CONTRIBUTION OF SALTMARSH TO TEMPERATE ESTUARINE FISH IN SOUTHEAST AUSTRALIA

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STATEMENT OF ORIGINALITY

The thesis contains no materials published elsewhere or extrated in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma. No other person's work has been used without due acknowledgment in the main text of the thesis. This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution. All research procedures reported in the thesis received the approval of the relevant Ethics/Safety Committees (where required).

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ABSTRACT

Saltmarsh is an important coastal habitat located in the littoral zone of estuaries. Australian saltmarsh area is decreasing due to agricultural and urban development and invasion by mangrove. The aim of the study was to assess the contribution made by saltmarsh as a habitat and a source of food items for fish. Three saltmarsh sites were studied, with Towra Point chosen as a site for detailed ecological study. When corrected for water volume, fish densities were found to be higher within the saltmarsh compared to the adjacent mangrove. Although the fish assemblages in saltmarshes differed significantly from mangroves the overall ratio between commercially and ecologically valuable species in these habitats are similar, a result suggesting the importance of temperate saltmarsh as habitat for economically important fish. Significant export of crab larva from saltmarsh (average crab larval abundance 2124.63 m^{-3} outgoing water) is a positive contribution to the estuarine food chain supplementing the nutritional requirements of estuarine fish. While the diet of the crabs producing this larvae seems dependant on the saltmarsh environment (given the contrasting isotopic signatures of *Sesarma erythrodactyla* in saltmarsh and mangrove, and the similarity of isotopic signatures in the saltmarsh for *Sesarma erythrodactyla* and *Helograpsus haswellianus*), the crabs do not seem to be dependent on any of the common species of saltmarsh plant, but rather depend on particulate organic matter (POM) derived from local and other sources. Crab larva are a prey item for many estuarine fish, including commercially important species, as evidenced by gut content analysis of fish visiting the saltmarsh flats during spring tides. The results strongly suggest that emphasis be given to ecosystem-based management for an estuary rather than component (e.g., vegetation) based managed as defined by the Fisheries Management Act (1994) and the State Environmental Planning Policy 14.

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CHAPTER ONE

INTRODUCTION

1.1 Estuaries

Estuaries are nursery habitats for many species of fish, prawn and crabs (Blaber 2000). Some species spend the majority of their life in the estuary, some move regularly into estuaries and others are short-term visitors from the inshore marine water. The abundance of animals in estuaries is linked to the quantity and quality of primary productivity, the spatial coverage of various substrates and the availability of habitats. The number of species in an estuary is influenced by salinity (Jones 1988), the variety and area of habitats (MacIntyre 1959, Jones *et al*. 1986), food, shelter and protection from predators (Blaber & Blaber 1980, Pollard 1984, Bell and Worthington 1992, Gray *et al*. 1996). Saltmarsh and mangrove vegetation occupies the intertidal and supratidal zones of fluvial and tidal delta environments of the estuary (West *et al.* 1985) and contributes to the productivity through production of organic matter, shelter for small fish, crustaceans and molluscs and the stabilization of sediments (Roy *et al*. 2001).

1.1.1 Estuaries in New South Wales.

Roy *et al*. (2001) classified estuaries in New South Wales into the following five categories. Category 1 comprises semi-enclosed bays that are characterized by marine water with little fresh water inflow. They are transitional between true estuarine environments and the coasts. Category 2 consists of tide-dominated estuaries having the largest entrances and tidal ranges similar to the open ocean. This category includes estuaries in microtidal areas where tides are locally more important than waves, and drowned river valleys with open access to the sea. Category 3 consists of wave-dominated estuaries having tidal inlets which are constricted by wave-deposited beach sand and flood-tidal deltas that are commonly smaller than those in tide dominated estuaries. Category 4 refers to those coastal water bodies that, for a combination of climatic and other reasons, become isolated from the sea for extended periods of time. Category 5 are Freshwater bodies. Estuarine zonations (Table 1.1) are also another important attribute which influences the abundance and diversity of fish in the estuary.

Table 1.1. Estuary zonation on the basis of depositional sedimentary environments (from Roy *et al*. 2001, Roy 1984, Roy and Boyd 1996)

Main depositional environments	**Sub-environments/habitats**	**Hydrological zones and substrate types (Source: Rochford 1951)**
Marine tidal delta	Rocky shoreline and rock reefs, tidal channels, tidal banks, tidal flats, delta front slope, back barrier sand flat,	Marine (Vegetated and unvegetated sand and muddy rocks)
Central mud basin	Rocky shoreline zone, basin floor, shell biotherms	Tidal (Unvegetated muds, sandy muds and muddy sands, vegetated rocks)
Fluvial delta	Levees, distributary channels, mid-channel shoals, delta mouth bar, crevasse splays, delta top and delta front, interdistributary bays	Gradient (Vegetated and unvegetated, sandy muds, muddy sands and sands)
Riverine channel and alluvial plain	Riverine channel, point bars, mid-channel bars, eroding banks, levees, floodplain, backswamp	Freshwater (Unvegetated sands, gravelly sands and mudy sands)

Geomorphologic factors, such as entrance conditions of an estuary, potentially control not only water exchange regimes between the ocean and estuary, but also the access and movement of fauna, especially migrant and transient species (Robinson *et al*. 1983, Potter and Hyndes 1994, 1999, Hannan & Williams 1998, Pease 1999, Griffiths and West 1999). The entrance conditions are in turn controlled by estuarine type and maturity (Roy *et al*. 2001). Larger, more open estuaries have a greater diversity of fish than smaller Category 4 estuaries (Pease 1999).

1.2 Saltmarsh and mangrove

Saltmarshes are the intermediate buffer zone between land and sea, and are located in the upper littoral zone of estuaries. One of the major characteristics of this habitat is that it is vegetated, but not forested, and inundated only by spring high tides. In the Sydney region, saltmarsh is generally only partially flooded by tides exceeding 1.2 m, and requires tide heights greater than 1.6 m for complete flooding (Clarke and Hannon, 1969). Saltmarshes are considered to be important coastal habitats because of their role in filtering surface water prior to entering the sea and their contribution to coastal productivity (Morrisey 1995). Saltmarshes are widely recognised as playing a major role in (1) coastal defense, (2) in wildlife conservation (3) and for being a key source of organic material and nutrients for a wide range of marine communities (Boorman 1999). One of the major differences between Australian and Northern Hemisphere saltmarshes is that the former typically occur landward of mangrove forests, high in the intertidal zone, and have considerably shorter and less frequent inundation periods (Thomas and Connolly 2001).

Mangroves, on the other hand, consist of trees and shrubs inhabiting the intertidal areas of rivers and bays and in temperate Australia are generally inundated twice daily (Hutchings and Saenger 1987). Mangrove forests are considered to be one of the most productive coastal ecosystems (Shelske & Odum 1961, Lear & Turner 1977, Bunt *et al*. 1979, Boto & Bunt 1981, Duke 1982, Boto *et al*. 1984, Robertson *et al*. 1988).

1.2.1 Significance of saltmarsh and mangrove for fish

Habitat for nekton

Saltmarshes of Europe and North America have been extensively studied for their ecological role, and the significance of saltmarsh contribution to fish diet and habitat has been widely demonstrated (Daiber 1977, Talbot and Able 1984, Kneib and Wagner 1994, Costa *et al*. 1994, 1995). It is not possible to conclude from these studies, however, that saltmarshes in temperate Australia perform a similar role. Only a few studies have been conducted in Australia demonstrating the presence of fish in the saltmarsh creeks (Gibbs 1986, Morton *et al.* 1987, Davis 1988), semi-permanent saltmarsh pools (Morton *et al*. 1988), and saltmarsh flats inundated at high tide (Connolly *et al*. 1997, Thomas and Connolly 2001). None of these studies compared the assemblages of the fish community with the adjacent inter-tidal habitats, nor did they demonstrate a trophic link between visiting fish and saltmarsh. Indeed, Adam (1990) and Morrisey (1995) report that very little is known about species visiting saltmarshes.

By way of contrast, considerable evidence internationally has revealed the importance of mangroves as a habitat for fish, prawn and crabs (Austin 1971, Little *et al*. 1988, Weinstein & Heck 1979, Baelde 1990, Chong *et al*. 1990, Tzeng & Wang 1992, Sedberry & Carter 1993, Nagelkerken *et al*. 2000) source of food (Odum & Heald 1972, Carr & Adams 1973, Ogden & Zieman 1977, Branch & Grindley 1979, Claridge *et al*. 1986, Thayer *et al*. 1987, Sasekumar *et al*. 1992). Primavera (1997) stated that mangrove pneumatophores prevent predation by some species. Acosta and Butler (1997) found that the survival of tethered spiny lobster was greater among mangrove prop roots than in seagrass or coral habitats. A higher density of juvenile shrimp, prawns, crabs and fishes were found in mangrove habitats than elsewhere (Kathiresan and Bingham 2001). Beck *et al*. (2001) described mangrove forest as juvenile fish habitat due to its contribution to the productivity of adults per uint area of juveniles while comparing with several different coastal habitats.

Studies conducted in Australia similarly suggested a role for the Australian mangrove as a habitat and source of food for nekton species (SPCC 1981, Robertson and Duke 1990,

Pollard and Hannan 1994, Laegdsgaard and Johnson 1995). Juveniles of commercially-important species use mangrove creeks as nursery habitat Bell *at al*. (1984) in temperate Australia, Laegdsgaard and Johnson (1995) in sub-tropical Queensland and Robertson and Duke (1987) in tropical Queensland. The habitat functions of sub-tropical mangrove both for feeding and as a nursery have been demonstrated by Morton (1990) who studied adult fishes, most of which were of direct economic importance. The mangrove forest and associated water system including creeks and gutters is of importance for the production of banana prawn *Penaeus merguiensis* in Northern Australia (Vance *et al*. 1990). Vance *et al*. (1996) noted that mangrove prop roots prevented large predatory fishes from penetrating distances beyond 26 m into the flooded forest The complex structure of mangrove provides maximum food availability and minimises the incidence of predation in Moreton Bay, Southeast Queensland (Laegdsgaard and Johnson 2001).

Contribution to the estuarine water

Overseas studies found that temperate saltmarsh exported detritus to coastal waters (Nixon 1980, Dame *et al*. 1986) and were a source of organic matter and nutrients for adjacent habitats (Odum 1961, Teal 1962, Mitsch and Gosselink 1986, Lefeuvre and Dame 1994). In reviewing the contribution of saltmarsh, Boesch and Turner (1984) concluded that saltmarsh detritus may not substantially important for the production of fishery species because of its poor nutritive value.

Mangrove litter, including particulate organic materials (Boto and Bunt 1981, Robertson *et al*. 1988, Alongi *et al*. 1989, Robertson 1986, Lee, 1998) are also exported from mangrove to adjacent coastal waters and are thought to contribute to coastal productivity. The work of Dittel and Epifanio (1990) and Dittel *et al*. (1991) in Costa Rica suggested that the export of crab zoea from mangrove to estuarine water was a significant source of organic carbon, though again, overseas studies are not necessarily applicable to Australian mangroves.

It is hypothesize that the temperate saltmarsh flats in Australia perform a habitat role for

nekton species and also export zooplankton in the form of animal larvae, which may contribute to the estuarine productivity and the diet of fish. The role of this potential source of zooplankton export from saltmarsh to the consumer estuarine fish species has not been elucidated in the temperate Australian situation. Furthermore the question remains as to whether estuarine fish require tidally bourn material from the saltmarshes. It is important to determine whether there is a substantial contribution made by temperate saltmarshes to the estuarine productivity, as well as to the diet of nekton.

1.2.2 Status of saltmarsh and mangrove wetlands

The saltmarsh area in Australia is declining for a variety development activities. Examples include the construction of Brisbane Airport (Hyland and Butler 1988), construction of flood-gates at Throsby Creek (Williams *et al*. 1999) and Ironbark Creek (Morrison 2001) on the Hunter River and development works within Port Jackson (Thorogood 1985). In addition, there has been widespread invasion of saltmarsh by mangrove (Saintilan and Williams 2000, Wilton 2002). A review of 29 photogrammetric surveys covering over 20 estuaries in Queensland, New South Wales, Victoria and South Australia showed an increase in the area of mangroves and a corresponding decrease in the saltmarsh habitat (Saintilan and Williams 1999, 2000; Table 1.2). In most of the twenty-seven estuaries studied in southern Australia, 20-50% of the saltmarsh area has been lost since the 1940s. These impacts have placed heightened pressure on saltmarshes already impacted by agricultural and urban developments (Kratochvil *et al*. 1972, Saenger *et al*. 1977, Zann 1997, Finlayson and Rea 1999). Saltmarshes have also been neglected by the State legislation including State Environmental and Planning Policy (SEPP) 14, which fails to protect saltmarshes in the Sydney metropolitan region where the impacts are greatest, and the Fishery Management Act (1994) which protects mangroves to the mean high water mark. Because one of the principal sources of saltmarsh loss has been their replacement by mangroves, it is important to distinguish the relative contribution of saltmarsh and mangrove to estuarine fish.

Table 1.2. Summarised results of losses of saltmarsh in southeastern Australian estuaries (from Saintilan and Williams 2001)

Location	Saltmarsh lost (% unless specified)	Period	Source
Qeensland			
Hinchinbrook Channel	78 (saltpan)	1943-1991	Ebert 1995
Oyster Point	75 (saltpan)	1944-1983	MacTainsh *et al*. 1988
Moreton Bay	65 hectares	1944-1988	Morton 1994
Coolangatta-Caloundra	11	1974-1987	Hyland & Butler 1988
New South Wales			
Tweed River	72	1947-1986	West 1993
	local increase	1930-1994	Saintilan 1998
Clarence River	15	1942-1986	West 1993
Macleay River	reduced	1956-1980	Middleton *et a*l. 1985
	35	1942-1986	West 1993
Hunter River (excluding Hexham)	67	1954-1994	Williams *et al*. 1999
Lake Macquarie	25	1954-1986	Winning 1990
Berowra-Marramarra Creek	25	1941-1994	Williams & Watford 1997
Careel Bay	92	1938-1994	Wilton 1997
Couranga Pt., Hawkesbury River	30	1954-1994	Saintilan & Hashimoto 1998
Lane Cove River	not specified	1930-1986	McLoughlin 1987
Homebush Bay Parramatta River	>80	1930-1983	Clark &Benson 1988
Quibary Bay, Botany Bay	70	1950-1997	Evans 1997
Weeney Bay, Botany Bay	100	1950-1994	Fenech 1994
Woolaware Bay, Botany Bay	63	1950-1994	Fenech 1994, Hughes 1998
Towra Point, Botany Bay	30	1942-1997	Mitchell & Adam 1989
Minnamurra River	49	1938-1997	Chafer 1998a
Comerong Island, Shoalhaven River	increase	1949-1996	Chafer 1998b
Currembene Creek	14 hectares	1944-1989	CSIRO 1994
Merimbula Lake	40	1948-1994	Meehan 1997
Pambula Lake	40	1948-1994	Meehan 1997
Victoria			
Corner Inlet	extensive	1941-1985	Vanderzee 1988
South Australia			
Gulf St Vincent	865 hectares	1935-1979	Burton 1982 Fotheringham 1994

1.3 Framework of investigation

An understanding of ecological significance requires a formal procedure of investigation. The present work is designed to investigate the relative importance of saltmarsh and mangrove wetlands for estuarine fish in a temperate situation. Several observations including crab and fish assemblages in saltmarsh and mangrove, larval export from saltmarsh and trophic interaction between saltmarsh and nekton were performed in this study. Each observation was based on testable hypotheses. Models are formulated (i.e., potential explanation of these observations) on the basis of these observations and predictions were made based on potential explanations.

1.4 Outline of the thesis

The main objective of the project was to examine the relative contribution of saltmarshes to estuarine fish in temperate situations with an aim to determine one aspect of the conservation value of rapidly declining saltmarshes in southeast Australia.

This thesis consists of seven main sections. Chapter 2 describes and compares fish sampling techniques in a shallow vegetated saltmarsh environment. Chapter 3 tests the model of temporal variation of fish abundance in saltmarsh and mangrove flats at Towra Point, using buoyant pop nets. Chapter 4 describes the spatial variability of fish assemblages within three geographically distinct saltmarshes and mangroves in Sydney region. Burrowing crab assemblages in saltmarshes and mangroves and the variability of burrowing crabs within the different saltmarsh vegetation communities were examined in Chapter 5. Chapter 6 investigates the contribution of crabs and gastropods to estuarine productivity by examining the inputs and outputs of zooplankton in saltmarsh and mangrove habitats. Chapter 7 investigates the often-asked question about whether fish visit saltmarshes for food. A Gut content analysis was utilized to determine the diet of itinerant fish in this habitat. The trophic links between resident crabs and saltmarsh and mangrove vegetation was also explored in this chapter. Finally, Chapter 8 synthesizes the main findings of the study and considers their implications for the management of estuaries.

CHAPTER TWO

COMPARISONS OF FISH CATCHES USING FYKE NETS AND BUOYANT POP NETS

2.1 Summary

The selection of appropriate sampling methods is a prerequisite for the proper design of surves detailing nekton assemblages. In the present study, two commonly used saltmarsh fish sampling methods, the fyke net and the buoyant pop net, were used to compare the assemblages of fish caught in a saltmarsh flat during monthly spring tides over a twelve month period. Both nets were made of 2 mm mesh. A total of 3514 fish and crustaceans of 21 species were captured by 48 fyke net sets and 818 fish of 16 species were captured by 48 pop net releases. Fyke and pop nets recorded significantly different (ANOSIM: $P<0.001$) assemblages, with a higher proportions of *Pseudomugil signifer* caught in the fyke nets and *Ambassis jacksoniensis* in the pop nets. Five species, *Sillago cilliata*, *Rhabdosargus sarba*, *Redigobius macrostoma*, *Taeniodes mordax* and *Metapenaeus macleayi*, were caught in the fyke nets only. Significance differences in the size of fish caught were recorded for two species, *Gobiopterus semivestitus* and *Gerres subfasciatus*, with larger fish, on average, caught in the pop nets. These results suggeste that pop nets are less efficient at catching smaller fish than are fyke nets.

2.2 Introduction

The development of suitable methods for the sampling of nekton in saltmarshes is complicated by the infrequent and relatively short periods of inundation. Further, conventional methods of sampling such as trawling are often not practicable due to the shallow water depths. In the Sydney region, spring tides heights of greater than 1.6 m are required to flood a saltmarsh (Clarke & Hannon, 1969), where the maximum spring tidal height is approximately 2 m. The exact extent of tidal inundation in any given saltmarsh will depend on the local topography and climatic conditions.

Studies conducted to date in Australia and overseas have used hand trawling (Gibbs 1986), fyke nets (Morton *et al*., 1987, Williams *et al*. 1996), block nets (Hettler 1989), lift nets (Rozas 1992), pop nets (Michel *et al*. 1989 Connolly et al. 1994), traps (Smith & Able 1994) and poisoning (Gibbs 1986) to collect fish from saltmarshes. The multiplicity of methods used makes regional and local comparisons difficult. Analogous studies in seagrass habitat suggest that contrasting results can be achieved using to different of methods. Sometimes fish assemblages collected from the same meadow of seagrass using two different methods (such as poisoning and trawling) can be more different than assemblages collected from different meadows with the same method (Gray and Bell 1986). Connolly (1994) found pop nets caught more fish than seine nets in a shallow seagrass habitat.

The present study simultaneously employed two commonly used saltmarsh fish sampling methods, fyke nets (Morton *et al*. 1987; Williams *et al*. 1996) and buoyant pop nets (Michel *et al*. 1989; Connolly *et al*. 1994) over 12 months to compare the assemblages caught. The aim of the study was to determine whether fyke and pop nets employed in the same environment yielded comparable results.

2.3 Study site and methods

The study was conducted on saltmarsh flats of Towra Point, within Botany Bay (Figure 2.1). The saltmarsh of Towra Point consists of two vegetation communities. The lower saltmarsh is dominated by *Sarcocornia quinqueflora* with *Sporobolus virginicus*, *Triglochin striata*, and *Suaeda australis* also present. *Juncus krausii* is the dominant species at higher elevations (Clarke & Hannon, 1967; Adam *et al*. 1988). The saltmarsh is flooded by spring tides through breaks in a levee bank which forms a boundary between the mangrove and saltmarsh habitats along most of the Woolooware Bay side of the wetland.

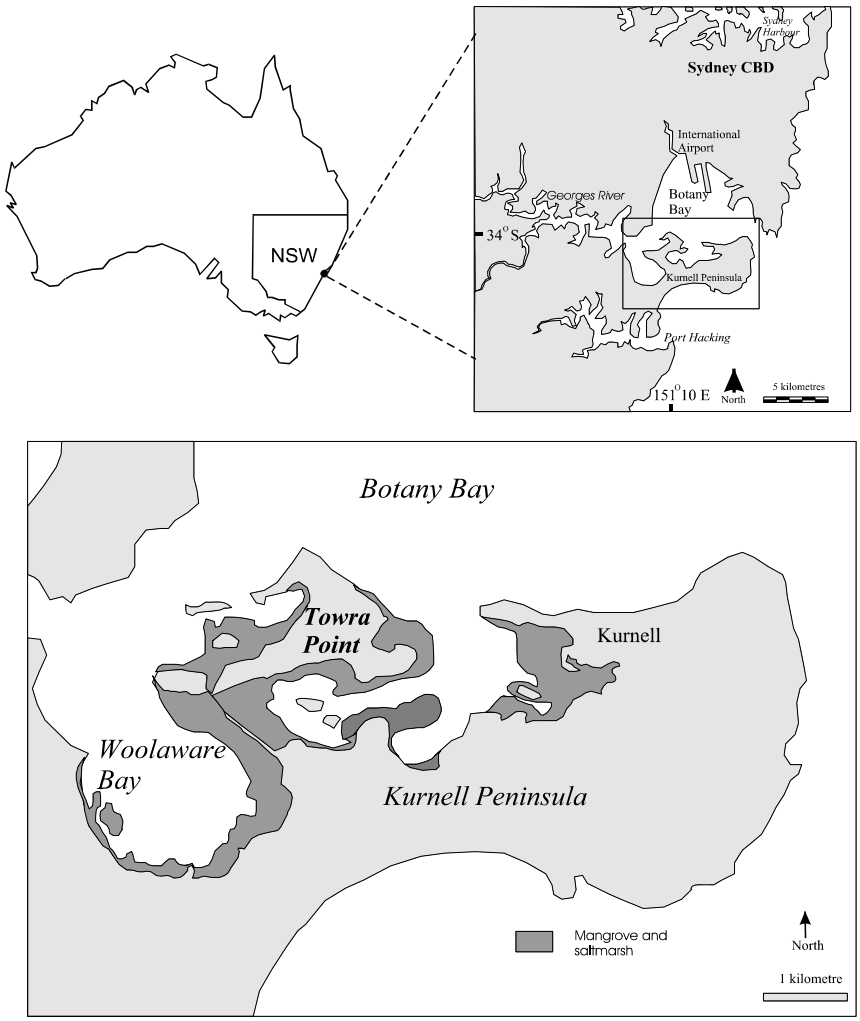


Figure 2.1 Location of Towra Point, Botany Bay showing the distribution of mangrove and saltmarsh.

