrobrachium intermedium				70534	6		45	113		2	150	24	10079	19560	34152	6403
	Macrobrachium cf novaehollandiae				18					1					14		3
	Palaemon debilis				237879	4	1		2106	45	28	66	8524	26071	37524	104896	58614
Pandalidae	Pandalid Type 1				21		2	16							3		
Hippolytidae	Hippolytid Type 1				2										2		
	Latreutes Type 1				4										4		
	Latreutes pygmaeus	Hump-backed shrimp			680			1						105	547	24	3
Atyidae	*Caradina maccullochi*				279				5			143	1	1	2	1	126
	Paratya australiensis				2				2								
Crangonidae	*Pontophilus* Type 1				43			42			1						
	Pontophilus Type 2				1						1						

Appendix 2. Continued

Class/Order/Family/Species		Common name	Minimum Length (mm)	Maximum Length (mm)	Total Number	Botany Bay			Hunter River			Macleay River			External Reference Estuaries		
						Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Wallamba River	Manning River	Nambucca River
Infraorder Brachyura		Crabs															
Calappidae	*Matuta planipes*				9		8	1									
Hymenosomatidae	*Amarinus laevatis*	False spider crabs			13	4						7				2	
	Amarinus spp.				345	94	1	3	41	1		147	12	16	3	14	13
	Halicarcinus ovatus				48	1	44	3									
	Hymenosoma hodgkini	Spider crab			568				26	69	16		395	28	21	12	1
Portunidae	*Ovalipes australiensis*	Sand crab			64		26	38									
	*Portunus pelagicus**	Blue swimmer crab			40		2	16	1	1	14				4	1	1
	*Scylla serrata**	Mud crab			3								1	1			1
Xanthidae	Thalamita sp1				4										3	1	
	Thalamita sp2				3										1	2	
	Xanthid Type 1				4										4		
Grapsidae	Grapsid Type 1				128		7		75	4	3	1	3	3	8	18	6
	Grapsid Type 2				18				2	3	3		3	4	2	1	
	Grapsid Type 3				6				3				1	1			1
	Grapsid Type 4				4					2			1		1		
Mictyridae	*Mictyris longicarpus*	Soldier crab			1									1			
Ocypodidae	Unknown Ocypodidae				1								1				
	Ocypodid Type 1	Stalk-eyed crabs			8				2	1			3	2			
	Ocypodid Type 2				25				3	18	1		2	1			
	Ocypodid Type 3				1				1								
CLASS CEPHALOPODA																	
	Juvenile squid*				11						3			2	6		
	Unknown squid				1										1		
Order Octopoda																	
Octopodidae	Octopodid Type 1				1		1										
Order Sepioidae		Squids															
Sepiolidae	*Euprymna tasmanica*	Dumpling squid			6		1								4	1	
Idiosepiidae	*Idiosepius notoides*	Dumpling squid			756	1	16	5			4			14	292	419	5
Teuthoidea	*Loliolus noctilucca*	Inshore squid			7		4				2				1		
CLASS INSECTA																	
Order Odonata		Damsel and dragon flies					P		P			P	P		P	P	P
Coenagrionidae									P			P			P		P
Corduliidae												P	P		P		P
Libellulidae												P					
Aeshnidae																	

Appendix 2. Continued

Class/Order/Family/Species	**Common name**	**Minimum Length (mm)**	**Maximum Length (mm)**	**Total Number**	**Botany Bay**			**Hunter River**			**Macleay River**			**External Reference Estuaries**		
					Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Wallamba River	Manning River	Nambucca River
Order Hemiptera	True Bugs						P	P	P		P			P		
Corixidae	Lesser water boatmen											P	P			P
Gerridae	Pond skaters							P			P					
Naucoridae					P			P	P		P	P			P	
Notonectidae	Water-boatman							P								
Veliidae	Water crickets															
Order Diptera											P					
Ceratopogonidae	Biting midges										P					
Chironimidae	Gnats						P									
Psychodidae	Moth-flies										P				P	
Stratiomyidae	Soldier-flies										P					
Tipulidae	Crane-fly															
Order Lepidoptera						P					P				P	
Pyralidae	Moths															
Order Trichoptera	Caddis-flies										P					
Leptoceridae																
Order Coleoptera	Beetles										P					
Dytiscidae								P			P					P
Hydrophilidae	Water-scavenger beetle															
CLASS HIRUDINEA	Leeches					P										
Unknown Hirudinea																
TOTAL NUMBER					31,660	5,732	147,225	55,879	86,273	209,568	19,746	52,337	249,944	138,044	379,197	121,799

* indicates economically important species
P = presence data only (abundances not recorded)

Appendix 3. Total biomass (in grams) of all fish and invertebrate species collected from the impacted wetland, near reference and far reference areas in Botany Bay, Hunter River, Macleay River and each of the external reference estuaries between March 1996 and December 1997.

Taxa are listed in alphabetical. * indicates economically important species.

Species	Total Weight (g)	Botany Bay			Hunter River			Macleay River			External Reference Estuaries		
		Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Wallamba River	Manning River	Nambucca River
FISH													
Acanthigobius flaviomonitus	256.1				96.3	63.6	96.2						
Acanthopagrus australis *	54809.8	42441.7	427.7	0.4	2836.6	1212.3	1026.3		2813.8	2607.6	747.4	437.7	258.2
Achoerodus viridis *	9.0			0.3						2.2		4.9	1.6
Ambassis jacksoniensis	39845.4	106.5	455.4	5103.9	2369.7	185.6	612.3	< 0.1	4961.6	4862.4	6270.6	6672.9	8244.4
Ambassis marianus	7147.6	16.2	45.0		9.1	10.7	20.1	4.8	2157.9	3940.4	461.0	60.7	421.7
Amblygobius phalaena	0.3											0.3	
Ammotretis rostratus *	142.5		48.0	85.5			9.0						
Anguilla australis *	887.0	0.1			886.9								
Anguilla reinhardtii *	3208.5	2540.0			601.9			0.2			66.4		
Arenigobius bifrenatus	2332.7	31.0			829.1	147.3	423.2		29.8	111.1	< 0.1	754.7	6.4
Arenigobius frenatus	469.5				1.5	4.4	0.6			8.7	437.6	16.7	
Arenigobius spp.	6.6									6.6			
Arothron hispidus	1.3									1.3			
Arripis georgiana *	22.0		22.0										
Atherinason hepsetoides	5.7			5.7									
Atherinomorus ogilbyi	5474.5		4929.5	531.4			12.2				1.4		
Bathygobius krefftii	25.5			3.9	0.7	0.5	0.4			7.7	10.1	2.2	
Butis butis	6.2								3.8	1.0	1.3		0.1
Callionymus limiceps	25.2			< 0.1			7.9				17.3		
Caranx spp.*	39.3									11.3	3.6	19.8	4.6
Centropogon australis	618.3	13.8	15.9	17.1	41.4	44.8	34.8	< 0.1	2.9	76.4	256.5	83.0	31.6
Chelidonichthys kumu *	2.4			1.3			0.9				0.2		
Chrysophrys auratus *	208.8		208.6							0.1		< 0.1	0.1
Cnidoglanis macrocephala *	109.0		0.2	1.8			107.0						
Cryptocentrus critatus	40.2				2.8	5.4			0.9	< 0.1	31.1		
Dactyloptera orientalis	3.2						3.2						
Dasyatis fluviorum	21865.0				2125.0	3775.0	10000.0		1395.0	885.0	3375.0	310.0	
Dicotylichthys punctulatus	2074.3									464.6	635.0	974.7	
Engraulis australis *	67.2					52.9	13.5		0.3	0.4	0.1	< 0.1	
Enoplosus armatus *	5.7		< 0.1	5.7									
Eocallionymus papilio	2.4			2.4									
Favonigobius exquisitus	1923.9		0.9	142.3	47.9	353.2	209.0	0.2	336.5	386.4	141.7	151.6	154.1
Favonigobius lateralis	1749.3	3.3	0.3	1696.6	0.2	4.9	10.5		0.3	4.8	28.1	0.2	
Favonigobius tamarensis	2566.9	2.3		0.2	638.0	121.2	53.7	4.0	212.6	210.5	670.8	435.9	217.6
Fistularia commersonii	9.0			2.6								6.4	
Galaxias maculatus	3.2	0.9	0.1				0.1		0.1	0.1	.0.8	1.0	
Gambusia holbrookii	257.9	29.9			6.2			200.5	1.7	0.1	0.6	4.3	14.5
Gerres subfasciatus *	10303.5		< 0.1	< 0.1	1728.9	762.2	1525.3		2639.1	1920.5	1575.3	152.2	< 0.1
Girella tricuspidata *	10789.4		< 0.1	0.3	0.1		500.1		29.4	1422.2	4884.6	3667.2	285.5
Glossogobius biocellatus	30.4					< 0.1			4.3	15.3	6.6	4.2	
Gobiomorphus australis	4.9												4.9
Gobiomorpus spp.	269.8				60.3			156.9	9.3			0.3	43.0
Gobiopterus semivestitus	3747.4	< 0.1	0.3	0.6	283.2	83.9	2.4	0.7	30.3	62.5	213.8	3067.6	2.1
Herklotsichthys castelnaui *	459.6								360.8	75.7	23.1		
Heteroclinus spp.	9.9		0.5	9.4									
Hippocampus whitei	1.4		1.4										
Hyperlophus translucidus *	0.0					< 0.1							
Hyperlophus vittatus *	3582.5	4.8	4.7	0.6	< 0.1	395.0	1279.9		552.5	153.4	80.7	1109.7	1.1
Hyperseleotris compressus	470.3				203.6	0.9		111.5	9.5	1.4		0.5	143.0
Hyporhamphus regulatus *	183.3		34.3	1.1		4.1	5.2		31.2	74.4	23.7	8.8	0.5
Hypseleotris galii	0.6							< 0.1					0.6
Juvenile Antenariidae	0.2											0.2	
Juvenile Balistidae	0.1		0.1										
Juvenile Callionymidae	0.1		0.1										
Juvenile Eleotrididae	0.6				< 0.1				0.6				
Juvenile Gobiidae	0.2				0.1	< 0.1	0.1				< 0.1	< 0.1	
Juvenile Leptoscopidae	< 0.1			< 0.1									
Juvenile Monacanthidae*	3.1		< 0.1	0.2						< 0.1	0.7	0.8	1.4
Juvenile Platycephalidae*	< 0.1		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1						
Juvenile Syngnathidae	< 0.1											< 0.1	
Juvenile Tetraodontidae	1.7			0.3	0.1	0.9	0.3				0.2		
Juvenile Trachichthyidae*	< 0.1			< 0.1									
Kathetostoma laeve	8.5		8.5										
Leptatherina presbyteroides	0.6			0.6									
Lesueurina platycephala	0.7		0.7	< 0.1									
Lethrinus genivittatus	0.2									0.2			
Liza argentea *	26783.1	1557.7		0.4	129.8	1058.3	137.1	9.9	7920.0	1898.8	11995.8	1379.8	695.5
Lutjanus argentimaculatus	0.3									0.3			
Lutjanus fulviflammus	2.0										0.4	1.6	
Lutjanus russelli	0.4								0.2				0.2
Macquaria novemaculeata *	386.2					386.2							
Marilyna pleurosticta	3932.2						13.6		461.2	732.7	383.8	2031.5	309.4
Meuschenia freycineti *	47.1			7.9						< 0.1	3.0	34.3	2.0
Meuschenia trachylepis *	8256.5		0.7	0.6	8.0				0.1	1577.2	3106.1	3269.6	294.2
Microcanthus strigatus	15.7		< 0.1	0.1						0.4		14.0	1.3
Monodactylus argenteus	343.2									119.8	28.8	47.4	147.1
Mugil cephalus *	14917.4	2163.4	527.2	529.0	2210.2	1423.8	428.9	661.7	1363.3	1643.7	841.4	2108.0	1016.8
Mugilogobius paludis	27.3		0.1		9.6	0.1		0.1	0.6		1.3	2.9	12.5
Mugilogobius spp.	1.0										1.0		
Myxus elongatus *	28938.3	16633.0	566.9	3297.1	51.3	1699.8	3004.9		899.1	436.5	1018.0	406.3	925.4
Notesthes robusta	1707.2				663.1					305.0	245.0	494.1	
Omobranchus anolius	0.1					< 0.1	0.1			< 0.1		< 0.1	