2.3.1 Fyke net design and installation

The fyke net (Morton *et al*. 1987, Williams *et al*. 1996) consists of a 4 m long funnel-shaped net with one central and two lateral wings and a 400 mm wide and 250 mm high entrance. Mesh size throughout was 2 mm. The net was secured in place by six large wooden stakes at its extremities; a metal plate kept the base of the entrance flush with the substrate. Where needed, small metal pegs were also placed to keep the entrance funnel and wings tight against the substrate. The wings had floats and leads along their tops and bottoms, respectively, to keep them upright (Figure 2.2). Four fyke nets were placed randomly in the lower saltmarsh zone, with openings facing the saltmarsh. Nets were positioned immediately before the flooding of the saltmarsh. Fish were collected from the fyke nets immediately after tide water had fully receded.

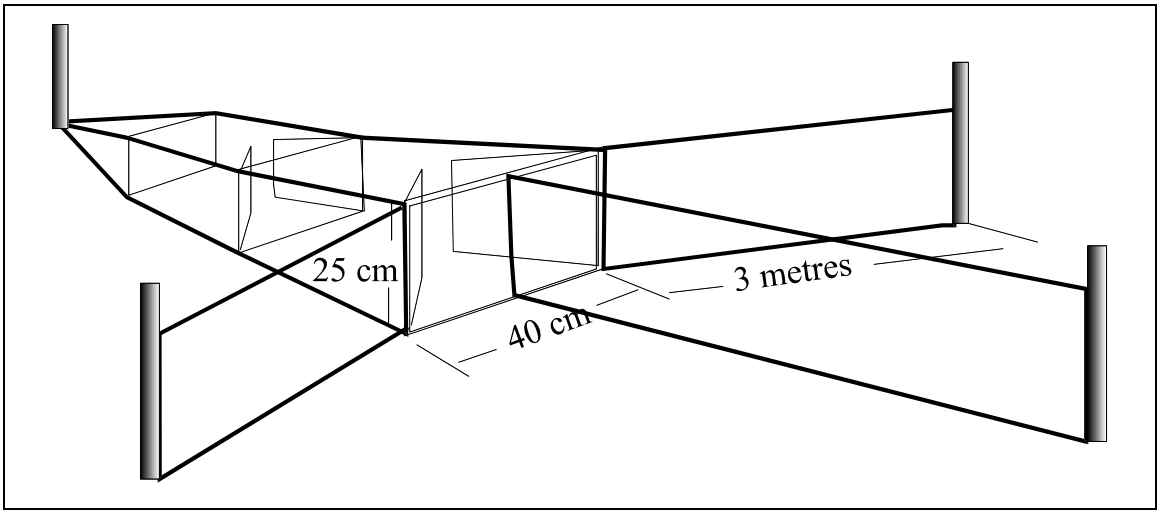


Figure 2.2 Design of the fyke net

2.3.2 Pop net design and installation

The pop net (after Michel *et al*. 1989, and Connolly *et al*. 1994) was made of 2 mm nylon mesh and were 5.5 X 5.5 m square, elevating when fully extended to a maximum height of 1.5 m. The top of the mesh was attached to 20 mm diameter PVC pipe, sealed for floatation. The base of the net was secured tightly to the marsh surface with tent pegs,

with the nets hidden prior to release inside shallow trenches, which were dug two months prior to the beginning of the experiment. Nets were weighed down with four concrete blocks attached by a nylon rope to a remote point 50 m from the nets (Figure 2.3), and released from this remote point at the peak of the tide. Nektons trapped inside were collected using a large sweeping hand net. Four replicate pop nets were placed randomly in the lower (*Sporobolus/Sarcocornia* dominated) segment of the saltmarsh.

Fyke and pop nets were deployed simultaneously during spring high tides (>1.8m) from March 2001 to February 2002 in every month when the saltmarsh flats were inundated by tidal water. Captured individuals were preserved with 10% formaldehyde solution for species identification, enumeration and length measurement. The total length (point of snout to the end of the tail) of fish and crustaceans was measured for *Ambassis jacksoniensis*, *Pseudomugil signifer*, *Gobiopterus semivestitus*, *Mugilogobius stigmaticus*, *Gerres subfasciatus*, *Acanthopagrus australis* and *Macrobrachium intermedium* the most common species caught.

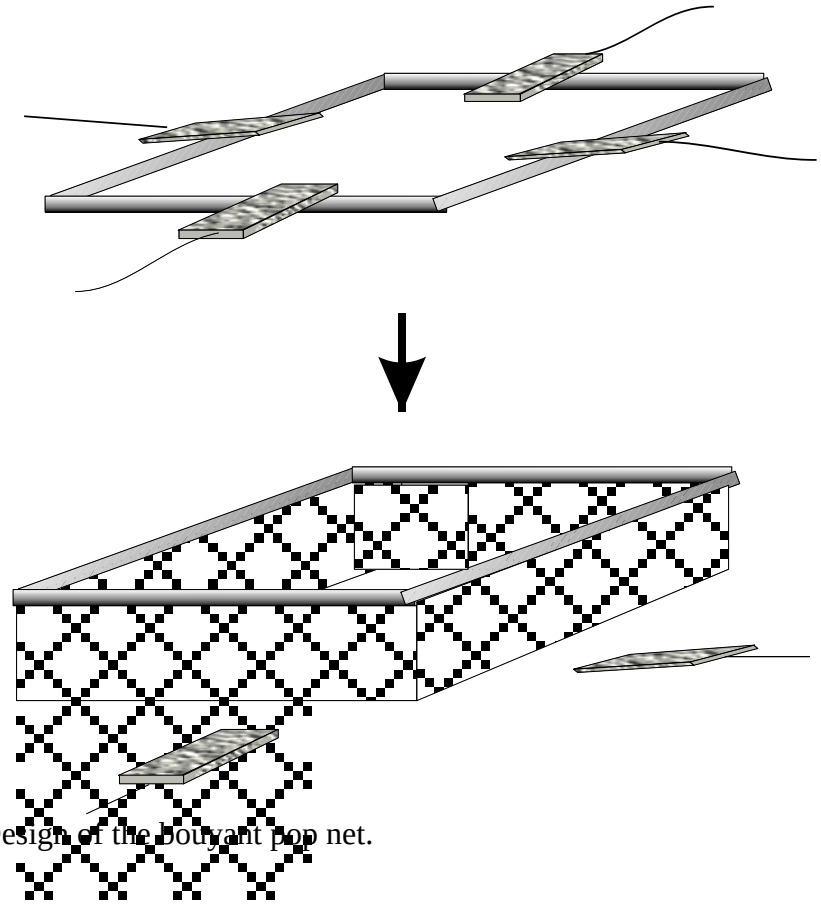


Figure 2.3 Design of the buoyant pop net.

2.3.3 Data analysis

Differences in composition of fish captured by fyke and pop nets were examined using Bray-Curtis measures of dissimilarity (Bray & Curtis 1957) with square root transformed data. Non-metric multidimensional scaling (nMDS) plots were constructed to demonstrate the patterns of fish community in different nets (Clarke & Warrick 2001). Multivariate techniques such as ANOSIM (Clarke & Warrick 2001) were used to test the statistical significance of differences between the fish community in fyke and pop nets. Univariate analysis (ANOVA) and *post-hoc* Student-Newmans-Kuels (SNK) tests were performed using GMAV5 (Underwood & Chapman 1989) to determine the significance of differences between net types for the numbers of individuals caught and the size of individuals for the most commonly caught species. Data was tested for homogeneity of variance using Cochran's test and transformed where appropriate.

2.4 Results

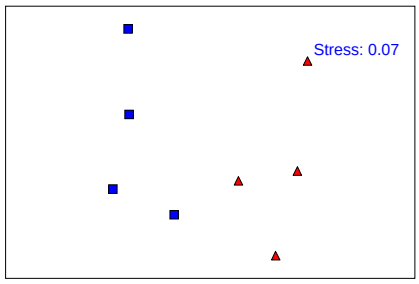
A total of 3512 fish and crustaceans comprising 21 species were caught by fyke nets, of which *Pseudomugil signifer* was most abundant (25.2%), followed by *Macrobrachium intermedium (23.6%), Ambassis jacksoniensis* (10.8%), *Gobiopterus semivestitus* (8.9%) and *Mugilogobius stigmaticus* (8.9%). Of the 818 fish of 16 species caught by pop nets, *A. jacksoniensis* was most abundant (43.03%), followed by *G. semivestitus* (18.7%) and *P. signifer* (9.3%) (Table 2.1). Five species were caught by fyke nets only, these being *Sillago cilliata*, *Rhabdosargus sarba, Redigobius macrostoma, Taenioides mordax*, and *Metapenaeus macleayi*. No species were caught in the pop nets that were not also caught in the fyke nets.

Table 2.1 Species caught from saltmarsh with fyke and pop nets at Towra Point, 2001–2002. The asterisk (*) designates species of commercial and or recreational fisheries significance.

Family	Genus/species	Common name	Fyke net		Pop net	
			No. of fish	% of total	No. of fish	% of total
Fish						
Atherinidae	*Pseudomugil signifer*	Blue eye	887	25.24	76	9.29
Gobiidae	*Pseudogobius olorum*	Blue spot goby	87	2.48	49	5.99
Gobiidae	*Mugilogobius stigmaticus*	Checkered mangrove goby	315	8.96	10	1.22
Tetraodontidae	T*etractenos hamiltoni*	Common toad	30	0.85	6	0.73
Platycephalidae	*Platycephalus fuscus*	Dusky flathead *	80	2.28	9	1.10
Mugilidae	*Liza argenta*	Flat tail mullet *	32	0.91	5	0.61
Gobiidae	*Gobiopterus semivestitus*	Glass goby	316	8.99	153	18.70
Chandidae	*Ambassis jacksoniensis*	Glassfish	378	10.76	352	43.03
Gobiidae	*Redigobius macrostoma*	Largemouth goby	12	0.34	0	0.00
Gobiidae	*Mugilogobius paludis*	Mangrove goby	58	1.65	14	1.71
Poeciliidae	*Gambusia holbrooki*	Mosquito fish	68	1.94	1	0.12
Mugilidae	*Myxus elongatus*	Sand mullet *	54	1.54	5	0.61
Sillaginidae	*Sillago clliata*	Sand whiting *	11	0.31	0	0.00
Mugilidae	*Mugil cephalus*	Sea mullet *	14	0.04	3	0.37
Gerreidae	*Gerres subfasciatus*	Silver biddy *	153	4.35	54	6.60
Gobiidae	*Taenioides mordax*	Snake head goby	6	0.17	0	0.00
Sparidae	*Rhabdosargus sarba*	Tarwhine *	1	0.03	0	0.00
		Unidentified fish	26	0.74	8	0.98
Sparidae	*Acanthopagrus australis*	Yellow fin bream *	103	2.93	21	2.57
Crustacean						
Atyidae	*Macrobrachium intermedium*	Grass shrimp	828	23.56	52	6.36
Penaeidae	*Metapenaeus macleayi*	School prawn *	55	1.57	0	0.00
Total no. of fish and crustacean			3514		818	
Total no. of species			21		16	
Total no. of species of commercial/recreational significance			9		6	

Non-metric multidimensional scaling (nMDS) ordinations showed different assemblages of fish caught in fyke and pop nets in all months except May 2001 (ANOSIM: P= 0.067), July 2001 (ANOSIM: P=0.1), August 2001 (ANOSIM: P=0.229) and January 2002 (ANOSIM: P=0.114) where assemblages of fish captured by fyke nets and pop nets were similar (Figure 2. 4). Overall, the analysis of similarities suggested a significant difference (ANOSIM: P<0.001) between fyke and pop nets assemblages of catch (Appendix 1.1).

March 2001



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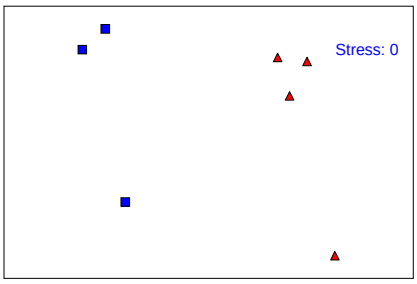

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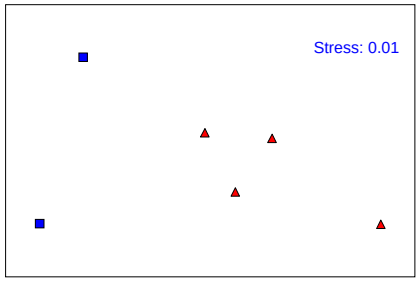

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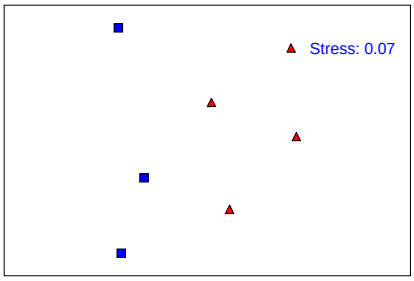

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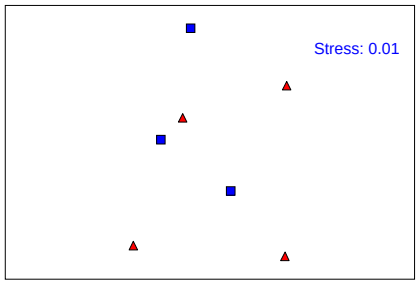

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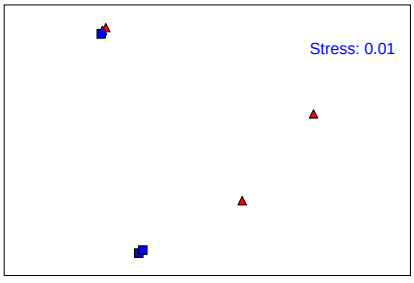

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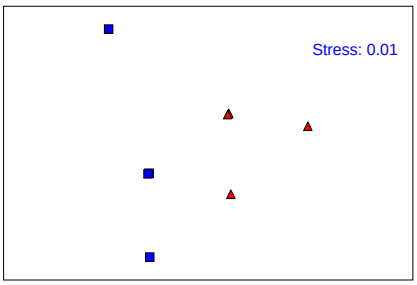

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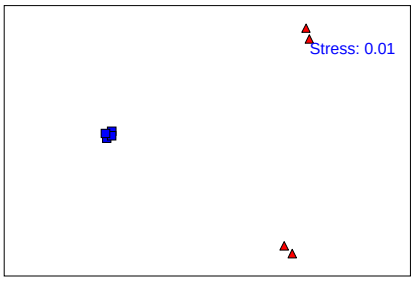

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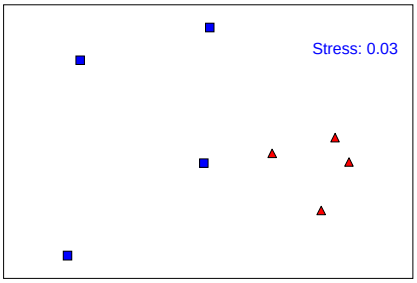

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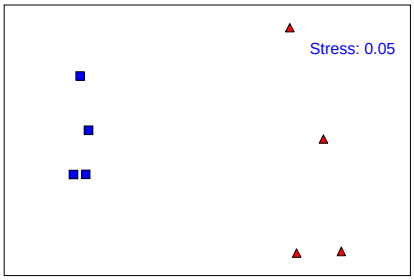
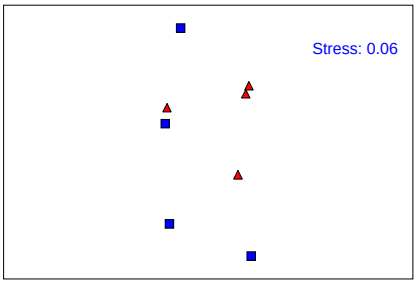
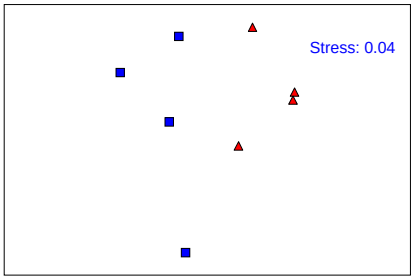


January 2002



February 2002



Fyke net Pop net

Figure 2.4 nMDS ordinations showing assemblages of fish caught in fyke and pop nets monthly, at Towra Point saltmarsh 2001-2002. Less than 4 pop nets results in some nMDS plots indicate no fish caught in some nets.

2.4.1 Comparison of abundances

In general, the analysis of variance (ANOVA) results for all species showed that the number of fish captured by the fyke nets (73.21 fish per fyke net) was significantly ($P<0.0001$) higher than the number of fish capture in pop nets (17.04 fish per pop net) (Table 2.2, Figure 2.5). Catch performance based on the most common species in both net types and showed that the fyke net catch was significantly higher than that of the pop net for *A. jacksoniensis*, ($P = 0.0105$), *P.signifer* ($P = 0.0002$), *M. stigmaticus* ($P = 0.0056$), *A. australis* ($P = 0.0153$) and *M. intermedium* ($P = 0.0010$). No significant difference was observed between the number of fish caught in fyke and pop nets *G. semivestitus* ($P = 0.1080$) and *G. subfasciatus* ($P = 0.0971$) (Appendix 1.2).

The fish density determined using the pop net was 0.56 fish m^{-2} of saltmarsh flat. It was not possible to calculate fish densities using the fyke net data set.

Table 2.2. ANOVAcomparison of catch of number of fish and crustaceans from fyke and pop nets in saltmarsh flats at Towra Point, Botany Bay, NSW.

Source of variation	DF	MS	F	P
Net	1	75712.666	27.69	0.0001
Residual	94	2734.764		
Total	95			

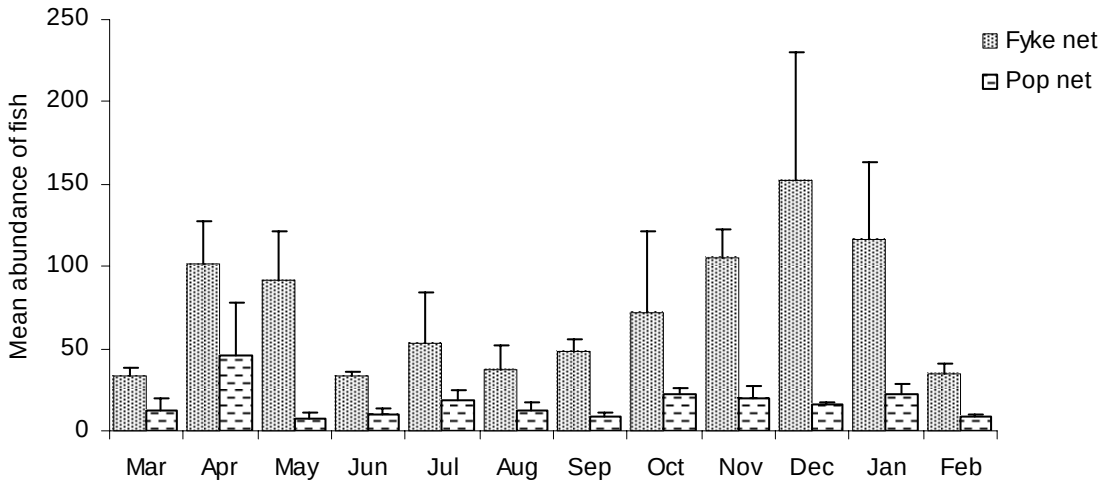


Figure 2.5 Mean number (+SE) of fish captured by fyke and pop nets through the year in saltmarsh flats at Towra Point, 2001-2002: n= 96.

2.4.2 Fish size difference between net types

Seven species, *A. jacksoniensis*, *P. signifer*, *G. semivestitus*, *M. stigmaticus*, *G. subfasciatus*, *A. australis* and *M. intermedium*, contributed 85% of the total catch in fyke nets, and 88% of the total catch in pop nets, respectively (Table 2 1). An analysis of variance (ANOVA) comparing the lengths of individuals of these species between net types demonstrated that significantly larger individuals of *G. semivestitus* ($P = 0.04$) and *G. subfasciatus* ($P = 0.03$) were retrieved from pop nets when compared with fyke nets (Figure 6). No significant size differences were observed between fyke and pop nets for individuals of *A. jacksoniensis*, *P. signifer*, *M. intermedium*, *M. stigmaticus* and *Acanthopagrus australis* (Figure 2.6) (Appendix 1.3).

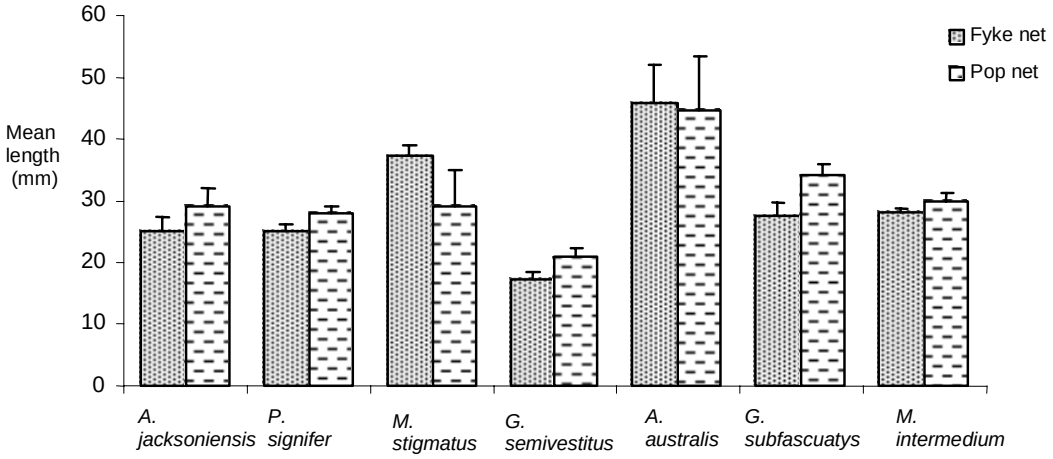


Figure 2.6 Mean length (mm) and standard errors (+SE) for most contributing species captured by fyke and pop nets at Towra Point saltmarsh, 2001-2002.

For the two species which showed differences in size between net types, *G. semivestitus* and *G. subfasciatus*, pop nets captured relatively higher number of *G. semivestitus* in the larger size range (21-25 mm) (Figure 2.7). Similarly, catches of *G. subfasciatus* were weighted toward the larger size categories in pop nets and the smaller size categories in the Fyke nets (Figure 2.8).

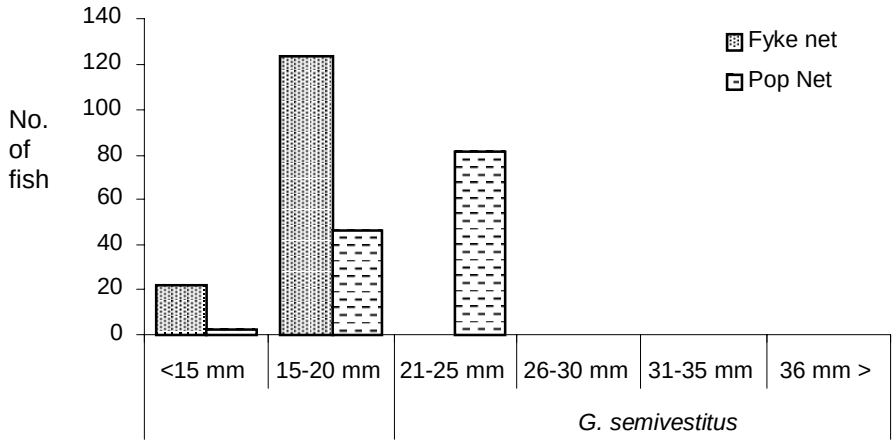


Figure 2.7 Size categories of glass goby (*Gobiopterus semivestus*) captured by fyke and pop nets at Towra Point saltmarsh, 2001-2002.

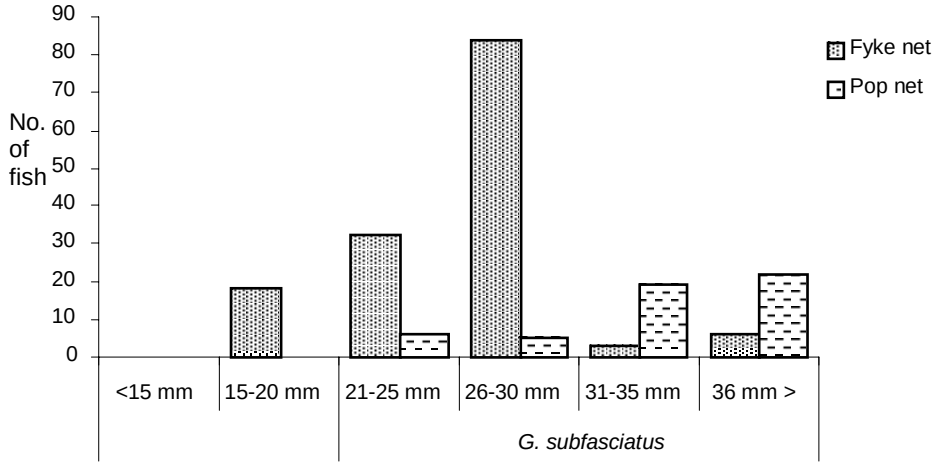


Figure 2.8 Number of fish in different size categories of silver biddy (*Gerres subfasciatus*) captured by fyke and pop nets at Towra Point saltmarsh, 2001-2002.

2.5 Discussion

Clearly, the two nets did not perform similarly. Differences were found relating to cost, ease of setting, the number of species captured and the efficiency of capturing smaller fish. Fyke nets had adventage of capturing nekton from all over the saltmarsh. Further, fyke nets could be positioned to capture fish from either the incoming or outgoing tide. On the contrary, pop nets only captured nekton at the peak of the tide when released. Therefore possibilities of capturing more fish and species are relatively high in fyke nets than pop nets. Pop nets had two advantages over fyke nets. Firstly, the catch of the pop net can be represented as a density on the basis of area, or volume of water, if the height of the tide at the time of release is measured. This facilitates comparisons between nets and localities in a way that is not possible for the fyke nets.

One limitation of the fyke nets employed in this study is that fish density could not be calculated from the catch data, because the volume of water moving through the net opening was not known, nor was the relationship between water volume passing the net

and catch efficiency. Fish may be attracted to the net or diverted from the net in a way that is not consistent with water flow volume even were it known.

However, there are a number of observations arising from the study that suggests that fyke nets are more efficient than pop nets in the survey of fish abundance and diversity in the saltmarsh. Firstly, in no case did the pop net capture a species not taken by the fyke net. Conversely, five species caught by the fyke nets (*Sillago clliata*, *Rhabdosargus sarba*, *Redigobius macrostoma*, *Taenioides mordax* and *Metapenaeus macleayi*) were not caught by the pop nets.

More telling is the differences between net types in the size of individuals caught for at least two species *G. semivestitus* and *G. subfasciatus*. The average size of fish retrieved from the pop nets was consistently larger than for fish caught in the fyke nets. Presuming the nets are sampling the same population, the result could suggest that smaller fish caught in the pop net were not retrieved. An analysis of size class distributions confirms this suggestion, because fish caught in the fyke net were smaller than those caught with pop-net.

Fyke nets were easier to install than pop nets and fish were more readily retrieved from inside the net. Installation of the pop nets was time consuming because of the necessity of preparing shallow trenches within which to hide the net. If ground disturbance during this process increased food availability, one might assume that numbers of fish taken by this method would be greater than the passive application of the fyke net. I suggest that the limitations in pop-net catch efficiency might be countered if the net was allowed a base, or a base inserted after release. The design of the fyke net might be improved with the installation of a flow meter which would allow one to standardize catch against water volume passing through the net. This might provide some opportunity for the comparison of catches between different nets and settings.

CHAPTER THREE

TEMPORAL VARIATIONS IN FISH CATCH USING POP NETS IN MANGROVE AND SALTMARSH

3.1 Summary

Fish assemblages utilising saltmarsh and mangrove during spring tides were surveyed over a 12-month period using buoyant pop nets. A total of 48 net releases in the saltmarsh identified 16 species, at an average density of 0.56 fish m^{-2}, with six species being of commercial importance. The same number of releases within the mangrove collected a total of 23 species at an average density of 0.76 fish m^{-2}. However, fish density 1.9 fish m^{-3} was higher within the saltmarsh than the adjacent mangrove when corrected for water volume. Multidimensional scaling revealed different assemblages of fish the in the two habitats, with higher numbers of *Ambassis jacksoniensis* and *Pseudomogil* sp. in the saltmarsh and higher numbers of *Mugilogobius* sp. and *Acanthopagrus australis* in the mangrove. These results suggest a potentially significant role for saltmarsh as a fish habitat in the estuaries of southeast Australia.

3.2 Introduction

Considerable evidence has demonstrated the association of mangrove and tidal creeks with juvenile fish and an inferred role of the former as nursery habitats in Australia (Gibbs 1985, Morton *et al*. 1988, Morton 1990, Saenger 1994, Blaber *et al*. 1995, Laegdsgaard and Johnson 1995, Halliday and Young 1996, Williams *et al*. 1996). These habitats provide a source of food for fish, prawns and crabs (Bell *et al*. 1984, Robertson and Duke 1987, 1990, Vance *et al*. 1990). In contrast, very little is known about the fish associated with Australian saltmarsh, which typically occurs landward of mangrove forests and higher in the inter-tidal zone, and consequently have shorter and less frequent periods of inundation (Thomas *et al*. 2001). To date most of our knowledge of fish communities in saltmarsh is gained from investigations in the USA and Europe (Connolly 1999).

Many of the saltmarsh investigations conducted in Australia have considered the presence of fish in creeks rather than on the flats. Studies have examined the abundance of juveniles of economically important species in tropical Australia (Davis 1988), in a tidal inlet adjacent to a saltmarsh in the subtropical region of southeast Queensland (Morton *et al*. 1987) and in a saltmarsh creek in Wallis Lake in temperate Australia (Gibbs 1986). When the flats *per se* were sampled, Connolly *et al*. (1997) recorded only 19 individuals from two species sampled from temperate saltmarsh in the Barker Inlet - Port River estuary, South Australia. Surveys from flats in subtropical Queensland provide a contrast, with 23 species taken during spring tides, with economically important species contributing substantially to the catch (Thomas and Connolly 2001). No studies have been reported between these latitudinal extremes for southeastern Australia.

In the present study I compared fish catch on saltmarsh flat and adjacent mangrove at Towra Point, Botany Bay. The study area is mid-way between the surveys of Connolly *et al.* (1997) and Thomas and Connolly (2001). The primary aim of the research was to test the assumption that mangroves support a higher species richness and abundance of nekton than do saltmarshes when both are flooded. This study is of additional significance in that the area of saltmarshes in New South Wales is in decline due to

encroachment by mangrove (Saintilan and Williams 1999, 2000). Saltmarsh is not protected under the Fisheries Management Act (1994), which protects mangrove to the mean high water mark.

3.3 Methods

3.3.1 Study site

The study compared temporal variations of nekton caught in mangrove and saltmarsh flats at the Towra Point Nature Reserve, in Botany Bay (Figure 3.1). The reserve is a relatively undisturbed sandy marine delta with mangrove forest dominated by *Avicennia marina* (McGuinness 1990). The lower saltmarsh is dominated by a *Sarcocornia quinqueflora/Sporobolus virginicus* association, with *Triglochin striata* growing in less well-drained positions. *Juncus krausii* and *Suaeda australis* are also present in higher elevation environments (Clarke & Hannon, 1967; Adam *et al*. 1988). The inundation of the saltmarsh occurs normally during Spring tides and sometimes when there are extended wet weather conditions. The marsh is inundated through breaks in a natural levee bank which creates a sharp boundary between the mangrove and saltmarsh along most of the Woolooware Bay side of the wetland.

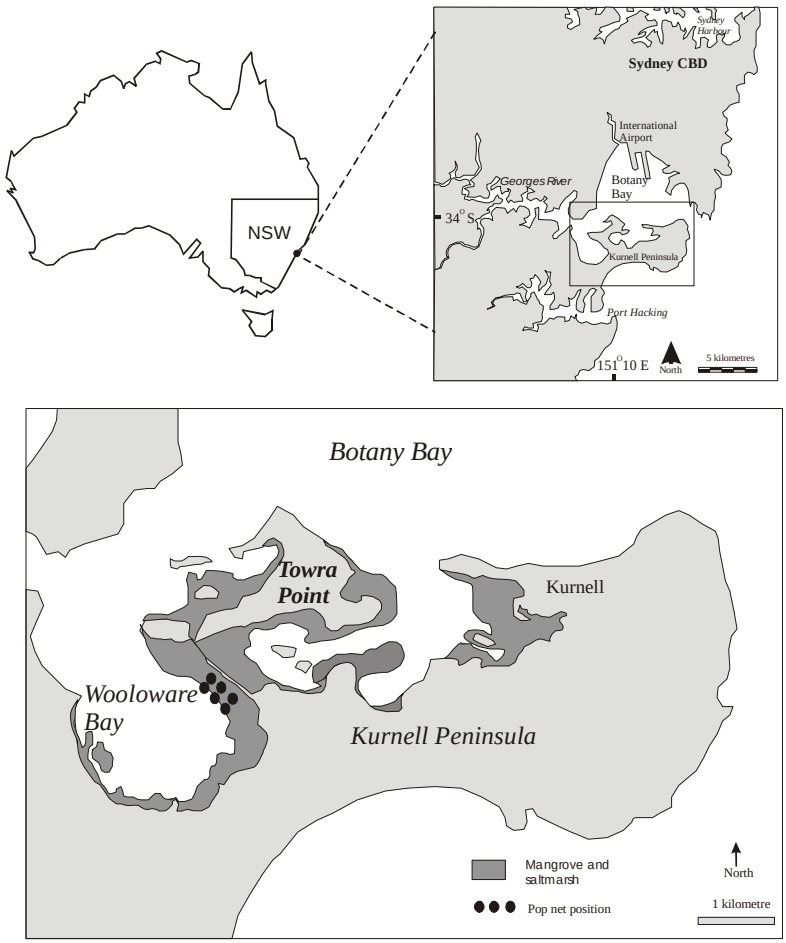


Figure 3.1 Map of Australia showing the location of study site, Towra Point, Botany Bay, Sydney, NSW

3.3.2 Fish collection

Buoyant pop nets (Michel *et al*. 1989; Connolly *et al*. 1994) were employed in the saltmarsh and adjacent mangrove flats to sample fish during the spring tide. The pop nets were identical to those described in chapter 2. Four replicate pop nets were set in saltmarsh and four replicate pop nets in the mangrove forest. Nets were placed randomly in the lower saltmarsh (*Sarcocornia/Sporobolus* zone), and randomly in the mangrove zone. Fish samples were collected monthly during spring high tides (>1.8m) from March 2001 to February 2002 when saltmarsh flats and mangroves were inundated by tidal water. Water temperature, tide height and time of sampling were recorded.

3.3.3 Statistical methods

Univariate analysis (ANOVA) and *post-hoc* Student-Newman-Kuels (SNK) tests were performed using GMAV5 (Underwood and Chapman 1989) to determine the significance of differences of fish abundance between saltmarsh and mangrove in different seasons. Data was tested for homogeneity of variance using Cochran's test and transformed where appropriate. A two-way analyses of variance were used (Underwood 1997) with season as the first factor with four levels (1= Autumn, 2= Winter, 3= Spring and 4= Summer) which were orthogonal and fixed. Habitat was considered as a second factor with two levels (1= saltmarsh and 2= mangrove) which were orthogonal and fixed. Margalef's index (d) d= (S-1)/Log(N) (Margalef 1969), where S is the total number of species and N is the total number of individuals used to determine species richness between and within habitats in different seasons. Margalef's index is used because of the high variability in individuals caught between samples.

Differences in assemblages of fish between saltmarsh and mangrove were examined using Bray-Curtis measures of dissimilarity (Bray and Curtis 1957) with square root transformed data. Nonmetric multidimensional scaling (nMDS) plots were also used to demonstrate the patterns of fish assemblages in different seasons between habitats (Clarke and Warrick 2001). Multivariate techniques such as ANOSIM (Clarke and Warrick 2001) were used to test the statistical significance of differences between the fish assemblages of habitats. The contribution made by particular species to differences in species assemblages was determined using SIMPER (similarity percentages-species contribution, Clarke and Warrick 2001) for habitats.

Links between environmental variables and fish assemblages in saltmarshes were explored using BIOENV (Clarke and Warrick 2001). Test for cyclicity in the distribution of monthly samples in mangrove and saltmarsh using the RELATE procedure in Primer Version 5 (Clarke and Warrick 2001).

3.4 Results

Twenty-six species of fish were caught at the study site. Sixteen species were from the saltmarsh and 25 species were from the mangrove (Table 3.1). *Ambassis jacksoniensis* was the most abundant species in the saltmarsh contributing 43.0% of the total catch by number, followed by *Gobiopterus semivestitus* (18.7%), *Pseudomugil signifer* (9.3%) and *Gerres subfasciatus* (6.6%). Six of the 16 species found in the saltmarsh were of commercial significance, whereas 12 of 25 species in the mangrove were of commercial significance. *A. jacksoniensis* was also the most abundant species in mangrove habitat and contributed 27.3% of the catch, followed by *Mugilogobius paludis* (19.5%), *G. subfasciatus* (10.1%) and *Taenioides mordax* (6.5%).

Seven species of fish (*A. jacksoniensis, P. signifer*, *G. semivestitus, M. stigmaticus, M. paludis*, *G. subfasciatus,* and *A. australis)* and one crustacean species, *Macrobrachium intermedium,* were found in saltmarsh and mangrove habitat through the year in varying abundances (Table 3.1). The abundances of these species were similar between environments.

Eight species of fish (*Pelates quadrilineatus*, *Sillago cilliata, Rhabdosargus sarba*, *Ammotretis rostratus*, *Girella tricuspidata*, *Redigobius macrostoma*, *Arenigobius bifrenatus* and *Taenioides mordax*), and two crustacean species (*Metapenaeus macleayi* and *Alpheus edwardsi*) were found only in mangrove over the twelve month sampling period (Table 3.1). Analysis of similarities (ANOSIM) for commercial species showed a significant difference (ANOSIM: P=0.01) between saltmarsh and mangrove habitats (Appendix 2.1).

Table 3.1. Species caught from saltmarsh and mangrove with pop nets at Towra Point 2001 –2002. The asterisk (*) designates species of commercial and or recreational significance.

Family	Genus/species	Common name	% contribution to catch									
			Autumn (March-May)		Winter (June-August)		Spring (Sept. – Nov.)		Summer (Dec.-Feb.)		All season	
			Saltm.	Mang.	Saltm.	Mang.	Saltm.	Mang.	Saltm.	Mang.	Saltm.	Mang.
Finfish												
Atherinidae	*Pseudomugil signifer*	Blue eye	8.40	0.00	25.45	4.35	4.41	3.55	1.60	1.90	9.29	2.33
Gobiidae	*Pseudogobius olorum*	Blue spot goby	0.00	0.00	0.00	10.14	0.98	4.86	25.13	7.58	5.99	4.38
Gobiidae	*Arenigobius bifrenatus*	Bridled goby	0.00	0.99	0.00	0.00	0.00	0.00	0.00	1.90	0.00	0.63
Gobiidae	*Mugilogobius stigmaticus*	Checkered mangrove goby	0.38	8.91	1.82	10.14	0.98	0.00	2.14	12.80	1.22	5.46
Tetraodontidae	*Tetractenos hamiltoni*	Common toad	0.00	0.00	0.00	1.45	2.54	0.00	0.53	2.37	0.73	0.54
Platycephalidae	*Platycephalus fuscus*	Dusky flathead *	0.00	0.00	0.61	4.35	0.49	0.00	3.74	2.84	1.10	0.81
Mugilidae	*Liza argenta*	Flat tail mullet *	0.00	1.32	0.00	1.45	1.47	3.36	1.07	1.90	0.61	2.42
Gobiidae	*Gobiopterus semivestitus*	Glass goby	4.20	6.27	15.76	11.59	46.56	5.61	11.23	0.00	18.70	5.10
Chandidae	*Ambassis jacksoniensis*	Glassfish	70.99	0.00	29.70	5.80	25.98	54.58	34.22	4.27	43.03	27.28
Bothidae	*Ammotretis rostratus*	Large toothed flounder*	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.72
Gobiidae	*Redigobius macrostoma*	Largemouth goby	0.00	0.00	0.00	2.90	0.00	0.93	0.00	0.00	0.00	0.63
Girellidae	*Girella tricuspidata*	Luderick*	0.00	0.00	0.00	4.35	0.00	1.87	0.00	0.00	0.00	1.16
Gobiidae	*Mugilogobius paludis*	Mangrove goby	0.00	38.28	3.03	24.64	2.54	12.52	2.14	8.53	1.71	19.50
Poeciliidae	*Gambusia holbrooki*	Mosquito fish	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.00	0.12	0.00
Mugilidae	*Myxus elongatus*	Sand mullet *	0.00	0.00	1.21	0.00	0.00	0.00	1.60	0.47	0.61	0.09
Sillaginidae	*Sillago clliata*	Sand whiting *	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.74	0.00	0.89
Mugilidae	*Mugil cephalus*	Sea mullet *	0.00	0.00	0.00	0.00	1.47	0.00	0.00	0.95	0.37	0.18
Gerreidae	*Gerres subfasciatus*	Silver biddy *	11.38	23.76	3.64	0.00	0.98	0.19	8.02	18.96	6.60	10.11
Gobiidae	*Taenioides mordax*	Snake head goby	0.00	15.51	0.00	5.80	0.00	4.11	0.00	0.00	0.00	6.53
Sparidae	*Rhabdosargus sarba*	Tarwhine *	0.00	0.00	0.00	2.90	0.00	0.00	0.00	2.37	0.00	0.63
Teraponidae	*Pelates quadrilineatus*	Trumpeter *	0.00	2.64	0.00	0.00	0.00	0.00	0.00	2.84	0.00	1.25
Sparidae	*Acanthopagrus australis*	Yellow fin bream *	3.44	0.99	0.00	8.70	1.96	4.86	4.28	12.80	2.57	5.55
Crustaceans												
Alpheidae	*Alpheus edwardsi*	Common pistol shrimp	0.00	0.66	0.00	1.45	0.00	0.19	0.00	0.00	0.00	0.36
Atyidae	*Macrobrachium intermedium*	Grass shrimp	0.76	0.66	18.75	0.00	5.88	0.56	3.74	9.95	6.36	2.33
Penaeidae	*Metapenaeus macleayi*	School prawn *	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.84	0.00	0.54
Total no. of species			**7**	**11**	**9**	**15**	**14**	**15**	**14**	**18**	**16**	**25**

Some species exhibited seasonal variability in abundance, and overall a bimodal pattern of Spring and Autumn abundance was evident for many of the most common species (Figure 3.2). Abundances of *A. jacksoniensis* and *M. paludis* were high in Autumn and Spring while *G. subfasciatus* was abundant in Autumn. A distinct peak abundance in the Spring was observed for *G. semivestitus* (Figure 3.2).

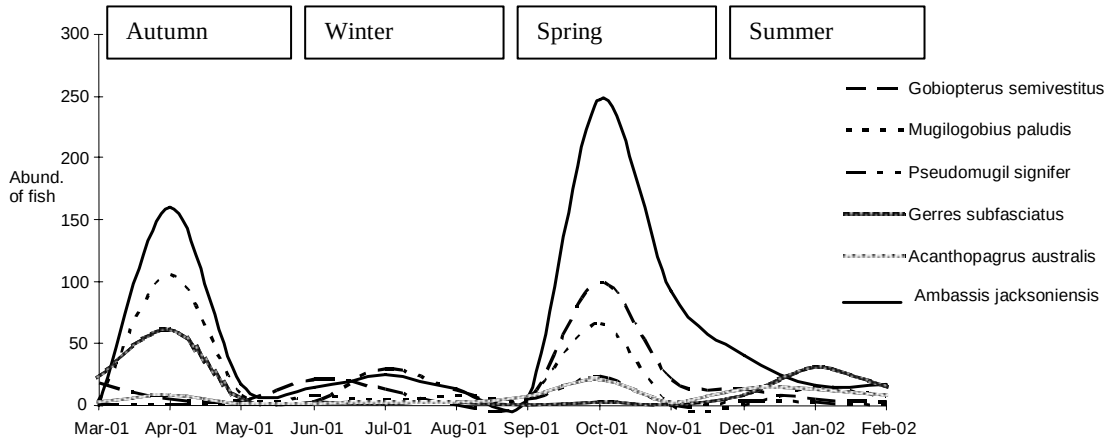


Figure 3.2 The abundance of most common fish in saltmarsh and mangrove during spring high tide at Towra Point using Pop nets, March 01- February 2002.

3.4.1 Fish abundance and species richness

Saltmarsh

The results of the ANOVA showed that fish abundance in saltmarsh habitat did not vary among seasons (P=0.81: Table 3.2). The analysis of variance using Margalef's measure of species richness between seasons in saltmarsh showed no significance difference between seasons for species richness. (Appendix 2.2)

Table 3.2. Results of an ANOVA test for differences in fish abundance between seasons in saltmarsh using pop nets at Towra Point, Botany Bay, NSW

Source of variation	DF	MS	F	P
Season	3	143.69	0.31	0.81
Residual	44	465.74		
Total	47			

Mangrove

Fish abundances in mangrove differed significantly between seasons (P=0.01: Table 3.3). The *post-hoc* SNK test for fish abundance in different seasons showed that fish abundance in winter was significantly higher than in spring. Fish abundance between autumn and winter, spring and summer, winter and summer, autumn and summer, autumn and spring were found not to vary significantly from each other.

Table 3.3. Results of an ANOVA test for differences in fish abundance between seasons in mangrove using pop nets at Towra Point, Botany Bay, NSW

Source of variation	DF	MS	F	P
Season	3	21.60	3.69	0.0188
Residual	44	5.86		
Total	47			

An analysis of variance using Margalef's measure of species richness between seasons in mangrove found no significant difference between seasons (degree of freedom (DF) 47 and P = 0.0636) (Appendix 2.3).

Saltmarsh and Mangrove

Fish abundance in saltmarsh and mangrove did not vary between seasons (P=0.10) and no significant differences were found in fish abundance between habitats (P=0.32, Table 3.4).

Table 3.4. Two way analysis results for fish abundance between seasons and habitats at Towra Point, Botany Bay, NSW

Source of variation	DF	MS	F	P
Season	3	1965.02	2.08	0.109
Habitat	1	937.50	0.99	0.322
Season. X Habitat.	3	1368.52	1.45	0.234
Residual	88	946.28		
Total	95			

The *post-hoc* SNK test for fish abundance between saltmarsh and mangrove habitats in different seasons showed that fish abundance was significantly higher in mangrove compared saltmarsh habitat in spring. The fish abundance between saltmarsh and mangrove in autumn, winter and summer were did not to different significantly (Figure 3.3).