Appendix 3. Continued

Species	Total Weight (g)	Botany Bay			Hunter River			Macleay River			External Reference Estuaries		
		Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Wallamba River	Manning River	Nambucca River
Pandaculus lidwilla	14.6									0.6	0.2	1.5	12.1
Paramonacanthus otisensis	26.8			0.6						19.7	3.9	0.8	1.8
*Paraplagusia unicolor**	0.2		0.2										
Parkraemeria ornata	1.5								0.3		< 0.1		1.2
Parupeneus signatus	2.8											2.8	
Pegasus volitans	2.3										2.3		
*Pelates quadrilineatus**	1.5												1.5
*Pelates sexlineatus**	8167.1		< 0.1	2.4	0.5	0.1	< 0.1	< 0.1	21.4	2498.2	2398.4	2705.5	540.6
Petroscirtes lupus	66.2									17.3	13.9	34.5	0.5
Philypnodon grandiceps	8730.1	7346.2		0.5	585.6	0.9	0.9	147.0	1.9		367.9	166.3	112.9
Philypnodon sp.	448.7	32.5			87.6			324.2	0.8	0.5			3.0
*Platycephalus arenarius**	166.9		124.5	20.1			22.3						
*Platycephalus bassensis**	85.2		3.2	82.0									
*Platycephalus fuscus**	9267.9			4.8	589.2	236.5	3891.4		516.8	1749.8	1070.5	1102.7	106.1
Plectorhinchus gibbosus	5.6			5.6									
*Pomatomus saltatrix**	1834.1		107.4		1.2	200.2	842.6		37.3	469.7	6.0	169.7	
Potamalosa richmondia	10.4							8.7	1.7				
Priacanthus macracanthus	0.5					0.5							
Psenes arafurensis	0.1												0.1
*Pseudocaranx dentex**	101.4		49.5				3.3		22.8	25.8			
Pseudogobius olorum	5777.7	184.0			640.9	8.5	10.3	651.3	229.6	306.0	1148.2	1518.3	1080.4
Pseudomugil signifer	1340.6		0.2		27.8	0.1		638.2	25.6	17.9	437.2	23.6	169.8
*Pseudorhombus arsius**	1613.4			41.5	107.0	249.7	538.9		125.4	71.8	476.6	2.5	
*Pseudorhombus jenynsii**	805.0					37.7	129.1			24.7	576.9	36.6	
Pseudorhombus spp.*	< 0.1										< 0.1		
Redigobius macrostoma	8278.7	0.4			795.4	18.3	8.5	5.0	35.2	969.2	1715.1	3152.3	1579.4
Repomucenus limiceps	3.8		< 0.1	3.8									
*Rhabdosargus sarba**	4056.2		90.9	306.3	13.9	56.5	357.1		302.4	2041.7	444.7	199.6	243.0
Saurida nebulosa	2.9									0.5		2.4	
Scatophagus argus	3.0									0.2	0.3	2.3	0.3
*Scomberoides lysan**	153.6		145.8						3.2	1.3	0.9	0.7	1.7
Siganus nebulosus	91.8			0.7						79.8		11.3	
*Sillago ciliata**	14648.9		2493.5	3163.6	25.9	1319.1	5438.3		1178.3	887.9	11.4	5.2	125.7
*Sillago maculata**	114.2		108.9	2.6			2.5				0.2		
Siphamia cephalotes	0.2		0.2										
Siphamia roseigaster	791.5									83.0	685.0	< 0.1 22.8	0.7
*Sphyraena obtusata**	19.9			1.0			< 0.1		5.4	3.6	3.9	6.0	
Stigmatopora argus	4.6		0.4	4.2									
Stigmatopora nigara	18.6		4.8	11.7								2.1	
*Synaptura nigra**	210.4				25.1				3.6	98.4	23.0	60.3	
Syngnathoides biaculeatus	24.0											24.0	
Taenioides Type 1	0.1					0.1							
Terapon jarbua	125.9	0.2		< 0.1	2.8				121.2			0.6	1.1
Tetractenos glaber	173.7			4.0		0.9	56.7				32.3	79.8	
Tetractenos hamiltoni	8240.4		326.8	86.3	9.3	120.9	1097.4		246.5	959.3	2673.3	2700.1	20.6
Torquigener pleurogramma	526.5		1.7	472.1			52.7						
Torquigener squamicauda	116.8	0.1	89.0	4.0			23.7						
Trachinocephalus myops	2.4		2.4										
*Tylosurus gavialoides**	1398.2										1397.7		0.5
Upeneus spp.	1.9		1.1	0.3						0.5			
Urocampus carnirostrus	44.2		< 0.1							1.7	19.3	20.9	2.2
*Valamugil georgi**	149.7					87.7			33.2	28.8			
Vanacampus margaritifer	11.5									2.0	5.4	3.3	0.8
Unknown Antennariidae	27.8				4.6	23.2							
Unknown Diodontidae	0.8											0.8	
Unknown Juvenile Fish	0.1		< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1		< 0.1	< 0.1	< 0.1	
INVERTEBRATES													
Acetes sibogae australis	29714.0	< 0.1	3.5	0.7	1405.4	5618.2	7314.3	6.7	649.7	10921.4	430.8	3359.8	3.3
Alpheus richardsoni	118.3		0.6		11.0	19.3	24.4	< 0.1	3.8	49.5	5.9	3.8	0.2
Amarinus laevatis	6.2	4.9						0.8				0.5	
Amarinus spp.	18.0	4.8	0.5	0.6	3.2	< 0.1		6.5	0.2	0.5	0.2	0.7	0.7
Caradina maccullochi	24.0				0.5			4.3	< 0.1	< 0.1	< 0.1	< 0.1	19.2
Chlorotocella leptorhynchus	81.7									0.3	81.1	0.2	0.1
Euprymna tasmanica	2.0		1.8								0.2	< 0.1	
Grapsid Type 1	50.7		4.8		33.7	6.3	0.2	< 0.1	0.3	0.1	1.7	3.4	0.2
Grapsid Type 2	0.9				< 0.1	0.1	0.1		0.7	< 0.1	< 0.1	< 0.1	
Grapsid Type 3	1.3				0.9				0.2	0.1			0.1
Grapsid Type 4	0.7					0.1			< 0.1		0.6		
Halicarcinus ovatus	2.7	0.1	2.3	0.4									
Hippolytid Type 1	< 0.1										< 0.1		
Hymenosoma hodgkini	7.5				0.5	1.6	0.3		4.2	0.4	0.3	0.3	< 0.1
Idiosepius notoides	60.8	< 0.1	1.6	0.9			0.2			0.8	22.3	34.7	0.3
Juvenile squid*	0.5						0.1			0.1	0.3		
Latreutes pygmaeus	20.5			< 0.1						3.0	17.1	0.4	< 0.1
Latreutes Type 1	0.3										0.3		
Loliolus noctilucca	6.4		5.0				0.7				0.7		
Macrobrachium cf novaehollandiae	74.3					12.6					54.6		7.1
Macrobrachium intermedium	7107.8	1.5		14.4	11.5		0.2	11.6	1.1	1553.7	1487.1	3393.1	633.6
Matuta planipes	122.7		122.5	0.2									
*Metapenaeus bennettae**	83.9				3.5	< 0.1	1.3	0.3	0.4	0.2	75.3	0.8	2.1
*Metapenaeus ensis**	15.5											3.2	12.3
*Metapenaeus macleayi**	3316.3		0.1	0.7	1077.5	646.4	9.3	5.3	383.3	210.3	518.2	365.9	99.2