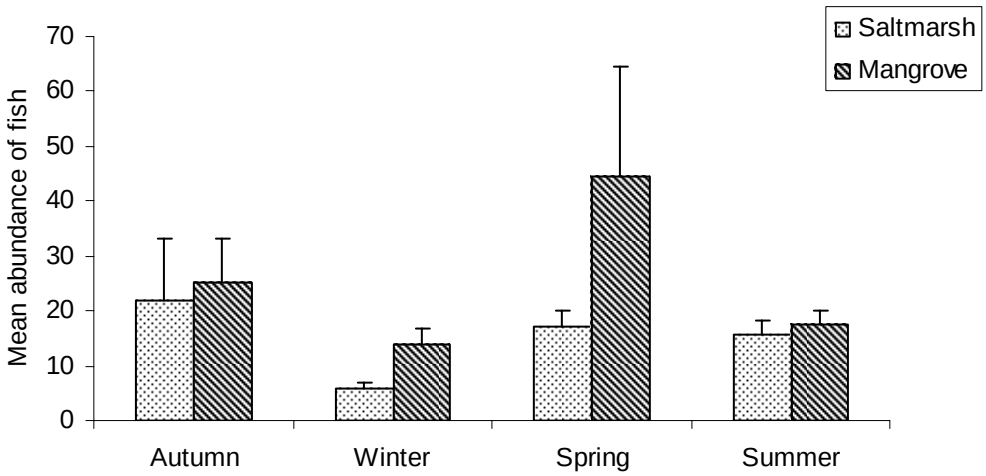


Figure 3.3 Mean abundance (+ SE) of fish in Towra Point saltmarsh and mangrove in different seasons using pop nets, 2001-2002: n= 96.

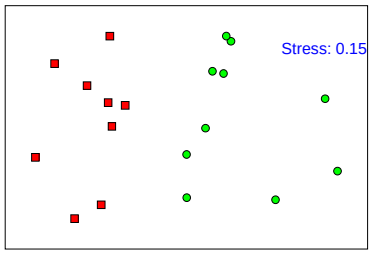
The overall abundances of fish, correcting for water volume (saltmarsh was inundated to

an average depth of 30 cm, and the mangrove habitat an average depth of 1.2 m) were 1.9 fish m^{-3} and 0.64 fish m^{-3} in saltmarsh and mangrove habitat respectively.

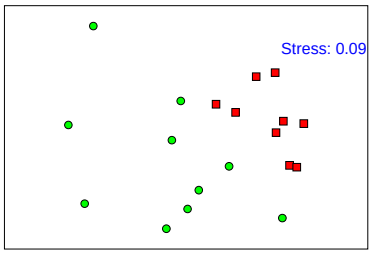
3.4.2 Fish assemblages in saltmarsh and mangrove

Non-metric multidimensional scaling (nMDS) ordinations showed different assemblages of fish in saltmarsh and mangrove habitat in all seasons (Figure 3.4).

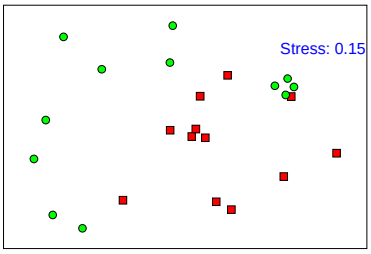
A. Autumn



B. Winter



C. Spring



D. Summer

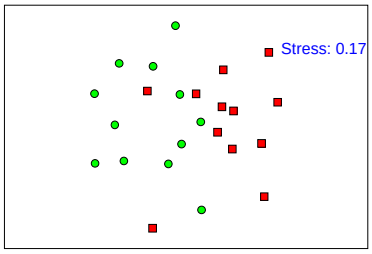


Figure 3.4 nMDS ordinations showing assemblages of fish in saltmarsh and mangrove in different seasons at Towra Point using POP nets.

=Saltmarsh =Mangrove

The results of a Analysis of Similarities (ANOSIM) showed that fish assemblages in saltmarsh and mangrove differed significantly in autumn (ANOSIM: P< 0.001), winter (ANOSIM: P< 0.001), spring (ANOSIM: P=0.004) and summer (ANOSIM: P<0.001). The dissimilarity between the two habitats in autumn appears primarily due to the higher abundance of *A. jacksoniensis* in saltmarsh and its absence from the mangrove, and the presence of *M. paludis* and *T. mordax* in mangrove and their absence from the saltmarsh (Table 3.5) (Appendix 2. 4).

The dissimilarity between the two habitats in winter appears primarily due to the greater abundance of *A. jacksoniensis*, *P. signafer* and *M. intermedium* in saltmarsh than mangrove habitat, and the presence *A. australis* in mangrove only. The dissimilarity between the two habitats in spring appears primarily due to the higher abundance of *G. semivestitus* in saltmarsh, and *A. jacksoniensis, M. paludis*, *T.mordax* and *Girella tricuspidata* in the mangrove.

The dissimilarity in summer appears primarily due to higher abundance of *A. jacksoniensis* and *P. olorum* in saltmarsh, *G. subfasciatus*, *A. australis* and *M. stigmaticus* in mangrove and absence of *P. quadrilineatus* and *S. cilliata* in saltmarsh respectively (Table 3.5).

Table 3.5. Contribution of fish species to differentiation between saltmarsh and mangrove in different seasons using pop nets at Towra Point, Botany Bay, 2001-2002.

Autumn Saltmarsh Vs. Mangrove (ANOSIM: P<0.001)				**Winter Saltmarsh Vs. Mangrove (ANOSIM: P<0.001)**				**Spring Saltmarsh Vs. Mangrove (ANOSIM: P<0.004)**				**Summer Saltmarsh Vs. Mangrove (ANOSIM: P<0.001)**			
Species	Av. Abund salt.	Av. Abund mang.	% contrib. to dissim.	Species	Av. Abund salt.	Av. Abund mang.	% contrib. to dissim.	Species	Av. Abund salt.	Av. Abund mang.	% contrib. to dissim.	Species	Av. Abund salt.	Av. Abund mang.	% contrib. to dissim.
Ambassis jacksoniensis	20.67	0.00	23.50	*A.jacksoniensis*	5.44	0.40	20.44	*A.jacksoniensis*	4.42	24.33	21.12	*A.jacksoniensis*	5.33	0.75	15.63
Mugilogobius paludis	0.00	11.60	20.32	*P.signifer*	4.67	0.30	13.80	*G.semivestitus*	7.92	2.50	16.87	*G. subfasciatus*	1.25	3.33	10.41
Pseudomugil signifer	2.44	0.00	4.87	*G.semivestitus*	2.89	0.80	12.28	*M.paludis*	0.42	5.58	8.05	*P. olorum*	3.92	1.33	9.29
Acanthopagrus australis	1.00	0.30	4.79	*M.intermedium*	3.44	0.00	10.70	*A.australis*	0.33	2.17	7.98	*A.australis*	0.67	2.25	8.63
Gobiopterus semivestitus	1.22	1.90	7.82	*M.paludis*	0.56	1.70	8.77	*T.mordax*	0.00	1.83	5.92	*G. semivestitus*	1.75	0.00	7.59
Gerres subfasciatus	3.44	7.20	14.26	*G. subfasciatus*	0.67	0.00	5.82	*L. argenta*	0.25	1.50	5.61	*P.quadrilineatus*	0.00	0.50	2.47
Taenioides mordax	0.00	4.70	4.89	*A. australis*	0.00	0.60	5.34	*G.tricuspidata*	0.00	0.83	3.78	*S. clliata*	0.00	0.83	2.97
Mugilogobius stigmaticus	0.11	2.70	8.27	*M. stigmaticus*	0.33	0.70	5.39	Unidentifiedsp.	0.67	0.58	5.43	*M.intermedium*	0.58	1.75	6.90
Macrobrachium intermedium	0.22	0.20	2.79	*P. olorum*	0.00	0.70	3.29	*P.signifer*	0.75	1.58	5.31	*M. paludis*	0.33	1.50	6.40
				P. fuscus	0.11	0.30	2.95	*P.olorum*	0.17	2.17	5.22	*P. fuscus*	0.58	0.50	4.74
				T. mordax	0.00	0.40	2.32	*M.intermedium*	1.00	0.25	3.21	*L. argenta*	0.17	0.33	3.11
								T.hamiltoni	0.42	0.00	2.60	*T.hamiltoni*	0.08	0.42	2.73
												R. sarba	0.00	0.42	2.55

Analysis of Similarities (ANOSIM) for different seasons showed that the assemblages of fish in saltmarsh differed between autumn and winter (ANOSIM: P= 0.049), autumn and spring (ANOSIM: P=0.017), winter and summer (ANOSIM: P= 0.038) and spring and summer (ANOSIM: P=0.029). No significant differences were observed in fish assemblages within saltmarsh between autumn and summer (ANOSIM: P=0.256) and winter and spring (ANOSIM: P=0.319) (Table 3.3). Differences in fish assemblages within the mangrove habitat were found between all seasons, with the exception of autumn and summer (P = 0.059, Table 3.6) (Appendix 2.5).

Table 3.6. ANOSIM results for fish assemblages in different seasons within saltmarsh and mangrove habitats at Towra Point, 2001-2002.

Season	Saltmarsh Significance level	Mangrove Significance level
Autumn vs. Winter	0.049	0.025
Autumn vs. Spring	0.017	0.0001
Autumn vs. Summer	0.256	0.059
Winter vs. Spring	0.319	0.021
Winter vs. Summer	0.038	0.027
Spring vs. Summer	0.029	0.002

The results of matched similarity matrices (RELATE) results for cyclicity in monthly catch showed that a significantly greater cyclicity than would be the case in a random distribution for saltmarsh (P=0.04) as well as mangrove habitat (P=0.003) (Figure 3.5).

A. Saltmarsh **B. Mangrove**

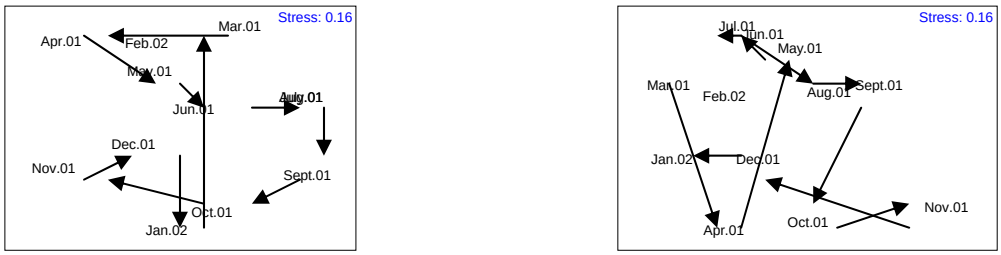


Figure 3.5 nMDS ordinations showing the distribution of monthly fish assemblages in saltmarsh and mangrove at Towra Point using pop nets.

The results using Biota and environmental matching (BIOENV) testing results for a correlations between environmental variables and fish assemblages in saltmarsh showed no correlations between time of sampling and fish assemblages (weighted Spearman rank correlation ρ=0.100), tide height and fish assemblages (ρ=0.096), temperature and fish assemblages (ρ=0.112), or between any combination of these variables (Appendix 2.6).

3.5 Discussion

The results of this study demonstrated that during spring tides the catch of fish in saltmarsh at Towra Point approaches that of adjacent mangrove. The mean density of the 16 species of fish caught in saltmarsh was 0.56 fish m^{-2} from 48 pop net releases. In a comparable study, Thomas and Connolly (2001) collected a total of 23 species from 134 pop net releases with density ranging up to 0.46 fish m^{-2} from the subtropical saltmarsh in Queensland. The nets used by Thomas and Connolly (2001) were smaller in size (25 m^2) than the nets used in the present study (30.25 m^2). The current study suggests a greater abundance, but lower diversity of fish, in the temperate saltmarsh of Towra Point compared with the subtropical saltmarsh in Queensland.

The density of fish was slightly higher in mangrove habitat (0.76 fish m^{-2}) than in

saltmarsh habitat, though this is not the case when density is corrected for water volume (0.63 m^{-3} in mangrove compared with 1.9 fish m^{-3} in the saltmarsh). The present study found 25 species of fish in mangrove habitat include 12 species were of commercial importance. Several studies conducted in Australian mangroves have suggested the importance of this habitat (Blaber *et al*. 1985; Thayer *et al*. 1987; Robertson and Duke 1987; Laegdsgaard and Johnson 1995) although these studies were concentrated in tropical and subtropical environment. Recently Clynick and Chapman (2002) surveyed fish in temperate mangroves and adjacent mudflats, revealing little difference in density between these two habitats.

The present study found seven species of fish in both saltmarsh and mangrove habitats throughout the year, of which four families (Chandidae, Atherinidae, Gobiidae and Gerreidae) were dominant. This result is somewhat different from the findings of Bell (1984) who reported that two of these families (Atherinidae and Gobiidae) and with Ambassidae were common in the fish community of temperate tidal mangrove creek in Botany Bay. Chandidae, Atherinidae and Gobiidae were common families among others in Alligator Creek, Lockhart River and Escape River in tropical Australia (Robertson and Duke 1987).

Thomas & Connolly (2001) found that fish assemblages in the subtropical saltmarshes of Queensland varied between winter and summer. A strong seasonal change in fish assemblages was also reported by Morton *et al.* (1987) who surveyed subtidal creeks of saltmarshes, and by Rountree and Able (1993) who survey New Jersey polyhaline marsh creeks in the USA. The present study observed Autumn and Spring peaks in the abundance of many of the common species, including *A. jacksoniensis*, and *M. paludis.* Other common species showed peak abundances in either Spring (*G. subfasciatus)* or Autumn (*G. semivestitus*). Bell (1980) and Anon (1981) described the recruitment of some juvenile species of fish to mangrove creek habitat when water temperatures were at maximum during summer. However, the present study found no correlations between fish assemblages and water temperature, with sampling hour or tidal height. The cyclicity of fish assemblages in saltmarsh and mangrove habitats suggests that the assemblages

approached their original composition after 12 months.

While a different assemblage of fish is found in saltmarsh compared to mangrove habitat, there is little to distinguish the two habitats in terms of overall fish abundance and density. Commercially important species were more likely to be found in the mangrove habitat, though some species were also found in the saltmarsh habitat. The results strongly suggest that despite infrequent inundation by tides, saltmarsh habitat does play a role as a fish habitat and further protection is needed regarding the legislation and associated policies that protect this habitat.

CHAPTER FOUR

SPATIAL VARIABILITY OF FISH ASSEMBLAGES IN SALTMARSH AND MANGROVE

4.1 Summary

In the present study fish assemblages in three geographically distinct saltmarshes and mangroves in the Sydney region were examined to explore the variation in saltmarsh and mangrove types and settings. Fyke nets were used over three common sampling periods. Sixteen species were caught from Towra Point saltmarsh, 5 were of commercial importance. Within the mangrove, 13 species were caught, 5 being of commercial importance. At Bicentennial Park 6 species were collected from the saltmarsh none of which were of economic significance. Within the mangrove, 16 different species of fish were caught, with 5 being of commercial importance. At Allens Creek 12 species were caught in the saltmarsh, five being of commercial importance. Within the mangrove, 10 different species of fish were caught, two being of commercially importance. Non-metric multidimensional scaling (nMDS) ordination results also showed differences in the fish assemblage between the Towra Point, Bicentennial Park and Allens Creek saltmarsh (ANOSIM: $P < 0.001$). Fish assemblages across sites within mangrove flats also varied significantly. The result shows a relatively greater range of species at Towra Point

saltmarsh than the other two sites may be related to proximity to the ocean. Geographic position seems a more important determinant of fish assemblages than vegetation type.

4.2 Introduction

The primary cause of saltmarsh decline in NSW is replacement by mangrove (Saintilan and Williams 1999, 2000). The reasons for mangrove encroachment are not yet clear, but appear to relate to natural as well as anthropogenic factors. Saltmarsh is not protected under the NSW Fisheries Management Act (1994), which protects mangrove to the mean high water mark. The relative important of mangrove and saltmarsh as a fish habitat is therefore of keen management interest, and for this reason the adjacent mangrove fish assemblages were also sampled.

The previous chapter demonstrated a diverse range of fish species visiting the Towra Point saltmarsh, with densities equivalent to that found in the mangrove. This temperate saltmarsh would seem more akin to the Southern Queensland saltmarsh suggested by Thomas & Connolly (2001) than that of Barker Inlet-Port River, South Australia examined by Connolly *et al*. (1997). Higher abundance of fishes, particularly young-of-the-year and juveniles also found in the saltmarshes in the North America (Cain and Dean 1976, Weinstein 1979, Weinstein *et al*. 1980, Haedrich 1983, Weinstein and Brooks 1983) Daiber 1977 and in Europe (Costa *et al*. 1994, 1995).

Before concluding that temperate NSW saltmarshes support a diverse fish fauna at high tide, it is necessary to consider variability between saltmarshes across estuarine and geomorphic settings. Towra Point is located close to the estuarine mouth and within a nature reserve, factors which might promote diversity.

The present study examined fish assemblages in three geographically distinct saltmarshes and mangroves in the Sydney region to take account of the variation in saltmarsh and mangrove types and settings. The null hypothesis was that there were no differences in visiting fish assemblages between locations or habitats.

4.2.1 Study site and Methods

The study compared fish assemblages in the saltmarsh and mangrove environments in three distinct settings, all supporting similar mangrove and saltmarsh vegetation. Towra Point, within Botany Bay (Figure 4.1), represents a relatively undisturbed sandy marine delta. Maximum tidal range is of the order of two metres. The mangrove forest is dominated by *Avicennia marina* and the saltmarsh by a *Sarcocornia quinqueflora/Sporobolus virginicus* association, with *Triglochin striata* growing in less well-drained positions. *Juncus krausii* and *Suaeda australis* were also present in higher elevation environments (Clarke & Hannon, 1967, Adam *et al*. 1988).

Allens Creek on the Hawkesbury River at Spencer is an example of a tributary delta within the fluvial deltaic segment of the Hawkesbury River estuary. Intertidal soils consist predominantly of silts and clays, and salinities are periodically diluted by freshwater flows (Saintilan 1996). The saltmarsh assemblage is similar to that of Towra Point, though *Sueda australis* is absent. *Avicennia marina* and *Aegiceras corniculatum* are well represented in the mangrove.

The site at Bicentennial Park site is also a tributary delta, occurring in the middle reaches of the Parramatta River. The site has a more disturbed history than Allens Creek, with the current mangrove and saltmarsh environments occupying positions of reclaimed dredge spoil. Mangrove forest in Bicentennial Park is extensive while the saltmarsh is patchy, and is dominated by *Sarcocornia quinqueflora, Sporobolus virginicus* and the introduced *Juncus acutus*. The mangrove is dominated by *Avicennia marina*.

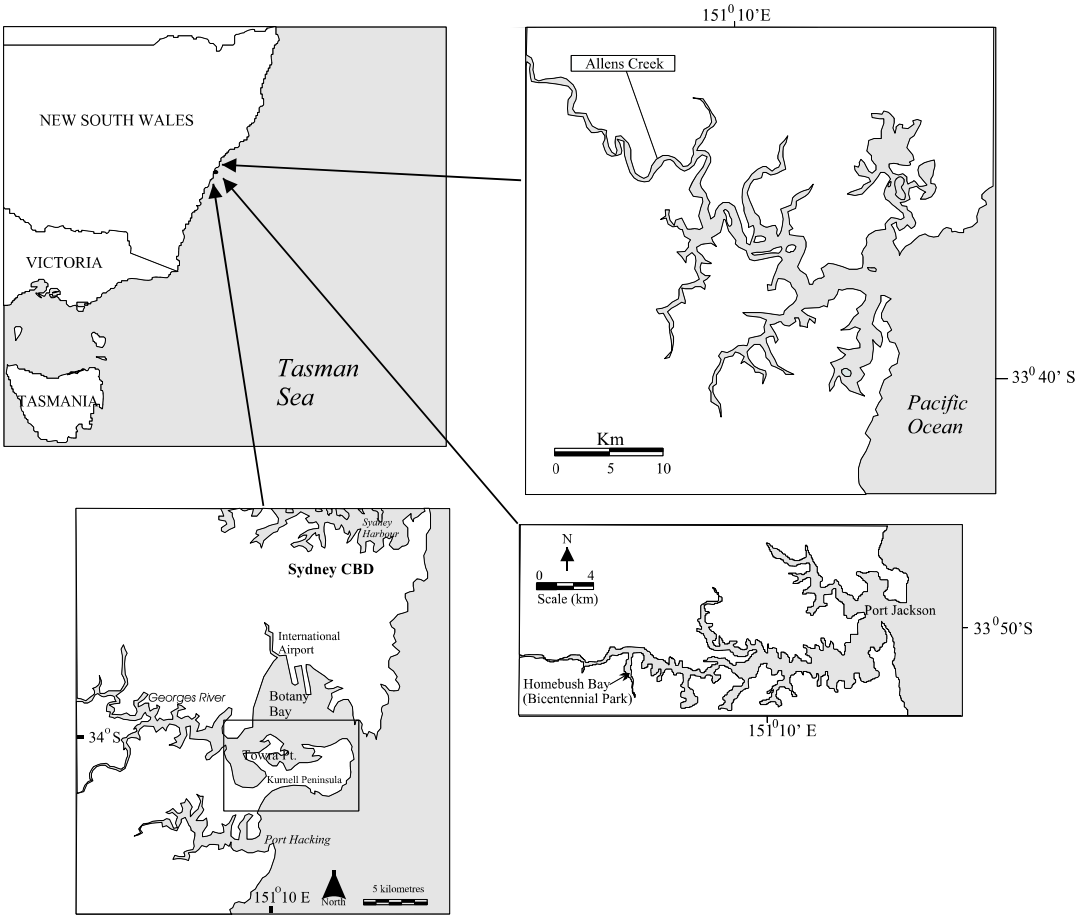


Figure 4.1 Map of Australia showing the location of study sites, Towra Point, Bicentennial Park and Allens Creek, NSW.

4.2.2 Fish sample collection

Fyke nets have previously been used (Morton *et al.* 1987, Williams *et al*. 1996) in the saltmarsh and mangrove wetlands to collect fish. We employed a 4 meter long funnel-shaped fyke net with one central and two lateral wings and a 40 cm wide and 25 cm high entrance. Mesh size throughout was 2 mm. The net was secured in place by six large wooden stakes tied to the extremities; a metal plate kept the entrance on the bottom. Where needed small metal pegs were also placed to keep the entrance funnel and wings tight against the substrate. The wings also had floats and leads along their tops and bottoms respectively to keep them upright. Multiple fyke nets were placed randomly in the saltmarsh and mangrove flats before tides flooded these habitats.

Fish were collected from the four replicate fyke nets after tide water fully receded from the saltmarsh and two replicate fyke nets from mangrove. Fish samples were collected from December 2001, January and August 2002 at Towra Point, Bicentennial Park and Allens Creek sites during spring high tide (>1.8m).

4.2.3 Statistical methods

Differences in assemblages of fish between saltmarsh and mangrove were examined by the Bray-Curtis measures of dissimilarity (Bray and Curtis 1957) using square root transformed data. Nonmetric multidimensional scaling (nMDS) plots were also used to demonstrate the patterns of fish assemblages in different sites between and within habitats (Clarke and Warwick 2001). Multivariate techniques such as ANOSIM (Clarke and Warwick 2001) were used to test the statistical significance of differences between the fish assemblages within habitats and between the sites. The contribution made by particular species to differences in species assemblages was determined using SIMPER (similarity percentages-species contribution, (Clarke and Warwick 2001) for habitats and sites.

Univariate analysis (ANOVA) and *Post-hoc* SNK tests were also performed to determine differences of fish abundance between sites in saltmarsh and mangrove with site considered as random factor with three levels {1= TP (Towra Point), 2= BP (Bicentennial Park) and 3= AC (Allens Creek)}. Data was tested for homogeneity of variance using Cochran's test and transformed where appropriate. Species richness d= (S-1)/Log(N); (Margalfe 1969) were determined using DIVERS (Clarke and Warwick 2001) between habitats and sites.

4.3 Results

Over 3 months 17 species of fish and decapods crustacean were caught at Towra Point (TP). Sixteen species were caught from saltmarsh, of which *Pseudomugil signifer* was

most abundant contributing 29.5% of the total catch, followed by *Macrobrachium intermedium* (18%), *Gerres subfasciatus* (9%) and *Ambassis jacksoniensis* (8.9%). Among 16 species found in the saltmarsh seven were of commercial importance (Table 4.1), the most abundant being *Gerres subfasciatus* (9%) followed by *Acanthopagrus australis* (4.9%). Within the mangrove, 13 species were caught, 5 being of commercial importance. *Ambassis jacksoniensis* was the most abundant species in mangrove contributing 46.4%, followed by *Macrobrachium intermedium* (15.5%) and *Gerres subfasciatus* (14.4%). Over the sampling periods, one species bridled goby (*Arenigobius bifrenatus)* was found only in mangrove (Table 4.1).

At Bicentennial Park (BP) 16 species were caught during the three sampling periods (Table 4.1) .Six species were collected from the saltmarsh none of which were of economic significance. *Pseudomugil signafer* was again the most abundant contributing 46.0% of the total catch by number, followed by *Mugilogobius paludis* (20.0%) and *Pseudogobius olorum* (17.0%). Within the mangrove, 16 different species of fish were caught, with 5 being of commercial importance. *Pseudogobius olorum* was the most abundant species in mangrove contributing 44.0% followed by *Gambusia holbrooki* (12.9%) and *Pseudomugil signafer* (7.4%). Among the commercial important species in mangrove the most abundant species was *Liza argentea* (2.5%) and *Gerres subfasciatus* (2.3%).

At Allens Creek 14 species of fish were collected (Table 4.1). Twelve species were caught in the saltmarsh, five being of commercial importance. The most abundant species in saltmarsh was *Gobiopterus semivestitus* (67.3%) followed by *Macrobrachium intermedium* (10.1%) and *Pseudomugil signifer* (7.9%). Of the commercially important species found in saltmarsh the most abundant was *Liza argentea* (2.8%) followed by *Platycephalus fuscus* (2.2%) and *Metapenaeus macleayi* (1.5%). Within the mangrove, 10 different species of fish were caught, two being of commercially importance. The most abundant species in mangrove was *Macrobrachium intermedium* 30.4% by number followed by *Gobiopterus semivestitus* (21.5%) and *Morgurnda australis* (13.9%).

Table 4.1 Species caught from saltmarsh (**S**) and mangrove (**M**) with fyke nets at Towra Point, Bicentennial Park and Allens Creek, 2001 –2002. The asterisk (*) designates species of commercial and or recreational significance.

Family	Genus/species	Common name	% contribution to catch					
			Towra Point		Bicentennial Park		Allens Creek	
			S	M	S	M	S	M
Fish								
Atherinidae	*Pseudomugil signifer*	Blue eye	29.55	3.73	46.00	7.37	7.88	2.53
Gobiidae	*Pseudogobius olorum*	Blue spot goby	6.46	2.80	17.00	44.01	0.89	0.00
Gobiidae	*Arenigobius bifrenatus*	Bridled goby	0.00	0.58	0.00	0.92	0.00	0.00
Gobiidae	*Mugilogobius stigmaticus*	Checkered mangrove goby	6.46	1.05	0.00	3.23	3.27	8.86
Tetraodontidae	T*etractenos hamiltoni*	Common toad	1.41	0.00	0.00	0.00	0.00	0.00
Platycephalidae	*Platycephalus fuscus*	Dusky flathead *	2.90	0.00	0.00	2.30	2.23	1.27
Mugilidae	*Liza argenta*	Flat tail mullet *	0.99	0.23	0.00	2.53	2.82	2.53
	Butis amboinensis	Flathead gudgeon	0.00	0.00	0.00	1.38	0.00	0.00
Gobiidae	*Gobiopterus semivestitus*	Glass goby	4.06	6.65	9.00	3.00	67.31	21.52
Chandidae	*Ambassis jacksoniensis*	Glassfish	8.94	46.44	0.00	2.30	2.08	5.06
Gobiidae	*Redigobius macrostoma*	Largemouth goby	0.00	0.00	0.00	0.00	0.00	3.80
Gobiidae	*Mugilogobius paludis*	Mangrove goby	0.99	0.82	20.00	6.91	0.30	10.13
Poeciliidae	*Gambusia holbrooki*	Mosquito fish	1.16	0.00	0.00	12.90	0.00	0.00
Mugilidae	*Myxus elongatus*	Sand mullet *	3.06	3.27	0.00	0.00	0.59	0.00
Sillaginidae	*Sillago clliata*	Sand whiting *	0.50	1.52	0.00	0.0	0.0	0.00
Mugilidae	*Mugil cephalus*	Sea mullet *	0.00	0.00	0.00	0.00	0.00	0.00
Gerreidae	*Gerres subfasciatus*	Silver biddy *	9.02	14.47	0.00	2.30	0.00	0.00
Gobiidae	*Taenioides mordax*	Snake head goby	0.00	0.00	0.00	0.00	0.00	0.00
	Mogurnda australis	Striped gudgeon	0.00	0.00	0.00	0.00	0.00	13.92
Sparidae	*Rhabdosargus sarba*	Tarwhine *	0.00	0.00	0.00	1.15	0.00	0.00
Teraponidae	*Pelates quadrilineatus*	Trumpeter *	0.00	0.00	0.00	0.00	0.00	0.00
		Unidentified fish	0.00	0.00	5.00	3.92	0.00	0.00
Sparidae	*Acanthopagrus australis*	Yellow fin bream *	4.97	2.92	0.00	1.15	1.04	0.00
Crustacean								
Alpheidae	*Alpheus edwardsi*	Common pistol shrimp	0.00	0.00	0.00	0.00	0.00	0.00
Atyidae	*Macrobrachium intermedium*	Grass shrimp	18.05	15.52	3.00	4.61	10.10	30.38
Penaeidae	*Metapenaeus macleayi*	School prawn *	1.49	0.00	0.00	0.00	1.49	0.00
Total no. of species			**16**	**13**	**6**	**16**	**12**	**10**

4.3.1 Fish assemblages in Towra Point

Non-metric multidimensional scaling (nMDS) ordinations between saltmarsh and mangrove at Towra Point showed different assemblages of fish in saltmarsh than in mangrove (Figure 4.2). Analysis of similarities (ANOSIM) show that fish assemblages in saltmarsh differed significantly (ANOSIM: P = 0.007) from mangrove (Appendix 3.1).

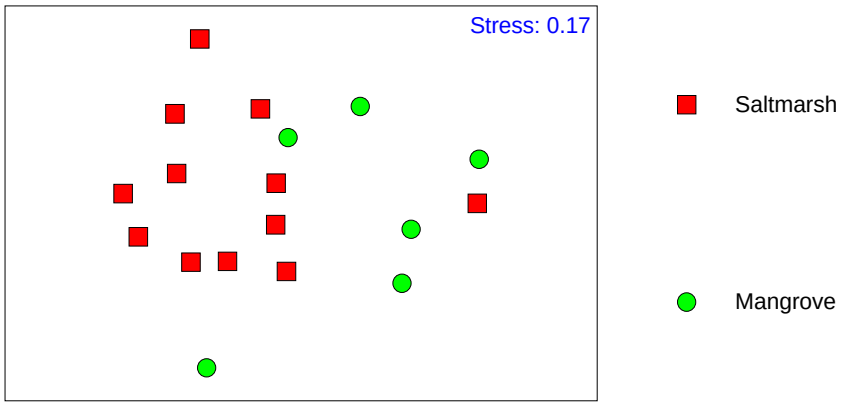


Figure 4.2 nMDS ordinations showing assemblages of fish in saltmarsh and mangrove in at Towra Point using fyke nets.

The dissimilarity between saltmarsh and mangrove appears primarily due to the higher abundance of blue eye (*Pseudomugil signifer*) in saltmarsh than mangrove and presence of dusky flat head, common toad (T*etractenos hamiltoni*) and school prawn (*Metapenaeus macleayi*) in saltmarsh and absence in the mangrove. Glassfish (*Ambassis jacksoniensis*), grass shrimp (*Macrobrachium intermedium*), and silverbiddy (*Gerres subfasciatus*) which were more abundant in mangrove than saltmarsh (Appendix 3.1).

4.3.2 Fish assemblages in Bicentennial Park

A non-metric multidimensional scaling (nMDS) ordination showed a separation of fish assemblages between saltmarsh and mangrove (ANOSIM P=0.011) at Bicentennial Park (Figure 4.3).

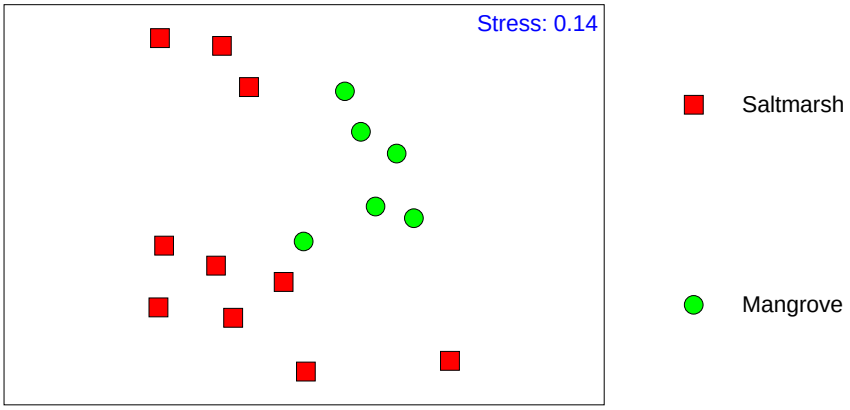


Figure 4.3 nMDS ordination showing assemblages of fish in saltmarsh and mangrove in Bicentennial Park, using fyke nets.

The dissimilarity between the two habitats appears primarily due to the abundance of mosquito fish (*Gambusia holbrooki*), flat tail mullet (*Liza argenta*), glassfish (*Ambassis jacksoniensis*) and yellow fin bream (*Acanthopagrus australis*) in mangrove and its absence from the saltmarsh during the period of sampling. Blue spot goby (*Pseudogobius olorum*), blue eye (*Pseudomugil signifer*) and mangrove goby (*Mugilogobius paludis*) and grass shrimp (*Macrobrachium intermedium*) being more abundant in mangrove than saltmarsh (Appendix 3.2).

4.3.3 Fish assemblages in Allens creek

A non-metric multidimensional scaling (nMDS) ordination showed different assemblages of fish in saltmarsh and mangrove (Figure 4.4). Analysis of similarities test (ANOSIM) results confirm this perception (P=0.032).

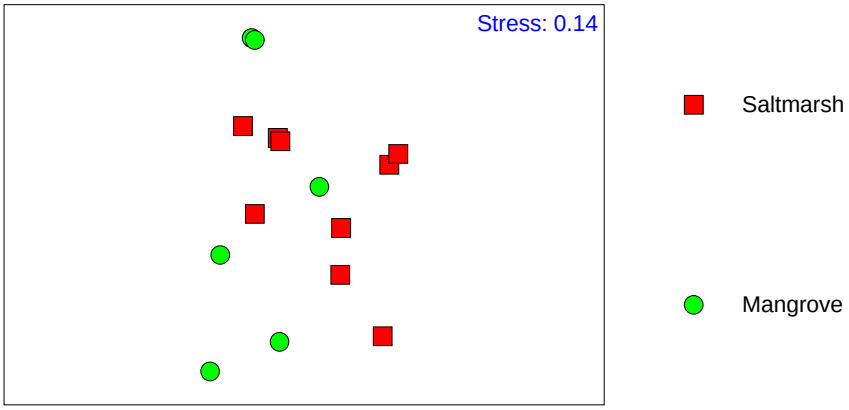


Figure 4.4 nMDS ordination showing assemblages of fish in saltmarsh and mangrove in Allens Creek, using fyke nets.

The dissimilarity between the two habitats appears primarily due to the abundance of striped gudgeon (*Mogurnda australis*) in the mangrove and its absence from the saltmarsh, abundance of school prawn (*Metapenaeus macleayi*) in saltmarsh and absence from the mangrove. Glass goby (*Gobiopterus semivestitus*), grass shrimp (*Macrobrachium intermedium*), blue eye (*Pseudomugil signifer*), checkered mangrove goby (*Mugilogobius stigmaticus*) and flat tail mullet (*Liza argenta*) were more abundant in saltmarsh than mangrove (Appendix 3.3).

4.3.4 Comparison of Fish assemblages between saltmarshes

A non-metric multidimensional scaling (nMDS) ordination (Figure 4.5) showed differences in the fish assemblage between the Towra Point, Bicentennial Park and Allens Creek saltmarsh (ANOSIM: P< 0.001) (Appendix 3.4).

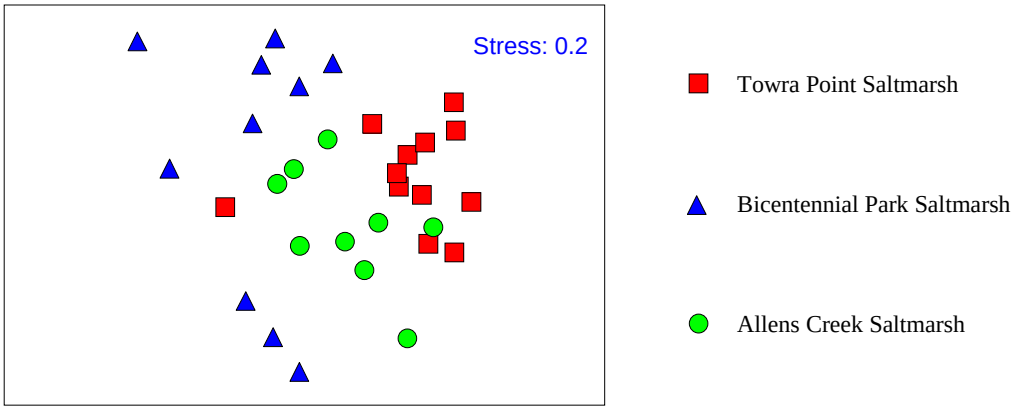


Figure 4.5 nMDS ordination showing assemblages of fish between Towra Point, Bicentennial Park and Allens Creek saltmarsh with fyke nets in December 2001, January and August 2002.

The dissimilarity between Towra Point and Bicentennial Park saltmarsh appears primarily due to the abundance of silver biddy (*Gerres subfasciatus*), glassfish (*Ambassis jacksoniensis*), checkered mangrove goby (*Mugilogobius stigmaticus*), school prawn (*Metapenaeus macleayi*), common toad (T*etractenos hamiltoni*), dusky flathead (*Platycephalus fuscus*), yellow fin bream (*Acanthopagrus australis*) and sand mullet (*Myxus elongates*) in Towra Point saltmarsh and their absence in Bicentennial Park saltmarsh. Also blue eye (*Pseudomugil signifer*), grass shrimp (*Macrobrachium intermedium*), blue spot goby (*Pseudogobius olorum*) and yellow fin bream (*Acanthopagrus australis*) were more abundant in Towra Point saltmarsh than Bicentennial Park saltmarsh (Table 4.2).

The dissimilarity between Towra Point and Allens Creek saltmarsh appears primarily due to the abundance of silver biddy (*Gerres subfasciatus*) and common toad (T*etractenos hamiltoni*) in Towra Point and their absence in Allens Creek. Also blue eye (*Pseudomugil signafer*), grass shrimp (*Macrobrachium intermedium*), glassfish (*Ambassis jacksoniensis*), blue spot goby (*Pseudogobius olorum*) and yellow fin bream (*Acanthopagrus australis*) were more abundant in Towra Point than Allens Creek saltmarsh and glass goby was more abundant in Allens Creek than Towra Point saltmarsh (Table 4.2).

The dissimilarity between Bicentennial Park and Allens Creek saltmarsh appears primarily due to the abundance of flat tail mullet (*Liza argenta*), glassfish (*Ambassis jacksoniensis*), dusky flathead (*Platycephalus fuscus*) and checkered mangrove goby (*Mugilogobius stigmaticus*) in Allens Creek and their absence in Bicentennial Park and higher abundances of glass goby (*Gobiopterus semivestitus*), grass shrimp (*Macrobrachium intermedium*) and blue eye (*Pseudomugil signifer*) in Allens Creek saltmarsh compared to the Bicentennial Park saltmarsh (Table 4.2).

Table 4.2 Contribution of fish species to differentiation across saltmarsh sites at Towra Point, Bicentennial Park and Allens Creek during December 2001, January and August 2002.

Towra Point Saltmarsh Vs. Bicentennial Park Saltmarsh				**Towra Point Saltmarsh Vs. Allens Creek Saltmatsh**				**Bicentennial Park Saltmarsh Vs. Allens Creek Saltmarsh**			
Species	Av. Abund TP salt.	Av. Abund BPsalt	% contrib. to dissim.	Species	Av. Abund TP salt	Av. Abund ACsalt	% contrib. to dissim.	Species	Av. Abund BPsalt	Av. Abund ACsalt	% contrib. to dissim.
Pseudomugil signifer	29.75	4.60	13.84	*Pseudomugil signifer*	29.75	5.89	11.81	*Gobiopterus semivestitus*	0.90	50.33	24.62
Macrobrachium intermedium	18.17	0.30	7.47	*Macrobrachium intermedium*	18.17	7.56	10.22	*Macrobrachium intermedium*	0.30	7.56	16.28
Gerres subfasciatus	9.08	0.00	10.05	*Gerres subfasciatus*	9.08	0.00	9.08	*Pseudomugil signifer*	4.60	5.89	12.69
Ambassis jacksoniensis	9.00	0.00	13.50	*Ambassis jacksoniensis*	9.00	1.56	9.53	*Liza argenta*	0.00	2.11	5.54
Mugilogobius stigmaticus	6.50	0.00	4.74	*Pseudogobius olorum*	6.50	0.67	5.32	*Ambassis jacksoniensis*	0.00	1.56	5.53
Acanthopagrus australis	5.00	0.00	7.01	*Acanthopagrus australis*	5.00	0.78	6.18	*Platycephalus fuscus*	0.00	1.67	6.53
Pseudogobius olorum	6.50	1.70	6.34	*Gobiopterus semivestitus*	4.08	50.33	15.49	*Mugilogobius stigmaticus*	0.00	2.44	6.09
Gobiopterus semivestitus	4.08	0.90	6.29	*Mugilogobius stigmaticus*	6.50	2.44	6.32	*Mugilogobius paludis*	2.00	0.22	6.75
Platycephalus fuscus	2.92	0.00	5.89	*Liza argenta*	1.00	2.11	4.32	*Pseudogobius olorum*	1.70	0.67	6.03
Mugilogobius paludis	1.00	2.00	5.21	*Platycephalus fuscus*	2.92	1.67	4.28				
Tetractenos hamiltoni	1.42	0.00	4.63	*Metapenaeus macleayi*	1.50	1.11	4.11				
Metapenaeus macleayi	1.50	0.00	4.29	*Tetractenos hamiltoni*	1.42	0.00	4.07				
Myxus elongatus	3.08	0.00	3.87								

4.3.5 Fish abundance and species richness across saltmarsh sites

ANOVA results showed that fish abundance in saltmarsh varied significantly (P=0.02: Table 4.3) across these sites.

Table 4.3. ANOVA results for fish abundance in saltmarsh of Towra Point (TP), Bicentennial Park (BP) and Allens Creek (AC), NSW: Cochran's Test C= 0.6060.

Source of variation	DF	MS	F	P
Site	2	25586.36	3.96	0.02
Residual	33	6460.25		
Total	35			

The *post-hoc* SNK test for fish abundance within the sites showed that mean fish abundance at Towra Point and Allens Creek were higher than at Bicentennial Park, but that no significant difference could be found between the abundances at Towra Point and Allens Creek.

Analysis of variance using Margalfe indices (d) for species richness for Towra Point saltmarsh was significantly higher (d=1.639) than in the Bicentennial Park (d=0.527) and Allens Creek (d=0.902), but no significance difference was found between Bicentennial Park and the Allens Creek saltmarsh.

4.3.6 Comparison of Fish assemblages between mangroves

A non-metric multidimensional scaling (nMDS) ordination within sites showed a different assemblage of fish between Towra Point, Bicentennial Park and Allens Creek mangrove (Figure 4.6).

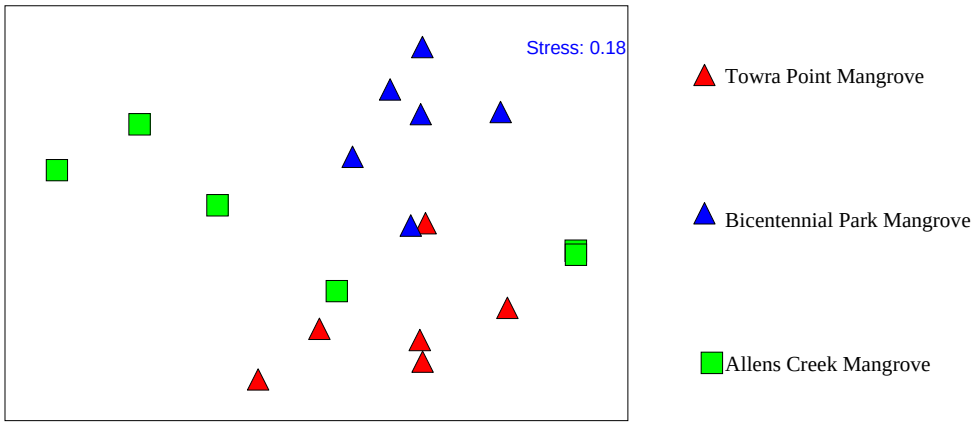


Figure 4.6 nMDS ordination showing assemblages of fish in Towra Point, Bicentennial Park and Allens creek mangrove with fyke nets in December 2001, January and August 2002.

Analysis of similarities (ANOSIM) test results showed that mangrove fish assemblages varied significantly between sites. ANOSIM results showed significant difference between Towra Point and Bicentennial Park (P=0.004), between Towra Point and Allens Creek (P=0.013) and between Bicentennial Park and Allens Creek (ANOSIM: P=0.002) for fish assemblages in mangrove (Appendix 3.5).

The dissimilarity between Towra Point and Bicentennial Park mangrove appears primarily due to the abundance of mosquito fish (*Gambusia holbrooki*) and flathead gudgeon (*Butis amboinensis*) in Bicentennial Park and their absence in Towra Point mangrove, abundance of sand mullet (*Myxus elongates*) in Towra Point mangrove and absence from the Bicentennial Park mangrove. Glassfish (*Ambassis jacksoniensis*), grass shrimp (*Macrobrachium intermedium*), glass goby (*Gobiopterus semivestitus*) and silver biddy (*Gerres subfasciatus*), were more abundant in the Towra Point mangrove and blue spot goby (*Pseudogobius olorum*) and checkered mangrove goby (*Mugilogobius stigmaticus*) were more abundant at Bicentennial Park (Table 4.4).

The dissimilarity between Towra Point and Allens Creek mangrove appears primarily due to the abundance of silver biddy (*Gerres subfasciatus*), sand mullet (*Myxus elongates*), yellow fined bream (*Acanthopagrus australis*) and blue spot goby (*Pseudogobius olorum*) in Towra Point mangrove and their absence in Allens Creek and abundance of striped gudgeon (*Mogurnda australis*) in Allens Creek and their absence in Towra Point mangrove. Also glassfish (*Ambassis jacksoniensis*), grass shrimp (*Macrobrachium intermedium*), glass goby (*Gobiopterus semivestitus*) were more abundant in Towra Point mangrove than Allenc Creek (Table 4.4).