Appendix 3. Continued

Species	Total Weight (g)	Botany Bay			Hunter River			Macleay River			External Reference Estuaries		
		Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Impacted Wetland	Near Reference	Far Reference	Wallamba River	Manning River	Nambucca River
Mictyris longicarpus	< 0.1									< 0.1			
Octopodidae Type 1	1.5		1.5										
Ocypodid Type 1	2.9				2.2	0.1			0.6	< 0.1			
Ocypodid Type 2	0.5				< 0.1	0.5	< 0.1		< 0.1	< 0.1			
Ocypodid Type 3	< 0.1				< 0.1								
Ovalipes australiensis	1017.4		688.4	329.0									
Palaemon debilis	36078.9	0.1	0.2		148.0	6.2	2.9	3.3	1102.6	4817.1	7370.6	15771.2	6856.7
Pandalid Type 1	0.5		< 0.1	0.5							< 0.1		
Paratya australiensis	0.3				0.3								
*Penaeus esculentus**	90.7				0.9				0.8	42.6	38.5	3.8	4.0
*Penaeus plebejus**	593.5	< 0.1	0.5	27.3	46.9	37.4	48.7	1.2	58.5	50.2	205.5	94.8	22.5
Penaeus spp.*	0.1						0.1						
Pontophilus Type 1	1.7			1.7			< 0.1						
Pontophilus Type 2	0.0						< 0.1						
*Portunus pelagicus**	601.1		46.4	124.3	0.1	< 0.1	350.5				53.1	0.2	26.5
*Scylla serrata**	69.8									59.6			10.2
Thalamita sp1	101.9										53.5	48.4	
Thalamita sp2	86.6										0.5	86.1	
Xanthid Type 1	8.6										8.6		
Unknown Ocypodidae	< 0.1								< 0.1				
Unknown Penaeidae*	0.4												0.4
Unknown squid	3.0										3.0		
TOTAL BIOMASS		73119.5	11729.6	16167.8	21504.9	20506.7	39768.0	2964.9	31348.0	52098.7	61534.4	62968.8	24946.3

Appendix 4.1. Results of the SNK-tests for the comparison of the Macleay River impacted wetland area with the near and far reference areas.

Tests were done for the significant ($p < 0.05$) terms in the three-factor ANOVA and the terms are (i) Area and (ii) Time x Area. Tests were not done for the nested terms in the analysis of variance *Abbreviations:* I = Impact; N = Near Reference; F = Far Reference; M' = March; F' = February; J' = June; S' = September; D' = December. Means are listed in ascending order and underlining indicates no significant differences were found between means ($p > 0.05$). # indicates that the test was not powerful enough to detect differences.

(i) Time x Area

	Species Richness	Biomass
Mar'96:	$\text{I} < \underline{\text{N}\quad\text{F}}$	$\text{I} < \underline{\text{N}\quad\text{F}}$
Jun'96:	$\text{I} < \underline{\text{N}\quad\text{F}}$	$\text{I} < \text{N} < \text{F}$
Sep'96:	$\text{I} < \underline{\text{N}\quad\text{F}}$	$\text{I} < \underline{\text{N}\quad\text{F}}$
Dec'96:	$\text{I} < \underline{\text{F}\quad\text{N}}$	$\text{I} < \underline{\text{F}\quad\text{N}}$
Feb'97:	$\text{I} < \underline{\text{N}\quad\text{F}}$	$\text{I} < \underline{\text{N}\quad\text{F}}$
Mar'97:	$\text{I} < \underline{\text{N}\quad\text{F}}$	$\text{I} < \underline{\text{F}\quad\text{N}}$
Jun'97:	$\text{I} < \underline{\text{N}\quad\text{F}}$	$\text{I} < \underline{\text{F}\quad\text{N}}$
Sep'97:	$\underline{\text{I}\quad\text{N}} < \text{F}$	$\underline{\text{I}\quad\text{N}\quad\text{F}}$
Dec'97:	#I F N	$\underline{\text{I}\quad\text{F}\quad\text{N}}$

	Acanthopagrus australis	*Mugil cephalus*	*Penaeus plebejus*	*Ambassis jacksoniensis*
Mar'96:	#I F N	$\underline{\text{N}\quad\text{F}\quad\text{I}}$	$\text{I} < \underline{\text{F}\quad\text{N}}$	$\text{I} < \text{N} < \text{F}$
Jun'96:	$\text{I} < \underline{\text{N}\quad\text{F}}$	$\underline{\text{F}\quad\text{I}\quad\text{N}}$	$\text{I} < \underline{\text{N}\quad\text{F}}$	$\text{I} < \text{N} < \text{F}$
Sep'96:	$\text{I} < \text{N} < \text{F}$	$\text{I} < \text{N} < \text{F}$	$\text{I} < \underline{\text{F}\quad\text{N}}$	$\text{I} < \underline{\text{N}\quad\text{F}}$
Dec'96:	$\text{I} < \underline{\text{F}\quad\text{N}}$	$\underline{\text{I}\quad\text{F}\quad\text{N}}$	$\underline{\text{I}\quad\text{N}} < \text{F}$	$\text{I} < \underline{\text{F}\quad\text{N}}$
Feb'97:	$\text{I} < \underline{\text{F}\quad\text{N}}$	$\underline{\text{I}\quad\text{F}\quad\text{N}}$	$\underline{\text{I}\quad\text{N}\quad\text{F}}$	$\text{I} < \underline{\text{F}\quad\text{N}}$
Mar'97:	$\text{I} < \underline{\text{F}\quad\text{N}}$	$\underline{\text{I}\quad\text{N}\quad\text{F}}$	$\underline{\text{I}\quad\text{N}} < \text{F}$	$\text{I} < \text{F} < \text{N}$
Jun'97:	$\text{I} < \text{N} < \text{F}$	$\underline{\text{I}\quad\text{F}\quad\text{N}}$	$\text{I} < \underline{\text{N}\quad\text{F}}$	$\text{I} < \underline{\text{N}\quad\text{F}}$
Sep'97:	$\underline{\text{I}\quad\text{N}} < \text{F}$	$\underline{\text{I}\quad\text{N}\quad\text{F}}$	$\text{I} < \text{N} < \text{F}$	$\text{I} < \underline{\text{N}\quad\text{F}}$
Dec'97:	$\underline{\text{I}\quad\text{N}\quad\text{F}}$	$\underline{\text{I}\quad\text{N}\quad\text{F}}$	$\underline{\text{I}\quad\text{F}} < \text{N}$	$\text{I} < \underline{\text{F}\quad\text{N}}$

	Gobiopterus semivestitus	*Philypnodon grandiceps*	*Pseudogobius olorum*
Mar'96:	$\underline{\text{I}\quad\text{N}} < \text{F}$	$\underline{\text{F}\quad\text{N}\quad\text{I}}$	$\underline{\text{I}\quad\text{N}} < \text{F}$
Jun'96:	$\underline{\text{I}\quad\text{N}} < \text{F}$	$\underline{\text{F}\quad\text{I}\quad\text{N}}$	$\underline{\text{I}\quad\text{N}\quad\text{F}}$
Sep'96:	$\text{I} < \underline{\text{N}\quad\text{F}}$	$\underline{\text{F}\quad\text{N}\quad\text{I}}$	#I N F
Dec'96:	$\underline{\text{I}\quad\text{N}\quad\text{F}}$	$\underline{\text{F}\quad\text{I}\quad\text{N}}$	#I F N
Feb'97:	$\text{I} < \underline{\text{F}\quad\text{N}}$	$\underline{\text{F}\quad\text{N}} < \text{I}$	$\text{N} < \text{F} < \text{I}$
Mar'97:	#I F N	$\underline{\text{F}\quad\text{N}\quad\text{I}}$	$\underline{\text{N}\quad\text{I}\quad\text{F}}$
Jun'97:	$\underline{\text{I}\quad\text{N}} < \text{F}$	$\underline{\text{F}\quad\text{N}} < \text{I}$	$\underline{\text{N}\quad\text{F}} < \text{I}$
Sep'97:	$\underline{\text{I}\quad\text{N}\quad\text{F}}$	$\underline{\text{F}\quad\text{N}} < \text{I}$	$\underline{\text{N}\quad\text{F}} < \text{I}$
Dec'97:	$\underline{\text{F}\quad\text{I}\quad\text{N}}$	$\underline{\text{F}\quad\text{N}} < \text{I}$	$\underline{\text{F}\quad\text{N}} < \text{I}$

Appendix 4.1. Continued

Species Richness

I: #	D’9	M’97	M’96	S’96	J’96	D’97	S’97	J’97	F’97
N: #	S’97	D’97	M’97	J’96	J’97	S’96	F’97	D’96	M’96
F:	D’97 <	S’97	D’96	F’97	S’96	M’97	J’96	J’97	M’96

Biomass

I: #	D’96	M’97	S’96	J’96	M’96	J’97	S’97	F’97	D’97
N:	S’97	S’96	J’96	D’97	J’97	M’96	M’97	D’96	F’97
F: #	S’97	D’97	J’97	S’96	D’96	M’97	F’97	M’96	J’96

Acanthopagrus australis

I:	M’96	J’96	S’96	D’96	F’97	M’97	J’97	S’97	D’97
N:	S’97	D’97	M’96	M’97	F’97	J’96	D’96	J’97 <	S’96
F:	M’96	D’97	M’97	F’97	D’96	J’96	S’97	J’97 <	S’96

Mugil cephalus

I:	D’96	M’97	D’97	F’97	S’97	J’97	J’96	S’96	M’96
N:	M’96	D’97	S’97	M’97	F’97	J’96	D’96	J’97	S’96
F:	J’96	D’97	M’96	S’97	F’97	D’96	M’97	J’97 <	S’96

Penaeus plebejus

I:	M’96	J’96	D’96	F’97	M’97	D’97	J’97	S’97	S’96
N: #	D’96	M’97	J’96	F’97	M’96	S’97	D’97	J’97	S’96
F:	D’97	F’97	M’96	M’97	D’96	J’96	J’97	S’97 <	S’96

Ambassis jacksoniensis

I:	M’96	J’96	D’96	F’97	M’97	J’97	S’97	D’97	S’96
N:	J’96	M’96	J’97	S’96	S’97	M’97	F’97	D’97	D’96
F: #	M’97	D’96	F’97	J’97	D’97	S’97	S’96	J’96	M’96

Gobiopterus semivestitus

I: #	S’96	D’96	M’97	J’97	S’97	D’97	M’96	F’97	J’96
N:	D’96	M’96	D’97	S’97	J’97	F’97	J’96	M’97 <	S’96
F:	D’97	D’96	M’97	F’97	S’97 <	J’97	M’96	S’96	J’96

Philypnodon grandiceps

I:	J’96	D’96	M’96	S’96	M’97 <	F’97	S’97	D’97 <	J’97
N:	M’96	S’96	F’97	M’97	S’97	D’97	J’96	J’97	D’96
F:	M’96	J’96	S’96	D’96	F’97	M’97	J’97	S’97	D’97

Pseudogobius olorum

I: #	M’96	D’96	M’97	J’96	S’96	F’97	J’97	D’97	S’97
N: #	M’97	S’97	D’97	F’97	M’96	J’97	J’96	D’96	S’96
F: #	D’97	S’97	F’97	M’97	J’97	D’96	M’96	J’96	S’96

Appendix 4.2. Results of the SNK-tests for the comparison of the Macleay River impacted wetland area with three external reference estuaries.

Tests were done for the significant ($p < 0.05$) terms in the asymmetrical ANOVA and the terms are (i) Time x Impact vs Reference and (ii) Time x Among Reference. Tests were not done for the nested terms in the analysis of variance. *Abbreviations:* I = Impact; R = Reference; M' = March; F' = February; J' = June; S' = September; D' = December. Means are listed in ascending order and underlining indicates no significant differences were found between means ($p > 0.05$). # indicates that the test was not powerful enough to detect differences.

(i) Impact vs Reference

Ambassis jacksoniensis I < R

(ii) Time x Impact vs Reference

	Species Richness	Biomass	*Philypnodon grandiceps*	*Pseudogobius olorum*
Mar'96:	I < R	I < R	I ___ R	I < R
Jun'96:	I < R	I < R	I < R	I < R
Sep'96:	I < R	I < R	I ___ R	I < R
Dec'96:	I < R	I < R	I ___ R	I < R
Feb'97:	I < R	I < R	R ___ I	I ___ R
Mar'97:	I < R	I < R	I ___ R	I < R
Jun'97:	I < R	I < R	R < I	I ___ R
Sep'97:	I < R	I < R	R ___ I	R ___ I
Dec'97:	I < R	I < R	R < I	R ___ I

Species Richness

I: #	D'96	M'97	M'96	S'96	J'96	D'97	S'97	J'97	F'97
R:	D'97	D'96	F'97	M'97	J'96	J'97	S'97	M'96	S'96

Biomass

I: #	D'96	M'97	S'96	J'96	M'96	J'97	S'97	F'97	D'97
R:	S'97	S'96	J'97	D'96	D'97	M'97	J'96	F'97	M'96

Philypnodon grandiceps

I: #	J'96	D'96	M'96	S'96	M'97	F'97	S'97	D'97	J'97
R:	D'97	S'97	M'96	F'97	J'97	M'97	D'96	S'96	J'96

Pseudogobius olorum

I:	M'96	D'96	M'97 <	J'96	S'96	F'97	J'97	D'97	S'97
R:	D'97	D'96	S'97	F'97	M'96	M'97	S'96	J'96	J'97

Appendix 4.3. Results of the SNK-tests for the comparison of the Hunter River impacted wetland area with the near and far reference areas.

Tests were done for the significant ($p < 0.05$) terms in the three-factor ANOVA and the terms are (i) Area and (ii) Time x Area. Tests were not done for the nested terms in the analysis of variance *Abbreviations:* I = Impact; N = Near Reference; F = Far Reference; M' = March; F' = February; J' = June; S' = September; D' = December. Means are listed in ascending order and underlining indicates no significant differences were found between means ($p > 0.05$). # indicates that the test was not powerful enough to detect differences.

(i) Area

Pseudogobius olorum	N F < I
Redigobius macrostoma	F N < I

(ii) Time x Area

	Biomass	*Mugil cephalus*	*Ambassis jacksoniensis*	*Gobiopterus semivestitus*
Mar'96:	#N I F	F N I	N < F < I	#F N I
Jun'96:	I N F	N I F	N F I	F I N
Sep'96:	I N F	F N < I	N I F	F N < I
Dec'96:	F N I	F N I	F N I	F N < I
Feb'97:	F N I	N F I	F N I	#F N I
Mar'97:	N I F	N F < I	N F < I	#F N I
Jun'97:	#I N F	I N F	N I F	N F I
Sep'97:	I N F	F I N	#I F N	F I N
Dec'97:	#F N I	F N I	N F < I	F N < I

Biomass

I: #	S'97	J'97	J'96	S'96	M'97	M'96	D'97	F'97	D'96
N:	S'97	S'96	J'96	M'96	J'97	F'97	M'97	D'96	D'97
F: #	S'97	D'97	S'96	F'97	D'96	J'96	J'97	M'96	M'97

Mugil cephalus

I: #	J'97	J'96	S'97	F'97	D'97	M'96	D'96	S'96	M'97
N:	F'97	M'97	D'97	J'96	J'97	D'96	S'96	M'96	S'97
F:	M'96	D'96	D'97	F'97	S'97	S'96	M'97	J'97	J'96

Ambassis jacksoniensis

I: #	S'97	J'97	J'96	S'96	F'97	D'96	D'97	M'96	M'97
N:	J'96	J'97	D'97	S'96	M'96	M'97	D'96	F'97	S'97
F:	J'96	S'97	D'97	F'97	S'96	D'96	J'97	M'97	M'96

Gobiopterus semivestitus

I: #	J'96	J'97	S'97	D'96	M'96	F'97	M'97	S'96	D'97
N:	J'97	D'96	D'97	M'96	F'97	M'97	J'96	S'96	S'97
F:	M'96	D'96	F'97	S'97	D'97	J'96	M'97	J'97	S'96

Appendix 4.4. Results of the SNK-tests for the comparison of the Hunter River impacted wetland area with three external reference estuaries.

Tests were done for the significant ($p < 0.05$) terms in the asymmetrical ANOVA and the terms are (i) Time x Impact vs Reference and (ii) Time x Among Reference. Tests were not done for the nested terms in the analysis of variance. *Abbreviations:* I = Impact; R = Reference; M' = March; F' = February; J' = June; S' = September; D' = December. Means are listed in ascending order and underlining indicates no significant differences were found between means ($p > 0.05$). $^{\#}$ indicates that the test was not powerful enough to detect differences.

(i) Time x Impact vs Reference

	Biomass	*Penaeus plebejus*	*Ambassis jacksoniensis*	*Philypnodon grandiceps*
Mar'96:	I R	I R	I R	R < I
Jun'96:	I < R	I R	I < R	R I
Sep'96:	I < R	R I	I < R	R I
Dec'96:	I R	I R	I R	I R
Feb'97:	I R	I R	I < R	I R
Mar'97:	I R	I R	R I	R I
Jun'97:	I < R	I < R	I < R	R I
Sep'97:	I < R	I < R	I < R	R I
Dec'97:	I R	I R	I R	R < I

Biomass

I: #	S'97	J'97	J'96	S'96	M'97	M'96	D'97	F'97	D'96
R:	S'97	S'96	J'97	D'96	D'97	M'97	J'96	F'97	M'96

Penaeus plebejus

I:	M'97	J'97	S'97	F'97	J'96	M'96	D'97	D'96 <	S'96
R:	J'96	M'97	F'97	D'97	D'96	M'96	J'97	S'97	S'96

Ambassis jacksoniensis

I: #	S'97	J'97	J'96	S'96	F'97	D'96	D'97	M'96	M'97
R:	D'96	D'97	M'97	S'97	F'97	S'96	M'96	J'97	J'96

Philypnodon grandiceps

I: #	F'97	D'96	J'97	S'97	S'96	M'97	J'96	M'96	D'97
R:	D'97	S'97	M'96	F'97	J'97	M'97	D'96	S'96	J'96

Appendix 4.5. Results of the SNK-tests for the comparison of the Botany Bay impacted wetland area with the near and far reference areas.