The dissimilarity between fish assemblages in the Bicentennial Park and Allens Creek mangrove appears primarily due to the abundance of blue spot goby (*Pseudogobius olorum*), mosquito fish (*Gambusia holbrooki*), flathead gudgeon (*Butis amboinensis*) and yellow fine bream (*Acanthopagrus australis*) in Bicentennial Park mangrove and their absence in Allens Creek, and the abundance of Striped gudgeon (*Mogurnda australis*) in the Allens Creek mangrove and its absence from the Bicentennial Park mangrove. Also contributing to the dissimilarity between sites was the higher abundance at Bicentennial Park of mangrove goby (*Mugilogobius paludis*), blue eye (*Pseudomugil signifer*) and checkered mangrove goby (*Mugilogobius stigmaticus*) and the higher abundance at Allens Creek of grass shrimp (*Macrobrachium intermedium*) and glass goby (*Gobiopterus semivestitus*) (Table 4.4).

Table 4.4 Contribution of fish species to differentiation across mangrove sites at Towra Point, Bicentennial Park and Allens Creek during December 2001, January and August 2002.

Towra Point Mangrove Vs. Bicentennial Park Mangrove				**Towra Point Mangrove Vs. Allens Creek Mangrove**				**Bicentennial Park Mangrove Vs. Allens Creek Mangrove**			
Species	Av. Abund TP mang	Av. Abund BPmang	% contrib. to dissim.	Species	Av. Abund TP mang	Av. Abund ACmang	% contrib. to dissim.	Species	Av. Abund BPmang	Av. Abund ACmang	% contrib. to dissim.
Ambassis jacksoniensis	66.33	1.67	14.29	*Ambassis jacksoniensis*	66.33	0.67	18.76	*Pseudogobius olorum*	31.83	0.00	22.64
Macrobrachium intermedium	22.17	3.33	8.17	*Gerres subfasciatus*	20.67	0.00	11.96	*Gambusia holbrooki*	9.33	0.00	7.98
Gerres subfasciatus	20.67	1.67	9.28	*Macrobrachium intermedium*	22.17	4.00	10.97	*Mugilogobius paludis*	5.00	1.33	7.63
Gobiopterus semivestitus	9.50	2.17	6.64	*Gobiopterus semivestitus*	9.50	2.83	8.46	*Pseudomugil signifer*	5.33	0.33	6.60
Gambusia holbrooki	0.00	9.33	6.28	*Pseudogobius olorum*	4.00	0.00	8.38	*Gobiopterus semivestitus*	2.17	2.83	6.54
Butis amboinensis	0.00	1.00	2.79	*Liza argenta*	4.67	0.00	8.12	*Macrobrachium intermedium*	3.33	4.00	6.26
Pseudogobius olorum	4.00	31.83	11.17	*Acanthopagrus australis*	4.17	0.00	5.53	*Mugilogobius stigmaticus*	2.33	1.17	4.41
Mugilogobius stigmaticus	1.50	2.33	3.74	*Mogurnda australis*	0.00	1.83	4.58	*Mogurnda australis*	0.00	1.83	4.71
Pseudomugil signifer	5.33	5.33	6.16	*Pseudomugil signifer*	5.33	0.33	4.95	*Liza argenta*	1.83	0.33	6.03
Myxus elongatus	4.67	0.00	6.14	*Mugilogobius stigmaticus*	1.50	1.17	4.70	*Ambassis jacksoniensis*	1.67	0.67	4.73
Mugilogobius paludis	1.17	5.00	5.20	*Mugilogobius paludis*	1.17	1.33	4.60	*Unidentified sp.*	2.83	0.00	4.38
Acanthopagrus australis	4.17	0.83	4.44					*Butis amboinensis*	1.00	0.00	3.90
Liza argenta	0.33	1.83	4.13					*Acanthopagrus australis*	0.83	0.00	3.67
Unidentified sp.	0.00	2.83	3.42					*Platycephalus fuscus*	1.67	0.17	2.97

4.3.7 Fish abundance and species richness across mangrove sites

ANOVA results showed that fish abundance in mangroves within different sites varied significantly (P=0.05: Table 4.5)

Table 4.5 ANOVA results for fish abundance in mangroves of Towra Point (TP), Bicentennial Park (BP) and Allens Creek (AC), NSW: Cochran's Test C= 0.8395

Source of variation	DF	MS	F	P
Site	2	25284.38	3.50	0.05
Residual	15	7219.80		
Total	17			

The *post-hoc* SNK test for fish abundance within the sites showed mean fish abundance at Towra Point to be significantly higher than the Allens Creek mangrove, but no significant difference could be found between the abundances at Towra Point and Bicentennial Park, and between Allens Creek and Bicentennial Park.

Analysis of variance using Margalfe indices for fish species richness between different mangrove forests revealed significantly higher species richness of fish in Bicentennial Park mangrove (d=1.855) than Allens Creek (d=0.916) and Towra Point (d=1.337). Species richness between Towra Point and Allens Creek were found not differ significantly.

4.4 Discussion

The diversity and abundance of fish visiting the saltmarsh plain has been described for a South Australian saltmarsh by Connolly *et al*. (1997) and a southern Queensland saltmarsh by Thomas and Connolly (2001). The results of the two studies present a contrast. The south Australian saltmarsh was depauperate, with only 19 individuals of two species caught across 48 pop net releases. The Moreton Bay site studied by Thomas and Connolly (2001) was more intensively utilised by fish during the high tide, with 577 individuals from 23 species collected across 134 pop net releases. The only published study between these two latitudes concerns saltmarsh creeks (Gibbs 1986) in Wallis Lake (32^0 20" S) where eleven species of fish including juveniles of seven commercially important species were collected. The possibility of a latitudinal gradient in saltmarsh fish diversity and abundance in eastern Australian therefore warrants examination.

With the exception of the heavily impacted Bicentennial Park saltmarsh, the saltmarshes examined in this study presented a range and abundance of fish more akin to the Queensland sites than the South Australian example. At Towra Point, 16 species were caught in the saltmarsh, which compares well with the 13 species caught during the same high tides in the adjacent mangroves. At Allens Creek on the Hawkesbury River 673 individuals from 12 species were caught, while 100 individuals from 6 species were caught at Bicentennial Park during the same spring tide cycles.

The greater range of species at Towra Point saltmarsh than the other two sites may be related to proximity to the ocean leading to a higher abundance of fish at the site. Drainage patterns might also influence abundance, with Morton *et al*. (1987) finding water depth in a tidal inlet, which fed a saltmarsh flat in Morton Bay, Queensland, being positively related to fish abundance.

The mangroves and saltmarshes of Bicentennial Park occupy land reclaimed by dredge spoil and have occupied their present position for approximately 30 years (Rogers and Saintilan 2001). Saltmarsh occurs in patches, occasionally infested with *Juncus acutus*. The site emerged as a relatively depauperate site with regards to fish diversity and abundance, lower than Towra Point, as well as Allens Creek which occurs in a similar

geomprphic setting (tributary bayhead delta in the middle reaches of the estuary). More systematic sampling would be required to test the hypothesis suggested by the result; that reclaimed or constructed saltmarshes are of lower fisheries value, even after several decades.

Clynick and Chapman (2002) similarly found significant differences of fish assemblages in patchy mangroves from site to site in the same bay and among bays, as did Louis *et al*. (1995) who found the distribution of species varying across eight mangrove stations sampled in the Bay of Fort-de-France, Martinique, and West Indies. The findings of spatial variability in fish use of mangroves raises issues about the relative importance of mangroves between geomorphic settings (Baran 2001).

An *a-priori* expectation might have been that mangrove environments support similar fish assemblages, which might be contrasted to saltmarsh fish assemblages. The data reveals much greater inter-site variability. Neither a mangrove or saltmarsh fish community could be characterized. Fish assemblages appear to depend on both position in the intertidal zone and position in the estuary. Again, more sampling is required to determine if these factors can be systematically defined in controlling fish distribution.

Table 4.6 Summary of results in Chapter 4 (Spatial Variability of Fish Assemblages in Saltmarshes and Mangroves)

Findings	Test	Differences
Fish assemblages		
Saltmarsh vs. mangrove	Analysis of Similirities (ANOSIM)	Fish assemblages differed significantly (P= 0.007) at Towra Point, Bicentennial Park (P= 0.011) and at Allens Creek (P=0.032).
Among salt marshes	Analysis of Similirities (ANOSIM)	Fish assemblages differed significantly (P<0.001) between the Towra Point, Bicentennial Park and Allens Creek
Among mangroves habitats	Analysis of Similirities (ANOSIM)	Fish assemblages differed significantly Between Towra Point and Bicentennial Park (P=0.004), Towra Point and Allens Creek (P=0.013) and Bicentennial Park and Allens Creek (P=0.002)
Fish Abundance		
Among saltmarshes	Analysis of Varience (ANOVA)	Fish abundance varied significantly (P=0.02)
Among mangrove habitats	Analysis of Varience (ANOVA)	Fish abundance varied significantly (P=0.05)
Fish Species		
Saltmarsh Vs. mangrove	Similarity percentages-species contribution (SIMPER)	At Towra Point, dusky flat head and school prawn presence in saltmarsh and absence in mangrove habitat. Mosquito fish, flat tail mullet, glassfish and yellow fin bream absence in the Bicentennial Park saltmarsh At Allens Creek, school prawn presence in saltmarsh and absence in mangrove habitat.
Among saltmarshes	Similarity percentages-species contribution (SIMPER)	Presence of silver biddy glassfish, checkered mangrove goby, school prawn, dusky flathead, yellow fin bream and sand mullet in Towra Point and absence in the Bicentennial Park. Presence of silver biddy and common toad in Towra Point and their absence in Allens

		Creek. Presence of flat tail mullet, glassfish, dusky flathead and checkered mangrove goby in Allens Creek and their absence in Bicentennial Park
Among mangrove habitats	Similarity percentages-species contribution (SIMPER)	Presence of sand mullet in Towra Point mangrove habitat and absence in the Bicentennial Park. Presence of silver biddy, sand mullet, yellow fine bream and blue spot goby in Towra Point and their absence in Allens Creek. Presence of blue spot goby, mosquito fish, flathead gudgeon and yellow fine bream in Bicentennial Park and their absence in Allens Creek.

CHAPTER FIVE

ESTIMATING BURROWING CRAB ASSEMBLAGES IN SALTMARSH AND MANGROVE HABITATS

5.1 Summary

Many researchers have recognized the importance of crabs in the mangrove ecosystem. However, very little is known about the diversity and abundance of burrowing crabs in temperate Australian saltmarshes. In the present study four different survey techniques were employed to investigate the diversity and abundance of crabs in the saltmarsh and mangrove at Towra Point, NSW. The techniques yielded different estimates of species abundance and richness. Four species of burrowing crab; *Heloecius cordiformis, Sesarma erythrodactyla Helograpsus haswellianus* and *Paragrapsus laevis,* were found in the saltmarsh. *H. cordiformis*, *S. erythrodactyla*, and *P. laevis* were also found in the mangrove habitat. A higher crab species richness was found in the *Sarcocornia quinqueflora* and *Sporobolus virginicus* communities than in those dominated by *Juncus krausii*. Pit traps were an effective means of capturing crabs, although the results underestimated *H. cordiformis* abundance. A visual census was found to be an effective means of estimating the density of *H. cordiformis* and *S. erythrodactyla*, but was ineffective in identifying crabs in the more heavily vegetated *Sporobolus* and *Juncus* communities. Surveying crabs beneath artificial blocks may have overestimated the density of *S. erythrodactyla*. Burrow counting is a quick and effective means of estimating crab density, although this method gives no information on assemblage

species richness.

5.2 Introduction

Many researchers have recognized the importance of crabs as 'keystone' species in mangrove ecosystems. Robertson (1986) demonstrated that grapsid crabs (*Sesarma* spp.) processed about 28% of the leaf litter in a mangrove forest (*Rhizophora* spp.) in tropical northeastern Australia. Other tropical Australian studies produced similar results, demonstrating a role played by grapsid crabs in the consumption of leaf litter (Robertson and Daniel 1989, Micheli 1993) and mangrove propagules (Smith 1987, Osborne and Smith 1990, Smith *et al*. 1989, McGuinness 1997). Recent research on Indo-pacific mangroves has confirmed the significant role of grapsid crabs through the processing of organic matter, which is the basis for a coprophagous food chain involving small invertebrates (Lee 1998).

Research has long demonstrated that brachyuran crabs are the prominent members of the intertidal macrofauna of mangrove ecosystems (Sasekumar 1974, Jones 1984, Macintosh 1988, Smith 1991), Studies conducted in Southeastern Australia found nine species of crabs in mangrove forests, of which three species were very common (Chapman and Underwood 1995). Very little is known about the population densities and distribution of crab species in temperate Australian saltmarsh. A variety of methods including Video recording (Colby & Fonseca 1984), burrow counts (Kerwin 1971; Aspey 1978; Krebs & Valiela 1978) and visual census (Golley *et al*. 1962; Nakasone 1982; Hagen 1993) have been used to estimate burrowing crab abundance in tidal mangroves. Of these, visual census and burrow counting have been the most widely employed in Australia (Nobbs and McGuiness 1999, MacFarlane 2002).

Visual census is a relatively simple and non-destructive method to count burrowing crabs. Burrow counting has some limitations, mainly relating to the burrowing behaviour of the target species. Different species of crabs sometimes share and exchange burrows (Griffin 1968; Christy 1982) and some species use interconnecting burrows. Many species of Ocypodid crab seal their burrows at the end of a period of activity on the surface and may not emerge for days, weeks, or even months (Colby & Fonseca 1984;

Warren 1987). However, Warren (1990) and MacFarlane (2002) both report a good correlation between crab burrow density and crab density estimated by other techniques.

The visual census of crabs is predicated upon the emergence of crabs from burrows and their activity on the surface. A variety of factor such as observation time, distance from the observer, and environmental variability may influence the number of crabs observed on the surface (Nobbs and McGuinness 1999). The semaphore crab *Heloecious cordiformis* is common in mangrove forests in temperate Australia and is most visible during low tide and daylight hours (Warren 1987). Populations of this species might be estimated relatively easily using visual census techniques. Some other species may be excluded from visual census due to their less frequent emergence from burrows.

Determining the absolute abundance of burrowing crabs in saltmarsh and mangrove habitats is made particularly difficult due to the destructive and exhausting nature of burrow excavation (Warren 1990). On the other hand, crab emergence from burrows, and their activity in the surface depends on their individual behaviour. For example, *Sesarma erythrodactyla* digs burrows and shelters under stones and debris. The shore crab *Paragrapsus laevis* is found active during day and night at low tide (Chapman and Underwood 1995).

Four different sampling techniques were employed in this study to estimate crab species richness and abundance in a temperate Australian saltmarsh and adjacent mangrove forest, in an attempt to compare the results of these techniques, and to clarify differences in assemblages between mangrove and saltmarsh habitats. The techniques employed were visual census, pit traps, burrow counting, and a novel technique of utilising artificial structures.

5.3 Study Site and Methods

This study was conducted in the mangrove forest and saltmarsh of Towra Point, Botany Bay, Australia (Figure 5.1). Towra Point was selected because of its large extent, relatively undisturbed condition, and diversity of saltmarsh communities. The mangrove forest is dominated by *Avicennia marina*, and the less common *Aegicerus corniculatum*

(McGuinness 1990). The saltmarsh flora is dominated by *Sarcocornia quinqueflora* and *Sporobolus virginicus*, with *Samolus repens Suaeda australis Triglochin striata* and *Juncus kraussi* also represented (Clarke and Hannon, 1967, Adam *et al*. 1988). The vegetation and inundation characteristics of the study area are similar to with other coastal wetland habitats in the region (Rogers & Saintilan 2002).

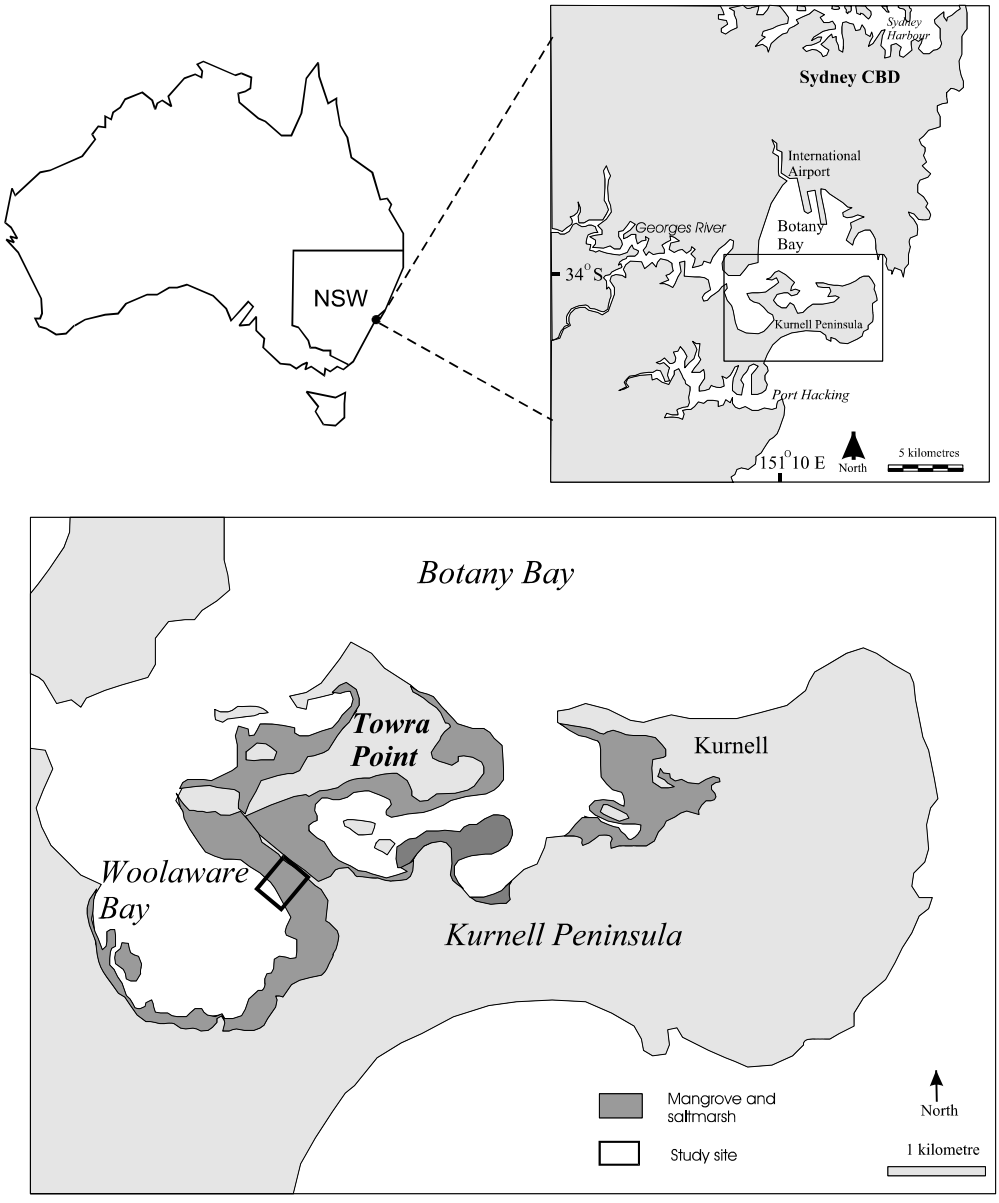


Figure 5.1 Map of Australia showing the location of saltmarsh and mangrove of Towra Point study area NSW.

Four different techniques used to assess crab abundance and diversity in saltmarsh and mangrove habitats at Towra Point are described next.

5.3.1 Visual census of crabs

Two sites within the saltmarsh dominated by *Sarcocornia quinqueflora* and two sites in a mangrove dominated by *Avicennia marina* were selected haphazardly to visually count crabs. A visual census of crabs was not possible within the *Juncus krausii* and *Sporobolus virginicus* communities because of the density of the vegetation. A visual census was performed in clear weather in April, August and December 2002. Saltmarsh and mangrove habitats were sampled in the same day after tide water had fully receded.

Six 0.25 m^2 quadrats marked with 0.2 meter PVC pipe were placed equidistantly in a circle at each site. The distance of each quadrat from the observer was approximately 10 m. The emergence of crabs inside quadrats was observed with a pair of binoculars. Quadrats were observed for three 10-minute intervals following the technique described by Nobbs and McGuinness (1999). Crabs were identified to species level.

5.3.2 Burrow counting

The burrow counting method (Warren, 1990, MacFarlane 2002) was performed on the same day of as the visual census in April, August and December 2002. Eighteen 0.25 m^2 quadrats were placed randomly within 20 x 50 metre plots in each of three distinct saltmarsh communities (*Sarcocornia*, *Sporobolus* and *Juncus*). In mangrove forest, eighteen 0.25 m^2 quadrats with a single 20 X 50 m plot were placed randomly to count crab burrows.

5.3.3 Pit-Trap Sampling

The Pit-trap described by Salmon and Hyatt (1983) was used with some modifications. The pit-traps consisted of a 0.15 m diameter plastic pot inserted to a depth of 0.15 m, the opening flushed with the marsh surface. Traps were baited with small fish 24 hours prior to the sampling. Seven traps were placed in each of three saltmarsh community types (*Sarcocornia*, *Sporobolus* and *Juncus*) and seven traps in mangrove (*A. marina*). Sample collection was performed in daylight hours once every month, from June 2002 to October 2002. Crabs were removed from the trap during sampling, classified to species and released. The traps were inverted after each sampling event, to prevent crab capture between sampling periods.

5.3.4 Artificial Structures

Rectangular shaped hollow-brick blocks were placed in the saltmarsh and mangrove approximately one year before the actual sampling was performed. The purpose was to mimic the habitat of crabs sheltering beneath structures. Fourteen brick blocks (0.4 m X 0.15 m X 0.2 m) were placed in a saltmarsh and seven blocks in the mangrove forest. Within the saltmarsh, seven blocks were placed in the *Sarcocornia* community and seven in the Sporobolus vegetation community. Blocks were placed in separate plots from those used in the visual census and pit-trap experiments. Sampling beneath the structures was performed in the day-time after tide water fully receded from saltmarsh and mangrove. Sampling occurred monthly from June 2002 to October 2002. During sampling blocks were lifted and the crabs hiding underneath the block were identified to species level. The captured crabs were then released.

Crabs caught by pit-traps and beneath artificial structures were examined for eggs to determine the period to which each species was in berry.

5.3.5 Statistical methods

Differences in the crab assemblages between saltmarsh and mangrove habitats were examined using Bray-Curtis measures of dissimilarity (Bray and Curtis 1957) with data normalised using a square root transformation. Non-metric multi-dimensional scaling (nMDS) plots were also used to demonstrate the patterns of crab assemblages between habitats for each method (Clark *et al*. 2001). Multivariate techniques including ANOSIM (Analysis of Similarity: Clark *et al*. 2001) were used to test for the statistical significance of differences between the crab assemblages between habitats, and within vegetation community in saltmarsh. The contribution made by particular species to the difference in species assemblages was determined using SIMPER (similarity percentages-species contribution, Clark *et al*. 2001) for habitats. Univariate analysis (ANOVA) was performed using GMAV5 (Underwood and Chapman 1989) to evaluate burrow abundance in mangrove and saltmarsh communities. A two-way analysis of variances (Underwood 1997) was used to compare burrow abundance between different vegetation communities and months. The vegetation community, as the first factor, presented four levels (1= *Sarcocornia*, 2= *Sporobolus*, 3= *Juncus*, 4= *mangrove*) and month as second factor, presented three levels (1= April, 2= August and 3= December), which were orthogonal and fixed. A Pearson correlation test between sampling techniques in saltmarsh and mangrove habitat was also conducted.