Tests were done for the significant ($p < 0.05$) terms in the three-factor ANOVA and the terms are (i) Area and (ii) Time x Area. Tests were not done for the nested terms in the analysis of variance. *Abbreviations:* I = Impact; N = Near Reference; F = Far Reference; M’ = March; F’ = February; J’ = June; S’ = September; D’ = December. Means are listed in ascending order and underlining indicates no significant differences were found between means ($p > 0.05$). $^{\#}$ indicates that the test was not powerful enough to detect differences.

(i) Area

Biomass	$\underline{\text{N} \quad \text{F}} < \text{I}$

(ii) Time x Area

	Species Richness	*Mugil cephalus*	*Philypnodon grandiceps*
Jun’96:	$\underline{\text{N} \quad \text{I} \quad \text{F}}$	$\underline{\text{I} \quad \text{F}} < \text{N}$	$\underline{\text{F} \quad \text{N}} < \text{I}$
Sep’96:	$\text{N} < \underline{\text{I} \quad \text{F}}$	$\underline{\text{N} \quad \text{F} \quad \text{I}}$	$\underline{\text{F} \quad \text{N}} < \text{I}$
Dec’96:	$\text{N} < \text{F} < \text{I}$	$\underline{\text{F} \quad \text{N}} < \text{I}$	$\underline{\text{F} \quad \text{N}} < \text{I}$
Feb’97:	$\underline{\text{N} \quad \text{I}} < \text{F}$	$\underline{\text{N} \quad \text{F} \quad \text{I}}$	$\underline{\text{N} \quad \text{F}} < \text{I}$
Mar’97:	$\underline{\text{N} \quad \text{I} \quad \text{F}}$	$\underline{\text{N} \quad \text{F} \quad \text{I}}$	$\underline{\text{F} \quad \text{N}} < \text{I}$
Jun’97:	$\underline{\text{F} \quad \text{I} \quad \text{N}}$	$\underline{\text{N} \quad \text{F} \quad \text{I}}$	$\underline{\text{F} \quad \text{N}} < \text{I}$
Sep’97:	$\underline{\text{N} \quad \text{F} \quad \text{I}}$	$\text{F} \quad \text{N} \quad \text{I}^{\#}$	$\underline{\text{F} \quad \text{N}} < \text{I}$
Dec’97:	$\underline{\text{I} \quad \text{N} \quad \text{F}}$	$\underline{\text{N} \quad \text{F} \quad \text{I}}$	$\underline{\text{F} \quad \text{N}} < \text{I}$

Species Richness

I:	$\underline{\text{S’97} \quad \text{J’97} \quad \text{S’96} \quad \text{J’96} \quad \text{M’97} \quad \text{F’97} \quad \text{D’97} \quad \text{D’96}}$
N: #	$\text{D’96} \quad \text{S’96} \quad \text{S’97} \quad \text{J’96} \quad \text{M’97} \quad \text{F’97} \quad \text{J’97} \quad \text{D’97}$
F: #	$\text{S’97} \quad \text{D’96} \quad \text{J’97} \quad \text{S’96} \quad \text{M’97} \quad \text{J’96} \quad \text{D’97} \quad \text{F’97}$

Mugil cephalus

I:	$\underline{\text{J’96} \quad \text{D’97} \quad \text{J’97} \quad \text{M’97} \quad \text{F’97} \quad \text{S’97} \quad \text{S’96} \quad \text{D’96}}$
N:	$\underline{\text{S’96} \quad \text{D’96} \quad \text{F’97} \quad \text{J’97} \quad \text{S’97} \quad \text{D’97} \quad \text{M’97}} < \text{J’96}$
F:	$\underline{\text{D’96} \quad \text{S’97} \quad \text{J’96} \quad \text{F’97} \quad \text{D’97} \quad \text{J’97} \quad \text{S’96} \quad \text{M’97}}$

Philypnodon grandiceps

I:	$\underline{\text{S’97} \quad \text{S’96} \quad \text{J’97} \quad \text{M’97}} < \underline{\text{D’96} \quad \text{J’96} \quad \text{F’97} \quad \text{D’97}}$
N:	$\underline{\text{J’96} \quad \text{S’96} \quad \text{D’96} \quad \text{F’97} \quad \text{M’97} \quad \text{J’97} \quad \text{S’97} \quad \text{D’97}}$
F:	$\underline{\text{J’96} \quad \text{S’96} \quad \text{D’96} \quad \text{M’97} \quad \text{J’97} \quad \text{S’97} \quad \text{D’97} \quad \text{F’97}}$

Appendix 4.6. Results of the SNK-tests for the comparison of the three external reference estuaries.

Tests were done for the significant ($p < 0.05$) terms in the asymmetrical ANOVA’s for Hunter River and Macleay River for the Time x Among Reference term. *Abbreviations:* W = Wallamba River; M = Manning River; N = Nambucca River; M’ = March; F’ = February; J’ = June; S’ = September; D’ = December. Means are listed in ascending order and underlining indicates no significant differences were found between means ($p > 0.05$). $^{\#}$ indicates that the test was not powerful enough to detect differences.

	Acanthopagrus australis	*Penaeus plebejus*	*Gobiopterus semivestitus*
Mar’96:	$\underline{\text{N W}}$ < M	N < $\underline{\text{M W}}$	N < W < M
Jun’96:	$\underline{\text{W M N}}$	$\underline{\text{N M}}$ < W	N < W < M
Sep’96:	$\underline{\text{N W}}$ < M	#N W M	N < W < M
Dec’96:	#N W M	N < $\underline{\text{M W}}$	N < $\underline{\text{W M}}$
Feb’97:	$\underline{\text{N M W}}$	$\underline{\text{N M W}}$	N < W < M
Mar’97:	$\underline{\text{M N W}}$	N < $\underline{\text{M W}}$	N < W < M
Jun’97:	$\underline{\text{N W}}$ < M	$\underline{\text{N M W}}$	N < W < M
Sep’97:	$\underline{\text{W N}}$ < M	N M W$^{\#}$	N < W < M
Dec’97:	$\underline{\text{N M W}}$	$\underline{\text{N M}}$ < W	N < $\underline{\text{W M}}$

Acanthopagrus australis
W: $\underline{\text{M’96 D’96 D’97 F’97 M’97 J’96 J’97 S’96 S’97}}$
M: $\underline{\text{M’97 F’97 D’97 D’96 J’96 M’96}}$ < $\underline{\text{S’96 S’97 J’97}}$
N: $\underline{\text{D’97 F’97 M’96 D’96 M’97 J’97 S’96}}$ < $\underline{\text{J’96 S’97}}$

Penaeus plebejus
W: $\underline{\text{M’97 F’97 J’96 M’96 D’96 J’97 S’96 D’97 S’97}}$
M: # J’96 D’97 M’97 F’97 D’96 J’97 M’96 S’97 S’96
N: # M’97 J’96 D’96 D’97 F’97 M’96 J’97 S’97 S’96

Gobiopterus semivestitus
W: $\underline{\text{S’96 D’96 M’96 D’97 M’97 J’97 J’96 S’97 F’97}}$
N: $\underline{\text{D’97 M’96 F’97 S’96 D’96 J’97 M’97 J’96 S’97}}$
M: D’97 < D’96 < $\underline{\text{M’97 F’97 S’97 M’96 J’96 S’96 J’97}}$

Appendix 5. Temperature measured in the field at each site between March 1996 and December 1997.

ns = not sampled.