5.4 Results:

The four techniques employed to investigate crab abundance in saltmarsh and mangrove habitat yielded different results (Table 5.I). Pit-traps collected four species in the saltmarsh: *H. cordiformis*, *S. erythrodactyla H. haswellianus* and *P. laevis*, *H. haswellianus* was the most abundant. Two species, *S. erythrodactyla* and *P. laevis* were caught using pit-traps in the mangrove forest, of which *S. erythrodactyla* was the most abundant species and was found in higher numbers there than in the saltmarsh.

Table 5.1 Species sampled in saltmarsh and mangrove by pit-trap, artificial structure and visual census at Towra Point, 2002.

Species	Pit-trap method				Artificial structure				Visual census method			
	Saltmarsh N=126		Mangrove N=42		Saltmarsh N=70		Mangrove N=35		Saltmarsh N=36		Mangrove N=36	
	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%
H. cordiformis	2	0.22	0	0	4	2.53	0	0	115	76.16	59	44.70
S. Erythrodactyla	198	21.52	97	52.15	141	89.24	56	90.3	36	23.84	73	55.30
H. haswellianus	642	69.78	0	0	12	7.59	0	0	0	0	0	0
P. lavies	78	8.48	89	47.85	1	0.64	6	9.68	0	0	0	0
Total	920		186		158		62		151		132	

Sampling from beneath artificial structures in saltmarsh and mangrove habitats revealed the same four species identified by pit-trap sampling within the saltmarsh, *S. erythrodactyla* was most abundant (89.24%), followed by *H. haswellianus* (7.59%). Two species within the mangrove forest were encountered beneath the structures, with results similar to findings obtained by pit-traps. *S. erythrodactyla* and *P. laevis* were captured, with *S. erythrodactyla* contributing 90.3% of the total count, followed by *P. laevis* (9.68%). Relatively higher numbers (average 2.01/artificial block) of *Sesarma erythrodactyla* were captured using this technique in the saltmarsh than in the mangrove forest (average 1.6/artificial structure).

The visual census produced different results. Two species, *H. cordiformis* and S. *erythrodactyla* were identified in both saltmarsh and mangrove habitats. Within the saltmarsh (*Sarcocornia* vegetation community only), *H. cordiformis* was the most abundant and contributing 76.16% of the total count, and was more abundant there. *S. erythrodactyla* was the most abundant species in mangrove forest, and was found at higher densities than in the saltmarsh. Field observations throughout the study period revealed that *H. haswellianus* had a prolonged breeding period from March to October, that *S. erythrodactyla* was in berry from November to February, and that *P. laevis* had a short breeding period from July to August.

5.4.1 Crab assemblages in saltmarsh and mangrove by pit-trap

A non-metric multidimensional scaling (nMDS) ordination differentiating vegetation community showed that the crab assemblages in mangrove forest were different from the assemblages within the *Sarcocornia*, *Sporobolus* and *Juncus* saltmarsh in each month sampled. A difference was also observed between assemblages in the *Sarcocornia* and *Sporobolus* community, and between the *Sarcocornia* and *Juncus* habitat although no difference was observed between assemblages in the *Sporobolus* and *Juncus* saltmarsh (Figure 5.2).

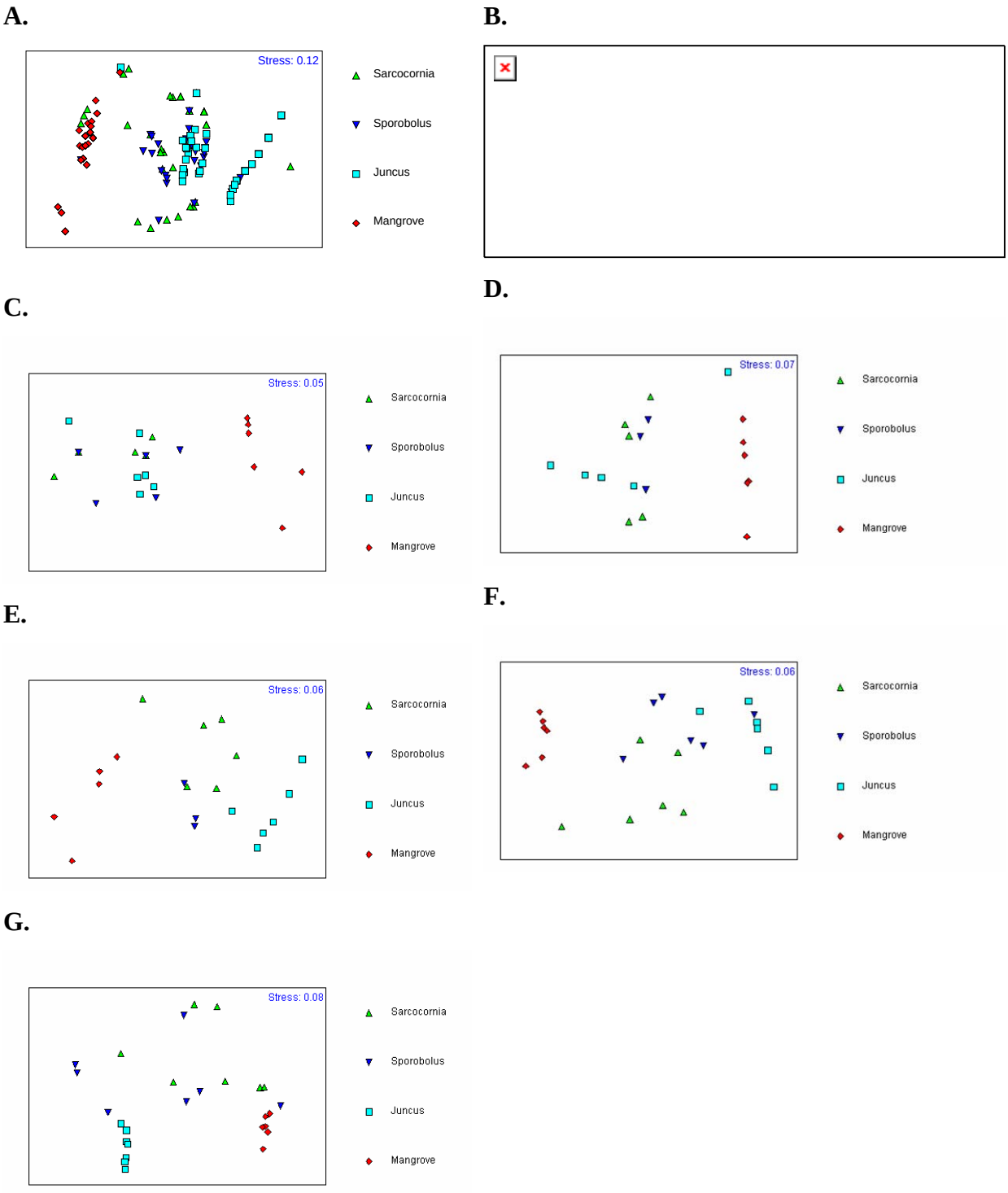


Figure 5.2 Results of an nMDA ordination showing the assemblages of crabs in different vegetation communities within the saltmarsh and mangrove using pit-traps at Towra Point, 2002. (A= all months, B= 12 June, C= 21 June, D= July, E= August, F= September, G= October).

An analysis of similarities (ANOSIM) test on the data collected using pit-trap showed that the crab assemblages in mangrove forest differed significantly from *Sarcocornia* (ANOSIM P<.001), *Sporobolus* (ANOSIM: P<0.001) and *Juncus* habitats (ANOSIM: P<0.001) respectively. SIMPER (Similarity percentages species contribution) tests showed that consistent differences between mangrove and the saltmarsh communities could be primarily attributed to a relatively higher abundance of *P. laevis* and *S. erythrodactyla* in mangrove forest (compared with *Sarcocornia* and *Sporobolus*), the absence of *H. haswellians* in mangrove and the absence of *P. laevis* in *Juncus* vegetation.

The results of the ANOSIM tests showed significant differences between *Sarcocornia* and *Sporobolus* assemblages (ANOSIM: P<0.001), in three of the six months sampled (June, August and September). The results fo the SIMPER method showed that these differences were due to a higher concentration of *H. haswellians* in the *Sporobolus* community. *Sarcocornia* and *Juncus* assemblages showed differences in crab assemblages in all months (ANOSIM: P<0.001), except July with the differences primarily due to the higher abundance of *H. haswellians* in the *Juncus* community. There was an insignificant (ANOSIM: P=0.091) difference between *Sporobolus* and *Juncus* crab assemblages (Appendix 4.1).

5.4.2 Crab assemblages in saltmarsh and mangrove by visual census

The nMDS ordination plots based on a visual census for all months together and for different months showed that the crab assemblages in saltmarsh habitat were different than in mangrove forest (Figure 5.3), although the visual census was conducted in *Sarcocornia* saltmarsh only.

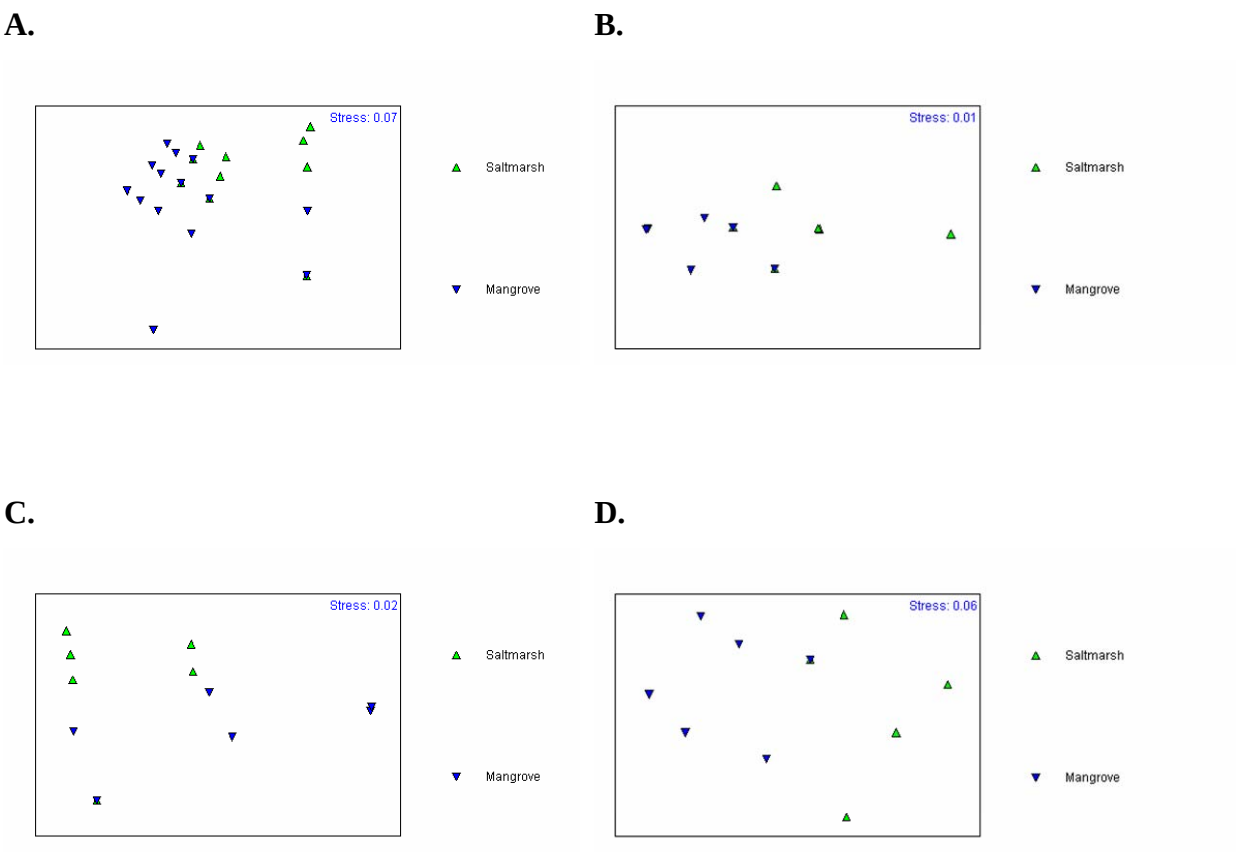


Figure 5.3: The results of an nMDA ordination showing the assemblages of crab in saltmarsh and mangrove using visual census at Towra Point, 2002 (A= all months, B= April, C= August, D= December)

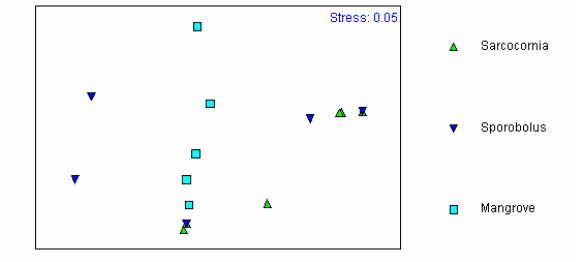
The crab assemblages in saltmarsh communities differed significantly from those in the mangrove forest in April, August and December (ANOSIM: $P<0.001$). The similarity percentages-species contribution (SIMPER) test revealed that the relatively higher abundances of *H. cordiformis* in *Sarcocornia* saltmarsh and *S. erythrodactyla* in mangrove forest were primarily responsible for the dissimilarity between assemblages in *Sarcocornia* saltmarsh and mangrove (Appendix 4.2).

5.4.3 Crab assemblages in saltmarsh and mangrove by sampling beneath artificial structures

Overall, a non-metric multidimensional scaling (nMDS) ordination differentiating the vegetation community showed that crab assemblages in mangrove forest were different from those in the *Sarcocornia* community, but crab assemblages within the *Sarcocornia* and *Sporobolus* community showed no differences.

The nMDS ordination plots for individual months differentiating mangrove, *Sarcocornia* and *Sporobolus* habitats revealed mixed results. The nMDS ordination in June only showed that the crab assemblages in mangrove forest were different from those in both saltmarsh communities. However, the nMDS results for the rest of the sampling months implied no differences of crab assemblages between mangrove and the saltmarsh vegetation or between vegetation communities in saltmarsh (Figure 5.4).

A.



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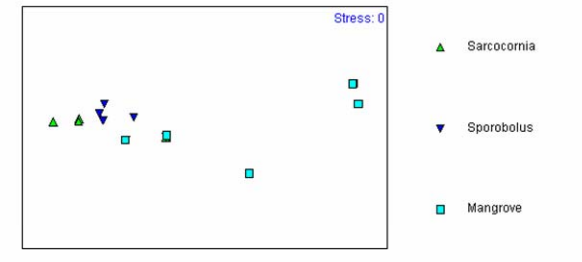
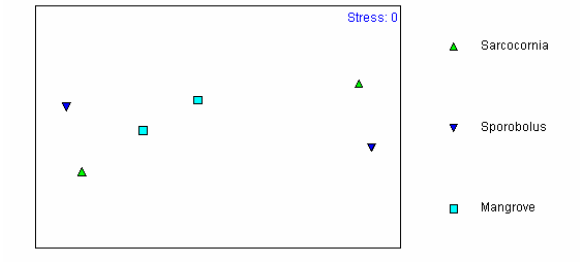
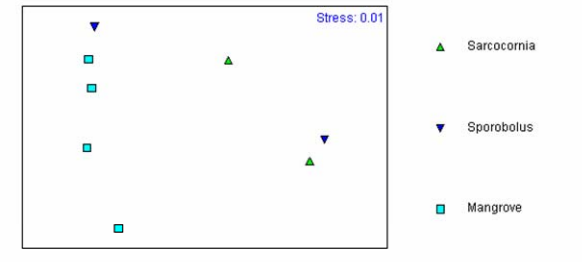


C.



D.



E. **F.**

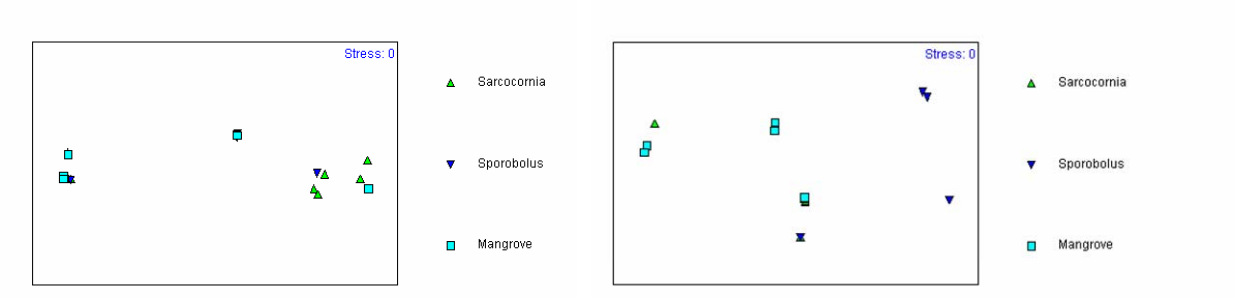


Figure 5.4.The results of an nMDA ordination showing the assemblages of crab in different vegetation community in saltmarsh and mangrove forest using artificial structure at Towra Point, 2002 (A= all months, B= June, C= July, D= August, E= September, F= October).

An Analysis of similarity (ANOSIM) test of data from sampling beneath structures revealed that the crab assemblages in mangrove habitat differed significantly from those in *Sarcocornia* community (P=0.017) but there were no significant differences between mangrove and *Sporobolus* habitats (P=0.09), or between the two saltmarsh communities (P=0.33). The results from the SIMPER tests showed that the abundance of *H. haswellians* in *Sarcocornia* communities and their absence in mangrove forest was mainly responsible for the difference in crab assemblages in these two habitats (Appendix 4.3).

June was the only month in which the ANOSIM tests revealed a difference between mangrove crab assemblage and those sampled in the *Sarcocornia* and *Sporobolus* communities. SIMPER test in June revealed that the difference between mangrove and *Sarcocornia* and *Sporobolus* assemblages were mainly due to the absence of *P. laevis* and higher abundance of *S. erythrodactyla* in the *Sarcocornia* and *Sporobolus* communities (Appendix 4.4).

5.4.4 Crab burrow abundance in saltmarsh and mangrove

The results of an ANOVA showed that burrow abundance was significantly differed between *Sarcocornia*, *Sporobolus*, *Juncus* and mangrove habitats ($P<0.0001$), while no significant differences were found in burrow abundance between months ($P=0.16$: Table 5.2).

Table 5.2 Results of a two way analysis for differences in burrow abundance between vegetation communities and months at Towra Point

Source of Variation	DF	MS	F	P
Vegetation	3	6071.42	249.35	0.0000
Month	2	43.72	1.8	0.16
Ve.Xmo.	6	63.50	2.61	0.018
Residual	204	24.34		
Total	215			

The *post-hoc* SNK test for vegetation communities showed that burrow abundance in the mangrove habitat was significantly higher than in *Sarcocornia*, *Sporobolus* and *Juncus* habitats. Burrow abundance in *Sarcocornia* and *Sporobolus* was significantly higher than in *Juncus* habitats. Burrow abundances between *Sarcocornia* and *Sporobolus* were not significantly different from each other (Figure 5.5).

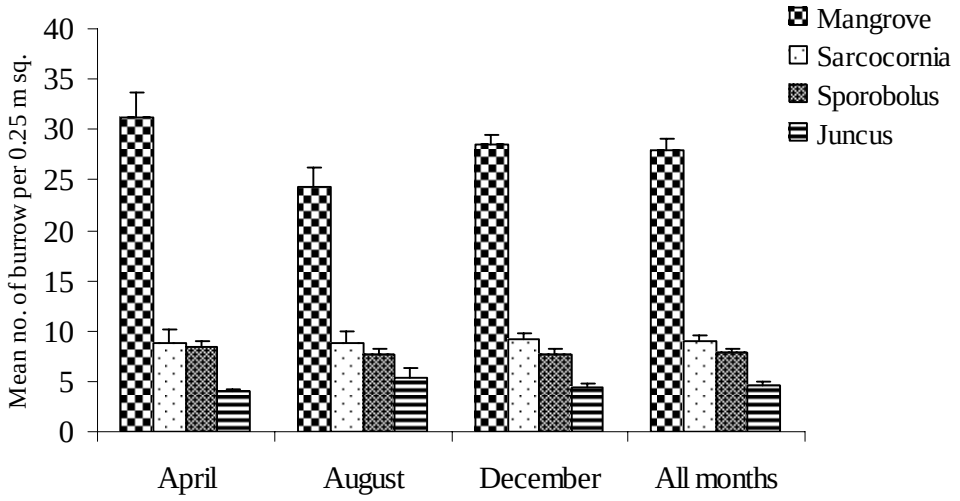


Figure 5.5 Burrow abundance in different vegetations in saltmarsh and mangrove by month and all months together at Towra Point. Mean and standard error (+SE) shown.

5.4.5 Correlations between sampling techniques in saltmarsh and mangrove

The results of a Pearson correlation to test for differences between sampling methods showed insignificant correlations between methods for data collected in the saltmarsh. No significant correlation was observed between trap and artificial structures (P=0.295), traps and visual census (P=0.954), traps and burrow counting (P=0.925), artificial structures and visual census (P=0.444), artificial structures and burrow counting (P=0.382), visual census and burrow counting (P=0.917) for estimating crab abundance in the *Sarcocornia* saltmarsh where all techniques were simultaneously employed.

In mangrove, a positive correlation was observed between the estimates of crab density using traps and burrows (P=0.002) and artificial structures were positively correlated with estimates of burrows (P=0.032) respectively (Appendix 4.5).

5.5 Discussion

A number of conclusions can be drawn from the data concerning the efficiency of the sampling techniques and the differences in crab assemblages between vegetation communities. Four species of crab were found in the saltmarsh, *Helocius cordiformis, Sesarma erythrodactyla Helograpsus haswellianus* and *Paragrapsus laevis.* The most striking difference was the absence of *H. haswellians* from the mangrove habitat and the abundance of this species in the saltmarsh. Pit-trap surveys were able to demonstrate a particularly high concentration of *H. haswellianus* species in the *Juncus* saltmarsh, which may be an artefact of the generally higher elevations at which this community is found. The result is in contrast to the results described by Skilleter and Warren (2000) who found *Parasesarma erythdodactyla* and *H. haswellians* to be the most abundant crabs caught in pit-traps in a subtropical mangrove forest in Moreton Bay, Queensland.

S. erythrodactyla was the most common species found within the mangrove habitat according to all methods. Harty (1997) identified a similar range of mangrove crabs for NSW and Victoria, with the addition of the mud crab *Scylla serrata,* which was not found in this survey.

Other results seemed to be an artefact of the sampling method. The artificial blocks seemed to provide a particularly suitable habitat for *S. erythrodactyla.* The method suggested this to be the most abundant species in the saltmarsh, while visual census identified a higher density of *H. cordiformis* in the *Sarcocornia,* and the pit-traps a higher density of *H. haswellianus* in the same environment.