Estuary	**Site**	**Temperature (°C)**								
		Mar-96	Jun-96	Sep-96	Dec-96	Feb-97	Mar-97	Jun-97	Sep-97	Dec-97
Nambucca R.	1	27.4	17.5	22.4	25.1	29.6	29.8	17.5	19.6	26.8
	2	23.5	17.3	21.0	26.0	30.0	28.7	18.0	20.3	25.9
	3	23.8	17.0	21.3	26.1	30.8	28.4	17.5	20.3	29.1
Macleay R.	1	25.5	16.2	16.7	26.6	34.2	25.5	13.0	22.9	28.9
	2	28.6	17.2	18.8	27.2	34.5	26.4	13.6	23.5	29.7
	3	26.5	17.0	21.2	28.1	32.9	26.9	12.7	19.8	28.8
	4	25.0	17.6	20.2	26.5	28.3	26.5	17.5	20.3	28.8
	5	25.0	16.7	22.0	25.5	28.7	26.9	17.8	21.0	28.6
	6	25.0	17.2	20.5	26.0	28.0	27.2	17.9	20.8	29.5
	7	25.2	18.7	19.2	27.2	28.3	29.8	18.5	20.0	26.0
	8	23.5	19.3	19.0	28.0	29.0	25.4	19.4	20.1	29.0
	9	23.5	19.1	20.3	26.5	27.0	30.5	19.8	20.3	27.7
Manning R.	1	23.6	16.6	18.7	26.4	25.6	27.3	19.5	18.6	24.1
	2	23.3	16.4	18.6	25.6	26.0	27.6	19.5	18.2	20.8
	3	24.4	16.0	19.8	26.9	25.0	27.0	19.1	17.6	23.4
Wallamba R.	1	27.0	16.2	18.3	25.9	26.5	26.0	17.0	19.5	25.4
	2	27.0	17.5	17.5	26.1	26.0	26.5	15.6	22.4	26.9
	3	26.0	18.8	17.0	26.3	25.5	26.4	18.0	20.0	24.6
Hunter R.	1	22.5	14.8	20.2	23.9	23.4	23.0	15.6	16.1	25.3
	2	22.5	14.9	20.5	23.5	24.0	22.5	15.9	16.0	24.9
	3	20.8	15.0	18.4	23.6	25.4	21.7	16.4	15.8	24.1
	4	23.5	15.1	17.0	24.7	24.9	24.0	17.9	17.1	25.9
	5	23.0	15.9	17.0	23.0	25.0	24.1	18.6	16.1	25.6
	6	23.9	17.0	20.0	24.4	24.8	24.0	20.0	17.4	25.1
	7	23.6	18.4	19.1	23.4	25.0	24.1	20.0	16.9	24.5
	8	23.4	19.0	19.4	22.0	24.4	24.1	20.0	16.9	27.4
	9	23.8	17.4	19.6	22.5	26.0	25.2	19.0	21.8	26.7
Botany Bay	1	ns	18.3	19.7	25.4	25.7	27.5	18.5	19.8	21.7
	2	ns	19.1	19.9	25.7	25.6	24.0	20.0	21.5	21.2
	3	ns	19.0	18.2	21.6	26.6	24.4	20.9	19.7	22.8
	4	ns	18.6	18.0	21.4	22.6	23.4	17.9	16.8	24.3
	5	ns	16.9	18.5	21.1	22.5	23.4	17.6	16.7	21.9
	6	ns	16.8	18.0	22.0	22.9	24.0	17.5	18.0	22.0
	7	ns	17.6	19.0	21.2	26.0	24.6	20.5	16.8	24.2
	8	ns	16.9	17.6	20.5	23.0	24.3	20.0	15.5	23.5
	9	ns	16.5	19.0	21.0	22.8	23.6	21.1	16.2	22.7

Appendix 6. pH measured in the field at each site between March 1996 and December 1997.

ns = not sampled.

Estuary	**Site**	**Time**								
		Mar-96	Jun-96	Sep-96	Dec-96	Feb-97	Mar-97	Jun-97	Sep-97	Dec-97
Nambucca R.	1	8.00*	7.66	8.73	7.50*	7.50	7.19	7.86	7.96	7.78
	2	7.75*	8.13	8.12	7.50*	7.50	7.32	8.02	8.21	7.53
	3	8.00*	7.89	8.21	7.50*	7.85	7.31	7.85	8.07	7.62
Macleay R.	1	4.00*	3.69	4.33	4.75*	6.54	5.35	6.94	7.12	6.80
	2	4.50*	5.95	5.09	4.50*	7.98	4.79	7.38	8.84	7.93
	3	4.00*	3.90	4.94	4.75*	7.30	5.24	7.24	7.98	7.72
	4	4.00*	6.97	6.83	5.79	7.48	6.34	7.97	8.03	7.79
	5	ns	7.55	7.71	5.92	7.40	6.63	7.71	8.07	7.64
	6	ns	7.31	7.32	5.98	7.46	6.57	7.72	7.99	7.72
	7	ns	8.18	8.10	7.07	7.98	7.27	7.90	8.22	8.22
	8	ns	7.30	8.13	7.14	7.96	7.35	8.01	8.15	8.09
	9	ns	8.79	8.19	7.48	7.89	8.30	8.12	7.97	8.20
Manning R.	1	8.00*	7.75	8.11	8.00*	7.37	8.00*	7.59	8.14	7.87
	2	8.00*	7.66	8.14	7.50*	7.50	7.50*	8.01	8.14	7.80
	3	8.25*	7.40	8.07	8.00*	7.86	8.00*	7.84	8.23	7.86
Wallamba R.	1	7.50*	7.50	8.04	8.00*	7.23	8.00*	7.77	8.17	7.76
	2	7.75*	7.93	8.12	8.00*	7.01	8.00*	7.88	8.33	7.97
	3	7.50*	8.54	8.09	8.50*	7.77	8.50*	7.94	8.23	7.95
Hunter R.	1	8.50*	7.70	7.02	8.50*	6.95	6.71	6.68	7.28	7.44
	2	8.50*	7.75	7.71	8.50*	7.59	6.79	6.46	7.28	7.76
	3	7.75*	6.59	7.94	8.00*	7.55	6.76	6.49	7.12	7.85
	4	8.50*	8.32	7.87	8.00*	8.19	7.20	7.38	7.99	7.89
	5	7.75*	7.42	7.90	8.00*	8.16	7.78	7.90	8.15	7.99
	6	8.50*	8.40	8.19	8.00*	7.93	7.78	7.89	8.39	8.04
	7	8.00*	7.89	8.14	8.00*	8.20	7.81	7.94	8.18	7.96
	8	7.75	7.40	8.20	8.00*	8.06	7.89	7.90	8.18	8.00
	9	8.00*	8.36	8.20	8.00*	8.32	7.83	7.77	8.24	8.08
Botany Bay	1	ns	7.60	8.59	7.50*	8.45	7.65	7.20	7.58	7.72
	2	ns	7.52	7.85	7.50*	7.68	7.70	7.28	7.47	7.80
	3	ns	7.53	7.86	7.50*	8.01	7.68	7.35	7.57	7.74
	4	ns	8.14	8.11	7.50*	7.96	7.98	7.89	8.17	8.26
	5	ns	8.61	8.04	7.00*	7.91	7.96	7.82	8.20	8.11
	6	ns	8.54	8.07	8.00*	7.99	8.00	7.78	8.19	8.11
	7	ns	8.96	8.18	8.00*	8.05	8.26	7.99	8.07	8.33
	8	ns	8.98	8.15	8.00*	8.20	8.11	7.99	8.09	8.19
	9	ns	8.81	8.13	8.00*	8.14	8.14	8.00	8.12	8.16

* pH measured using pH test strips

Appendix 7. Salinity measured in the field at each site between March 1996 and December 1997.

ns = not sampled.

Estuary	Site	Salinity (ppt)								
		Mar-96	Jun-96	Sep-96	Dec-96	Feb-97	Mar-97	Jun-97	Sep-97	Dec-97
Nambucca R.	1	9.7	9.8	16.0	3.7	17.4	3.5	20.4	19.4	21.9
	2	14.0	18.5	19.0	5.6	19.3	4.8	25.4	20.8	22.5
	3	15.6	21.0	20.5	6.2	20.3	7.0	26.3	21.2	24.5
Macleay R.	1	1.6	1.4	1.5	0.8	2.0	1.0	1.0	11.88	24.9
	2	4.5	4.0	4.5	1.1	9.3	1.3	10.8	22.3	26.6
	3	2.5	2.5	3.5	0.8	10.3	0.8	6.0	27.2	28.9
	4	16.5	14.7	15.7	2.0	17.0	4.0	26.0	30.5	28.1
	5	17.8	17.9	19.9	3.3	14.8	6.5	27.0	29.8	28.0
	6	17.2	16.7	18.8	2.5	16.5	5.8	28.1	30.6	28.4
	7	19.9	22.0	26.1	14.0	21.0	11.0	30.0	30.5	33.9
	8	21.0	22.0	26.5	13.9	20.9	11.3	29.5	30.1	29.3
	9	21.0	22.4	26.1	17.2	21.5	12.5	29.5	30.2	31.2
Manning R.	1	13.5	19.5	25.3	12.1	11.4	14.5	23.0	25.8	31.4
	2	21.9	19.5	27.3	14.1	14.0	14.5	28.0	27.1	34.4
	3	31.5	23.0	32.5	26.0	27.0	26.8	29.9	31.8	34.7
Wallamba R.	1	22.4	14.0	28.4	17.0	29.3	21.5	23.1	28.9	34.9
	2	30.5	18.5	30.1	22.7	32.5	20.2	25.1	30.1	35.4
	3	31.4	34.7	32.7	25.8	31.9	23.6	31.4	30.0	35.2
Hunter R.	1	11.0	1.4	7.0	4.3	5.6	1.0	2.0	1.56	18.3
	2	15.5	12.5	13.0	13.6	3.9	1.1	7.4	5.94	27.7
	3	20.3	14.0	17.8	18.7	6.5	1.3	11.0	7.42	28.7
	4	20.3	9.1	13.6	12.4	0.5	0.6	15.0	19.6	21.5
	5	30.5	13.8	21.7	31.4	2.5	16.5	29.7	26.7	34.7
	6	30.7	24.8	33.7	25.7	4.0	18.7	33.4	31.8	34.9
	7	27.3	32.0	34.0	32.1	7.6	19.4	33.1	31.6	35.1
	8	30.5	33.3	34.5	33.3	17.8	19.8	33.6	30.8	34.7
	9	25.8	26.8	31.3	32.3	13.1	18.5	29.0	29.9	34.9
Botany Bay	1	ns	13.1	12.3	21.0	6.6	13.1	7.9	6.85	21.5
	2	ns	19.1	17.3	27.2	13.4	20.9	17.7	14.8	22.0
	3	ns	24.7	31.0	35.1	13.4	23.7	15.1	18.6	28.4
	4	ns	30.3	33.2	35.3	31.5	30.1	30.5	30.3	35.0
	5	ns	32.8	33.5	34.5	32.0	32.6	32.6	32.0	35.4
	6	ns	33.0	33.5	34.7	32.4	33.1	32.5	32.0	35.3
	7	ns	32.1	34.5	35.7	27.5	34.6	33.85	32.0	35.2
	8	ns	33.3	35.2	35.7	31.6	35.0	33.5	32.0	35.4
	9	ns	31.6	34.3	35.7	32.1	34.4	33.7	32.3	35.5

Appendix 8. Nutrient analyses.

The concentrations of total phosphorous were greatest in the Hunter River compared to any of the other estuaries sampled during the study period (Figure A.8.1). In particular, at the site furthest upstream in Ironbark Creek the total phosphorous concentration was the greatest recorded throughout the study period. In Botany Bay, the total phosphorous concentrations at the site furthest upstream in the impacted wetland area was greater in September 1996 and February 1997 than for any other site sampled during the study period (Figure A.8.1). The Macleay River impacted wetland area had lower total phosphorous concentrations compared to the near or far reference areas and in particular, in September 1996 the concentrations at the upper-most site in the Macleay River impacted wetland area had the lowest recorded value of 0.002 mg/L (Figure A.8.1).

Nitrogen was recorded in various forms from each site during the study period (total Kjeldahl nitrogen, ammoniacal nitrogen and the proportion of nitrate, nitrite and total nitrogen). The concentrations of total nitrogen and the proportion of nitrate and nitrite were only measured in September and December 1997.

The highest concentrations of all forms of nitrogen were recorded from the Botany Bay wetlands area and particularly in September 1997 (Figures A.8.2, A.8.3, A.8.4). In comparison, the levels of all forms of nitrogen in the external reference estuaries was consistently lower than for any of the wetland estuaries (Figures A.8.2, A.8.3, A.8.4).

There was a single extreme concentration of total Kjeldahl nitrogen and ammoniacal nitrogen recorded from the Hunter River far reference area in September 1996 (Figures A.8.2 and A.8.3). The ammoniacal nitrogen concentrations were consistently higher at all estuaries during December 1997.

Nitrate and nitrite were never detected in the samples collected from the Macleay River or the external reference estuaries (Figure A.8.4). However in the Hunter River, the concentrations of nitrate and nitrite were present in all samples except at the middle site in Ironbark Creek during December 1997.

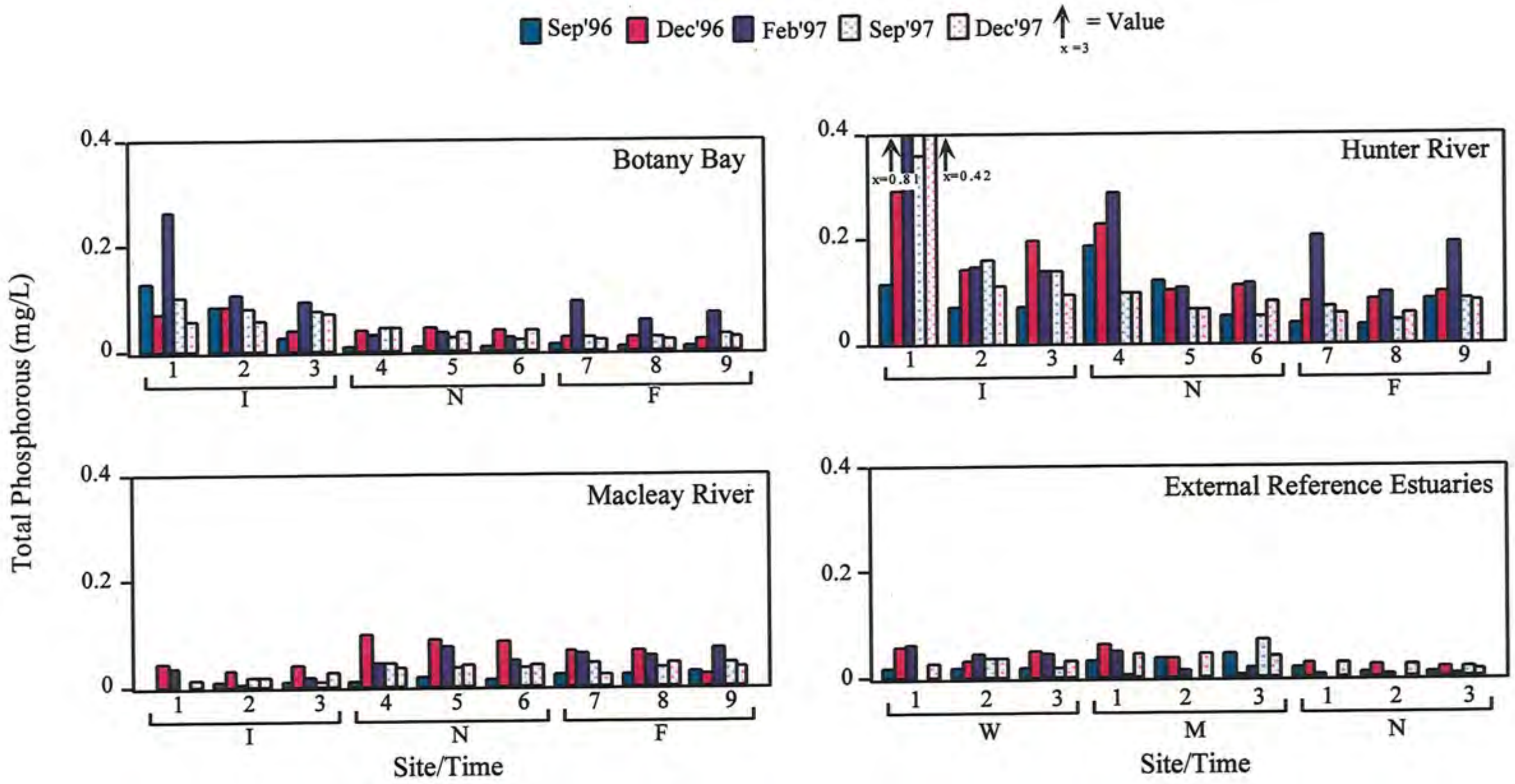

Figure A.8.1. Concentrations of total phosphorous (mg/L) at the sites within the impacted (I), near (N) and far reference (F) areas for each of the wetland estuaries and each of the external reference estuaries.

W = Wallamba R., M = Manning R., N = Nambucca R. Samples were collected during September and December 1996 and February, September and December 1997. All samples were analysed by AWT-EnSight laboratories using Metrix Method DW48.

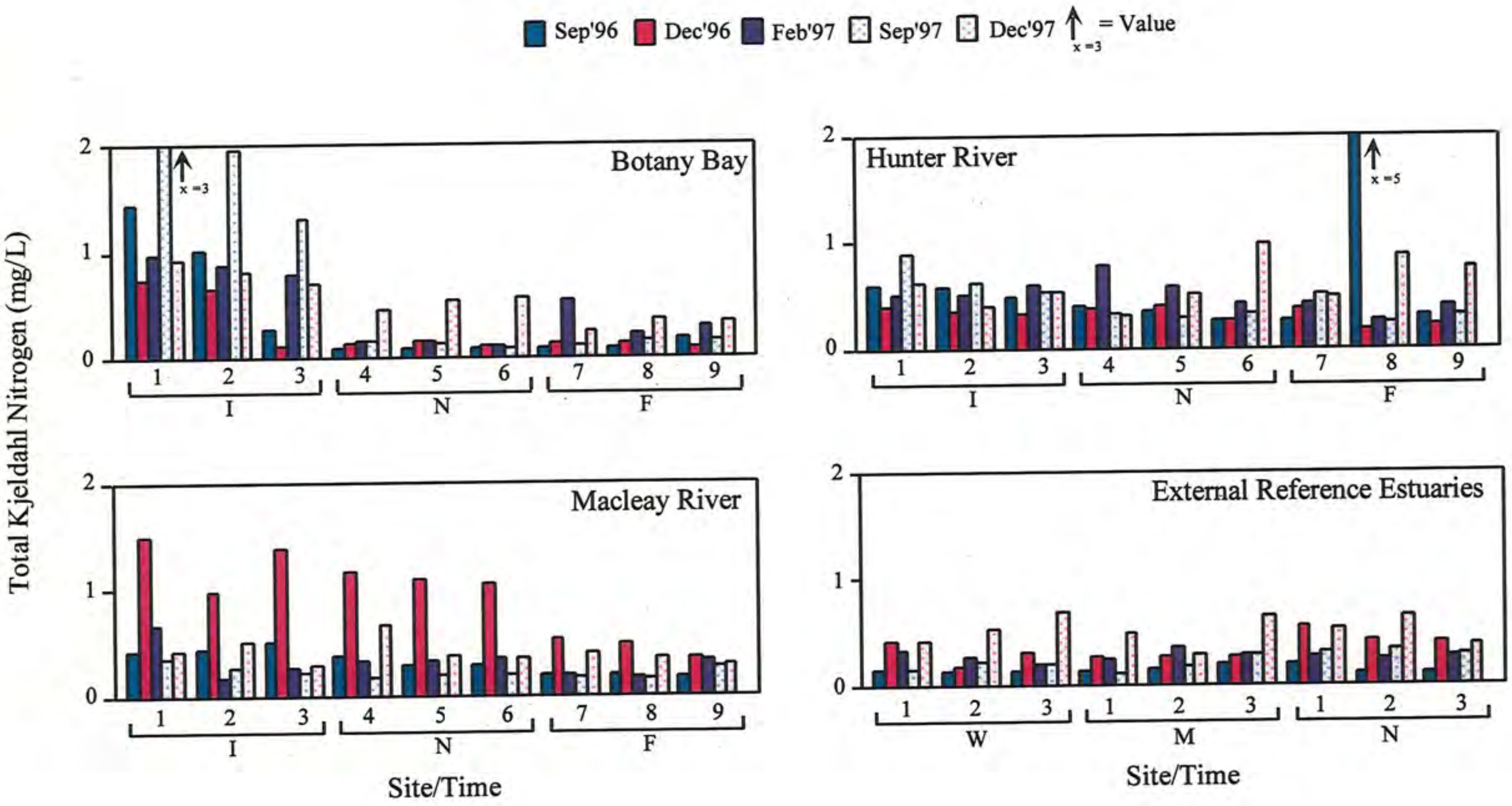

Figure A.8.2. Concentrations of total Kjeldahl nitrogen (mg/L) at the sites within the impacted (I), near (N) and far reference (F) areas for each of the wetland estuaries and each of the external reference estuaries.

W = Wallamba R., M = Manning R., N = Nambucca R. Samples were collected during September and December 1996 and February, September and December 1997. All samples were analysed by AWT-EnSight laboratories using Metrix Method DW54 and method DW56 for low level TKN in clean waters.

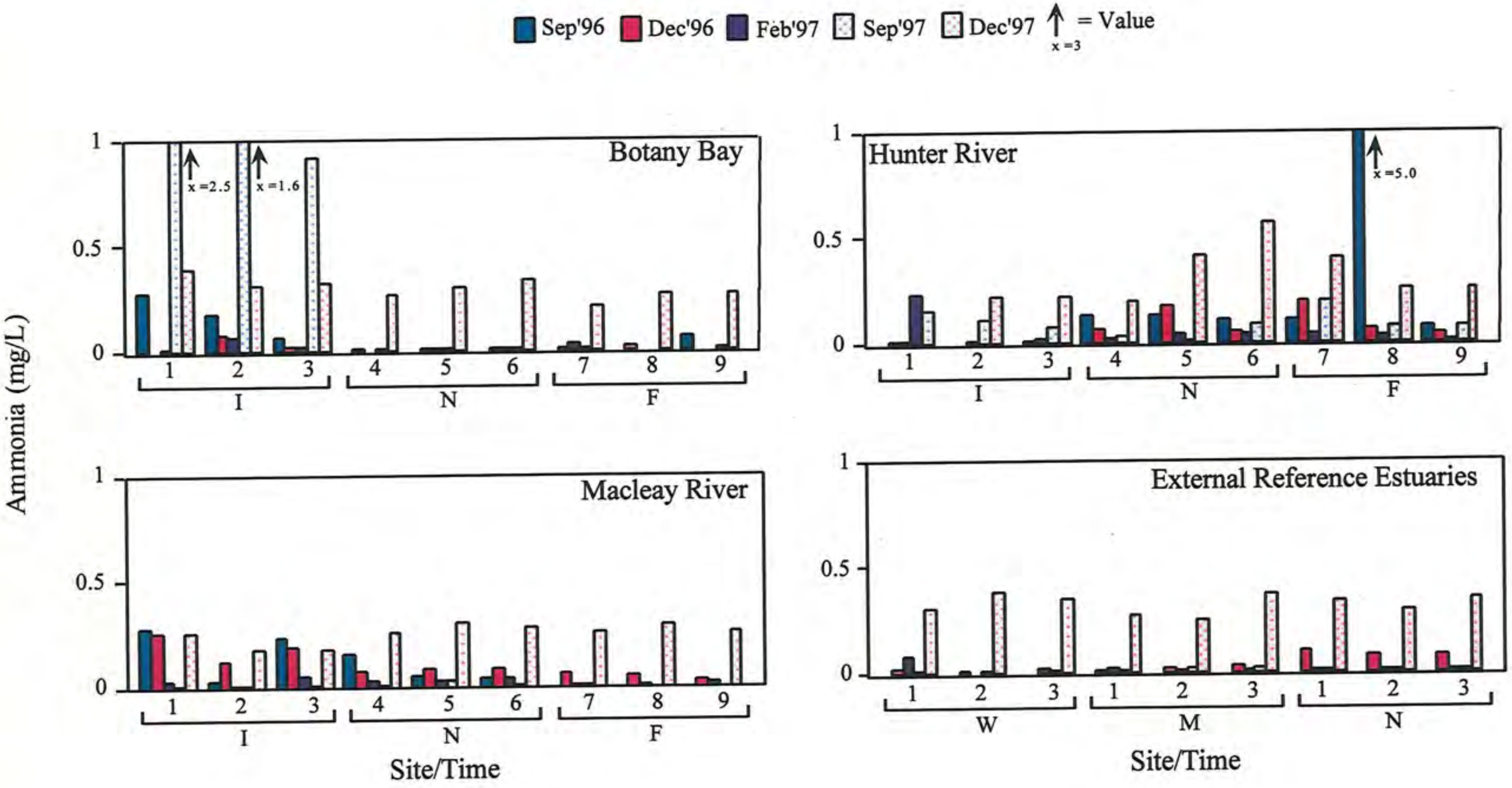

Figure A.8.3. Concentrations of ammoniacal nitrogen (mg/L) at the sites within the impacted (I), near (N) and far reference (F) areas for each of the wetland estuaries and each of the external reference estuaries.

W = Wallamba R., M = Manning R., N = Nambucca R. Samples were collected during September and December 1996 and February, September and December 1997. All samples were analysed by AWT-EnSight laboratories using Metrix Method DW40.

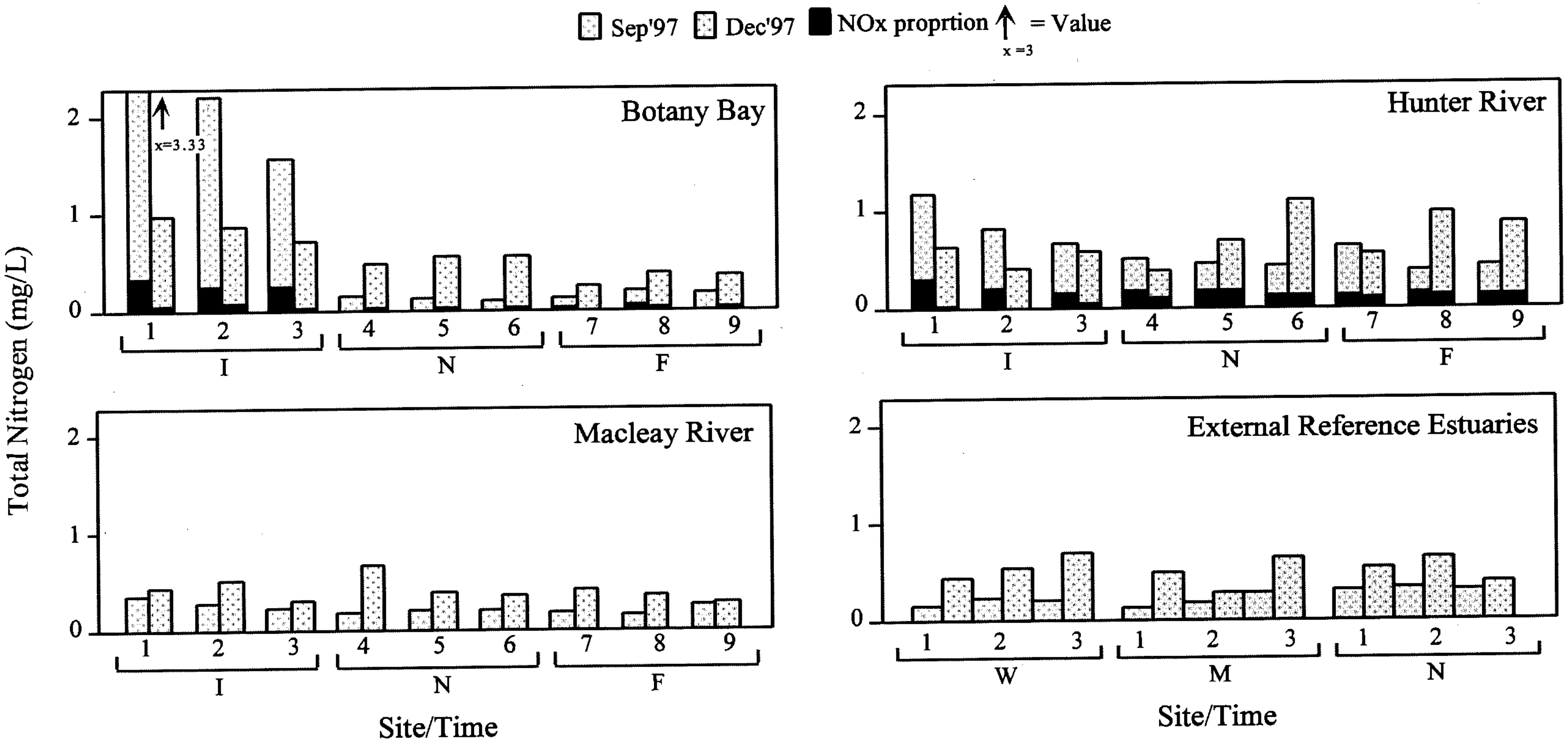

Figure A.8.4. Concentrations of total nitrogen (mg/L) and the proportion of nitrate/nitrite (NOx) at the sites within the impacted (I), near (N) and far reference (F) areas for each of the wetland estuaries and each of the external reference estuaries.

W = Wallamba R., M = Manning R., N = Nambucca R. Samples were collected during September and December 1997. For the samples collected in September and December AWT-EnSight laboratories calculated total kjeldahl nitrogen as the subtraction of NOx from total nitrogen (Metrix Method DW56)