For all its advantages, the visual census was found to be a relatively inefficient sampling technique, perhaps due to presence of observer during sampling. The presence of human observers in field-based studies of animal behaviour may have a profound effect on the subjects (Macfarlane and King 2002). The census technique failed to identify *P. laevis* in the mangrove, and both *P. laevis* and *H. haswellianus* in the saltmarsh, even though *H. haswellianus* is the most abundant species according to the pit-trap method. This result can in part be attributed to the use of visual census in the *Sarcocornia* community only, due to the thickness of vegetation in the other saltmarsh vegetation types. Skilleter *et al.*

(2000) found difficulties applying visual census in the mangrove of western shore of Moreton Bay, Queensland, because the accumulated leaf litter and the density of mangrove saplings made the crabs difficult to identify and count. A further difficulty with the use of visual census is the degree to which environmental factors influence emergence (Crane 1975, Powers & Cole 1976, Krebs and Valiela 1978, Christy1978).

Burrow counting showed a remarkable degree of temporal consistency over a period of nine months. The mangrove habitat had a far higher density of burrows compared to saltmarshes, an observation that did not correspond to the comparable density of crabs identified by other methods. The relatively rich saltmarsh crab fauna identified in this study corresponds to Northern Hemisphere saltmarshes (Mense & Wenner 1989; Thomas *et al*. 1990; Fitz *et al.* 1991). The variation between burrow density and overall assemblage density is likely to be due to the presence of other crab species besides *H. cordiformis*, which in other studies has shown correlation between burrow numbers and density measured by excavation and video observation (MacFarlane 2002) and by visual census (Warren 1990). Burrow abundance declines with elevation and inversly to the density of *H. haswellianus*. This species, along with *S. erythrodactyla* and *P. laevis*, might show a more variable relationship between burrow density and crab density than that shown by *H. cordiformis*, in a way described by Crichton (1960), Warner (1969), Griffin (1971), and Seiple & Salmon (1982).

Pit-traps showed the greatest efficiency among four techniques employed in saltmarsh and mangrove for surveying crabs. However, the pit-traps were inefficient in capturing the ocypodid crab *H. cordiformis*, which visual census found to be abundant in both saltmarsh and mangrove. Nobbs and McGuinness (1999) also reported that the related Australian *Uca* rarely fall into pit-traps. For this reason, I suggest a combination of pit-trap and visual census, as the most comprehensive strategy for the non-invasive sampling of burrowing crabs.

Table 5.3 Summary of results for Chapter 5 (Estimating Burrowing Crab Assemblages in Saltmarsh and Mangrove Habitats).

Findings	Test	Differences
Crab assemblages		
Saltmarsh vs.mangrove by pit-trap	Analysis of similarities (ANOSIM)	Significant (P<0.001)
Sarcocornia vs. *Sporobolus* community	Analysis of similarities (ANOSIM)	Significant (P<0.001)
Sarcornia vs. *Juncus* community	Analysis of similarities (ANOSIM)	Significant (P<0.001)
Sporobolus vs. *Juncus* community	Analysis of similarities (ANOSIM)	Insignificant (P>0.091)
Saltmarsh vs. mangrove by visual census	Analysis of similarities (ANOSIM)	Significant (P<0.001)
Sarcocornia saltmarsh vs. mangrove by articicial structures	Analysis of similarities (ANOSIM)	Significant (P=0.017)
Burrow abundance		
Saltmarsh vs. mangrove	Analysis of varience (ANOVA)	Significant (P<0.0001)
Crab species		
Saltmarsh vs. mangrove	Similarity percentages-species contribution (SIMPER)	Four species of crabs were found in the saltmarsh, *Helocious cordiformis, Sesarma erythrodactyla*, Helograpsus haswellianus and *Paragrapsus laevis*. Three species were found in the mangrove, *H. cordiformis*, *S. erythrodactyla* and *P. Laevis*.
Crab abundance		
Saltmarsh vs. mangrove	Similarity percentages-species contribution (SIMPER)	Higher abundance of *H. haswellians* in *Sporobolus* saltmarsh and higher abundance of *P. laevis* and *S. erythrodactyla* in mangrove habitat.

CHAPTER SIX

EXPORT OF ZOOPLANKTON FROM SALTMARSH TO ESTUARY

6.1 Summary

The contribution made by saltmarsh to estuarine zooplankton was examined through a comparison of inputs and outputs of tidal water in the mangrove and saltmarsh environments of the Kurnell Peninsula, NSW. Saltmarshes proved to be a net exporter of crab zoae and gastropod larvae, although they were a sink for copepods and amphipods. Crab larvae export was more pronounced from saltmarsh than mangrove habitats, and displayed a strong winter and smaller summer peak. Zooplankton densities were higher in water exiting saltmarsh than in any of the shallow-water estuarine environments sampled. The presence of high concentrations of zooplankton, predominantly crab larvae, in the saltmarsh represents an efficient, if periodic, food source for estuarine fish.

6.2 Introduction

The export of detritus from mangrove forests (Boto & Bunt 1981, Flore-Verdugo *et al*. 1987) and saltmarshes in the USA (Nixon 1980, Dame *et al*. 1986) has been studied extensively, although mostly in the form of larger litter. The materials exported from these habitats to coastal water are believed to contribute to primary production as well as food for many aquatic consumers, including fish. However, experimental studies of detritus utilization by macro-consumers have shown that the role of detritus in estuarine food chains is far more complex (Boesch and Turner 1984). While some studies of saltmarshes in North America stated that a major part of the primary production in an saltmarsh is exported to adjacent waters; this was not found to be the case in detailed studies (Morrisey 1995). Furthermore, studies of the productivity of various plant communities in Botany Bay (Larkum 1981) suggested that saltmarshes contributed only 6% to the primary productivity within the bay, while seagrass, mangrove and phytoplankton were the major contributors. The contribution of saltmarsh detritus may not be as direct or important to the food chains supporting fishery species than was once thought (Boesch and Turner 1984).

On the other hand, studies of the export of animal biomass from mangrove areas have suggested a contribution of crabs to the flow of animal biomass (crab zoea) between the mangroves and more offshore systems (Lee 1995). The work of Dittel and Epifanio (1990) and Dittel *et al*. (1991) in Costa Rica showed a net export of crab zoea to estuarine waters. This flow of animal biomass in the form of crab zoea may play a very crucial role to estuarine food chain. Robertson *et al.* (1988) found that brachyuran zoea, a major prey of fish in North-eastern Australia, were an order of magnitude more abundant in mangrove habitats in summer, when a number of species of juvenile fish were recruited into the tidal creeks. Some North American studies reported that larvae of *Uca* spp. are flushed from the marsh environment soon after hatching (Christy and Stancyk 1982, Lambert and Epifanio 1982). Extrapolation from Northern Hemisphere studies to Australia is difficult because of the different topographic situation and structure of the marshes, as well as the different species assemblage (Mazumder and Saintilan *in press*). Here, I hypothesize a role for crabs and gastropods inhabiting saltmarsh in contributing to

estuarine productivity through the export of larvae.

The survey of zooplankton dynamics described in the chapter has four major objectives

1) to investigate a potential contribution of saltmarsh to estuarine water through the net production and export of zooplankton

2) to examine the abundance of zooplankton within shallow estuarine habitats during an ebbing tide

3) to compare the export of zooplankton from mangrove and saltmarsh, and

4) to examine the variation in zooplankton assemblages across sites

6.3 Study sites and Methods:

6.3.1 Study Sites

Towra Point

The study investigated zooplankton import and export from saltmarsh environments in four distinct sites (Figure 6.1). Towra Point, within Botany Bay, represented a relatively undisturbed sandy marine delta. Four species of crabs (*Heloecius cordiformis*, *Sesarma erythrodactyla Helograpsus haswellianus* and *Paragrapsus laevis*) were found in the saltmarsh. Three of these species; *H. cordiformis*, *S. erythrodactyla,* and *P. laevis* were also found in the mangrove at Towra Point (Chapter 5, Mazumder and Saintilan 2003)

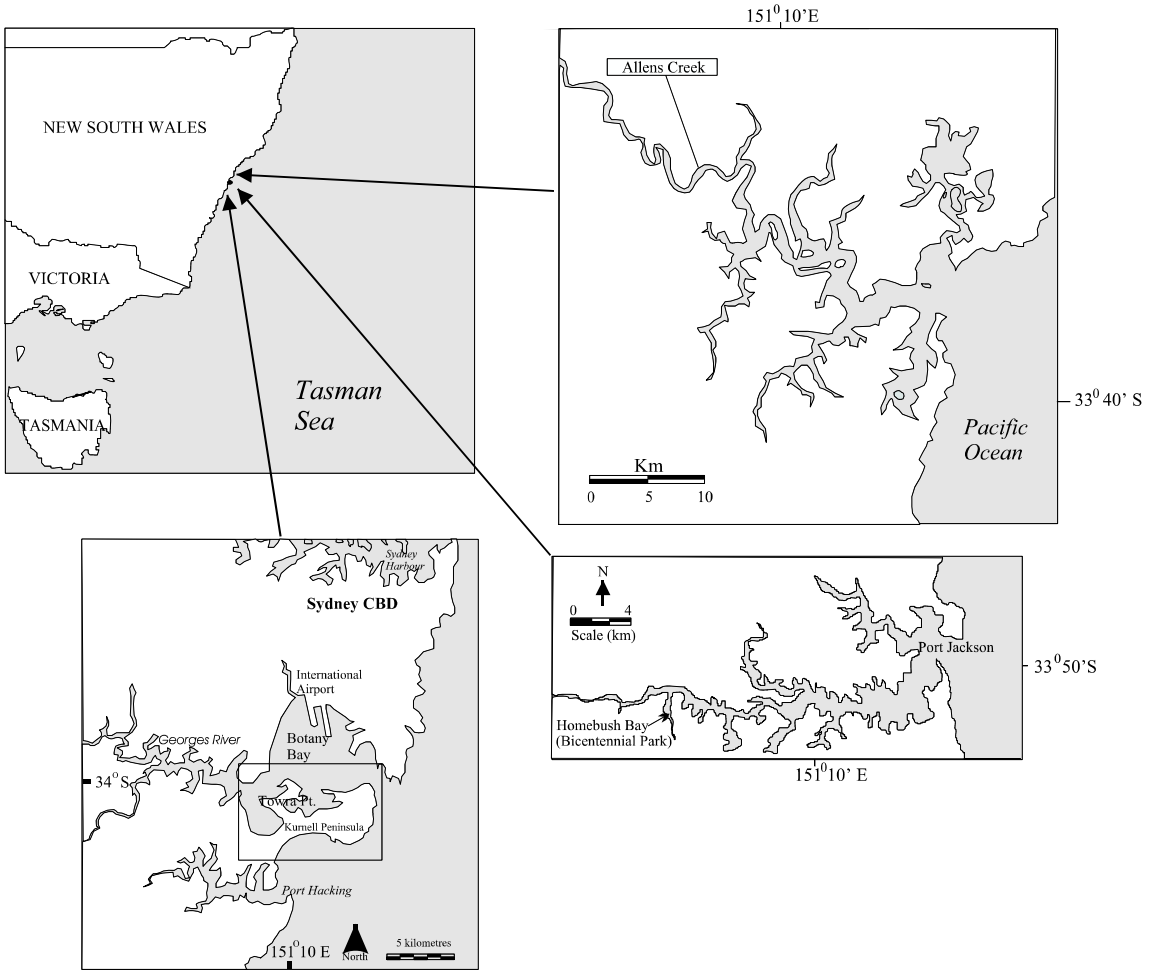


Figure 6.1. Map of Australia showing the location of study sites, Towra Point, Kurnell, Bicentennial Park and Allens Creek, NSW**.**

Kurnell

The Kurnell mangrove occupies the north-eastern shore of Quibray Bay, and is adjacent to the Towra Point wetlands. The site was chosen because the saltmarsh has been reclaimed, and the wetland vegetation consists of a mangrove stand dominated by *Avicennia marina* growing on a sand delta.

Allens Creek

Allens Creek on the Hawkesbury River at Spencer is an example of a tributary delta within the fluvial deltaic segment of the Hawkesbury River estuary. The saltmarsh assemblage is identical to that of Towra Point, though *Suaeda australis* is absent. The saltmarsh flat is drained by a single creek that is constrained by a bridge crossing near its entrance, and this location was utilized for zooplankton sampling.

Bicentennial Park

The Bicentennial Park site is also a tributary delta within the middle reaches of the Parramatta River. The mangrove forest in Bicentennial Park is extensive while the saltmarsh is patchy and dominated by *Sarcocornia quinqueflora, Sporobolus virginicus* and *Juncus acutus*. The mangrove forest is drained by Powells Creek, and a bridge crossing was used as an access point for zooplankton sampling.

6.3.2 Zooplankton collection from Towra Point

The mangrove and saltmarsh environments on the Woolaware Bay side of Towra Point are separated by a low natural levee, punctured at intervals by tidal creeks. These breaks in the levee were utilized as fixed replicate points for sampling zooplankton inputs and outputs. A 1.5 meter long 350 micro-meter mesh plankton net with a 40cm diameter opening was deployed monthly within the levee breaks during incoming and outgoing spring tides. Four replicate samples were taken at two points during the incoming and outgoing tides, each haul being of two minutes duration, to yield a total of 16 samples. Zooplankton samples were collected from March 2001 to August 2002 during the spring high tide. Typically larger tides in winter months are at night and in summer are in the day. The volume of water (Table 6.1) passing through the net was calculated using General Oceanics Flow-meter (model M-2030). The ebb tide flows more quickly than the flood tides, a fact that is adjusted in the volumetric comparisons.

Table 6.1 The volume of in-flowing and out-flowing tidal waters of the saltmarsh at Towra Point 2001/02.

Month	Location 1		Location 2	
	In-flowing tide (cubic metres)	Out-flowing tide (cubic metres)	In-flowing tide (cubic metres)	Out-flowing tide (cubic metres)
Mar. 01	9.53	11.11	12.70	9.60
Apr. 01	10.05	10.05	10.05	12.93
May 01	8.62	12.07	6.70	8.62
Jun. 01	6.03	6.03	10.05	12.07
Jul. 01	8.62	12.07	6.70	10.05
Aug. 01	16.89	13.41	13.20	13.20
Sept. 01	10.72	13.79	13.41	14.19
Oct. 01	12.07	12.07	13.41	13.41
Nov. 01	6.70	8.04	8.04	10.05
Dec. 01	6.03	9.28	6.03	6.03
Jan. 02	10.05	12.07	12.07	12.07
Feb. 02	8.62	10.05	8.62	12.07
Mar. 02	8.62	12.07	6.70	10.05
Apr. 02	8.62	7.54	7.54	7.54
May 02	10.05	12.07	6.70	8.62
Jun. 02	6.03	6.03	10.05	10.05
Jul. 02	8.62	10.05	6.03	8.62
Aug. 02	10.05	12.07	7.54	10.05

6.3.3 Larvae Collection

Crab larva collection within near shore habitats at Towra Point

A permanent transect was laid out from the upper boundary of the saltmarsh to a point approximately 150 m offshore. The transect was divided into four sectors (A = saltmarsh, B = mangrove, C = seagrass and D = bay, unvegetated) to examine zooplankton distribution across a range of shallow habitats. Location ‘A’ was a break in a levee separating mangrove and saltmarsh habitats, which provided a fixed point from which saltmarsh inputs and outputs could be assessed. Crab larvae released in the saltmarsh

entered the mangrove forest through this point and then dispersed into the bay water. By sampling within the mangrove forest (location B), we sought to determine whether the densities of larval within the mangrove forest were as high as in the saltmarsh. Location B (in the middle of mangrove) was 50 m seaward of A. Locations C and D were approximately 100 m and 150 m from location A and were sampled to determine the rate of dilution of wetland-sourced zooplankton into the estuarine waters (Figure 6.2).

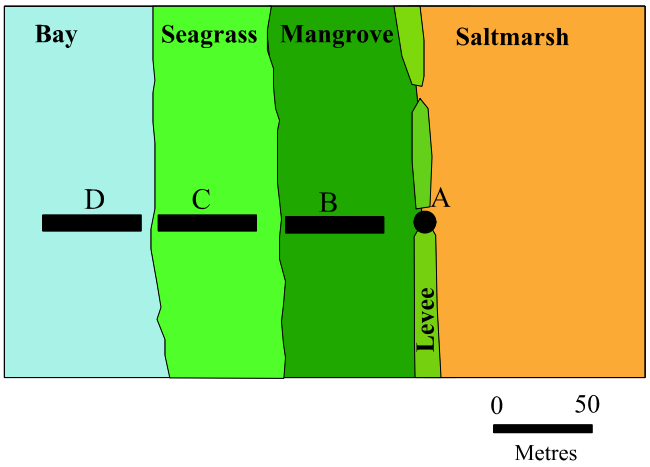


Figure 6.2 The position of a transect in saltmarsh, mangrove, seagrass and bay habitats for sampling zooplankton at Towra Point, Sydney, NSW.

Two 1.5 m long 350 micro-meter mesh plankton nets with 40 cm diameter opening were used; one net collected larva released from the saltmarsh and other net collected larva from the three other locations during ebb tides. Four replicate zooplankton samples were taken from each sector sequentially, with each haul being two minutes long. The volume of water passing through the net (Table 6.2) was calculated using General Oceanics Flow-meter (model M-2030). Samples were collected in September 2002, as year-round sampling at saltmarsh (point ‘A’) suggested that a median volume of crab larvae from *Helograspus haswellianus* was released at this time.

Table 6.2 The volume water sampled during out-flowing tidal waters of saltmarsh, mangrove, seagrass and bay at Towra Point, 2001/02.

Month	**Saltmarsh (cubic meter)**	**Mangrove (cubic meter)**	**Seagrass (cubic meter)**	**Bay (cubic meter)**
Sept.02	14.08	10.44	11.90	12.33

Zooplankton collection from Kurnell

The Kurnell mangrove was chosen to sample the mangrove outputs. A 1.5 m long 350 micro-meter mesh plankton net with 40 cm diameter opening was used to collect zooplankton in incoming and outgoing tides. Four replicate tows from a small zodiac boat were performed during incoming and outgoing tides from the only creek draining the mangrove forest. Each plankton tow was two minutes long. Four samples were collected from the flood tide and four samples from the ebb tide. Samples were collected in December 2001, January and June 2002 during the spring high tide, at times when the Towra saltmarsh was also sampled for zooplankton. A General Oceanics Flow-meter (model M-2030) was used to calculate the amount of water (Table 6.3) passing through net while towing.

Table 6.3 The volume of water sampled during in-flowing and out-flowing tidal waters at Kurnell mangrove at Quibray Bay, 2001/02.

Month	**Kurnell mangrove**	
	In-flowing tide (cubic meter)	**Out-flowing tide (cubic meter)**
Dec. 01	10.24	14.08
Jan. 02	10.85	11.66
Jun. 02	8.98	13.04

Zooplankton collection from Bicentennial Park

In Bicentennial Park, zooplanktons were collected from the mouth of the main entrance channel entering the mangrove forest. Through this channel zooplankton released from

the saltmarsh and mangrove entered into the bay water. A plankton net (1.5 m long, 350 micro meter-mesh with 40 cm diameter opening) was deployed during incoming and outgoing spring tides. Four replicate samples were taken during the incoming and outgoing tides, each haul being of two minutes long. Zooplankton samples were collected in December 01, January and August 02 during the spring high tide. The volume of water passing through the net (Table 6.4) was calculated using a General Oceanics Flow-meter (model M-2030).

Table 6.4 The volume of water sampled during incoming and outgoing tide at Bicentennial Park, 2001/02.

Month	**Bicentennial Park**	
	In-flowing tide (cubic meter)	**Out-flowing tide (cubic meter)**
Dec. 01	12.07	15.08
Jan. 02	10.05	12.07
Aug. 02	12.93	16.45

Zooplankton collection from Allens Creek

Four replicate incoming and outgoing samples were collected in December 01, January 02 and August 02 during the spring high tide. A General Oceanics Flow-meter (model M-2030) was used to calculate the volume of water (Table 6.5) passing through the net during zooplankton collection.

Table 6.5 The volume of water sampled during incoming and outgoing tide at Allens Creek 2001/02.

Month	**Allens Creek**	
	In-flowing tide (cubic meter)	**Out-flowing tide (cubic meter)**
Dec. 01	10.83	12.07
Jan. 02	12.67	15.84
Aug. 02	9.38	12.42

After each operation zooplankton concentrated in the funnel attachment of the net were collected and preserved with 10% formaldehyde solution. Zooplankton investigation and density estimates followed the methods of Edmondson, and Winderg (1971). Because the object of this study was to determine the relative importance of crab larvae in zooplankton export, zooplankton were grouped in five major categories: crab larva, gastropod larvae, copepod, amphipod and other zooplankton

6.3.4 ***Pilot Study***

A pilot study was conducted at Towra Point to test the methodology and the degree of variability within tidal sequences for crab larval release. Samples were collected from the three consecutive spring tideal (from 1.7 m onwards) events, for three separate months. At Towra Point, tides reported as less than 1.7 m at Fort Dennison did not cover the saltmarsh completely. Four replicate outgoing samples were collected on three consecutive days from the two sampling points (100 m apart) in March, November and January 01. A General Oceanics Flow-meter (model M-2030) was used to calculate the volume of water passing through the net during larval collection. ANOVA and *Post-hoc* SNK tests were performed using GMAV5 (Underwood and Chapman 1989) to determine the difference of crab larval released (abundance) between three consecutives high tides in a month.

6.3.5 Results of Pilot Study

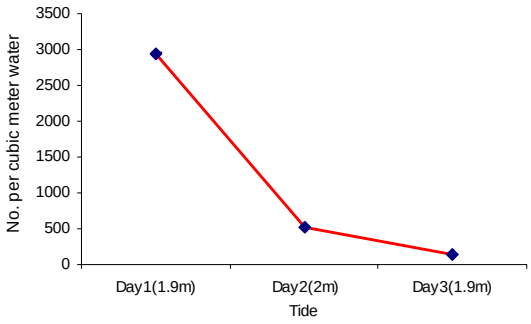
Results of an ANOVA showed that crab larval exported from the saltmarsh varied significantly (*P<0.0001*) between tides in every sampling month (Appendix 5.1).

The *post-hoc* SNK test showed that significantly larger larval release occurred in January in the first high tide in the sequence, which was higher than in subsequently larger tides (Figure 6.3 A-C). Larval release in November was significantly higher in the largest tide in the sequence than in previous high tides and, in March, significantly higher release was

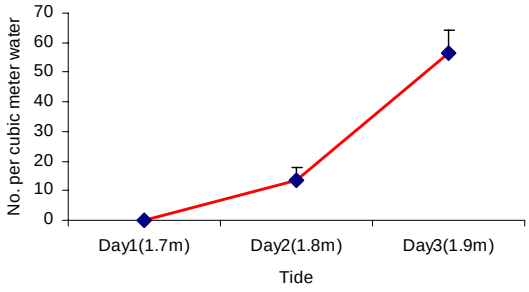
found in first high tide in the sequence.

The results of the study suggest that crabs living in the saltmarsh released larvae in the high spring tide, but not necessarily in the first high tide in the sequence to cover the saltmarsh. The first tide reaching 1.8 meters may be a signal to crabs prompting a more substantial release on the subsequent high tide. Crabs do not necessarily wait for the largest tide in the sequence because no larger tide may come in some months. Based on the results of the pilot study, it was decided not to sample tides early or late in the spring tide sequence.

A. January 2001



B. November 2001



C. March 2001

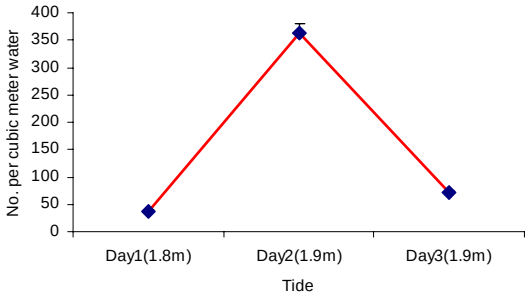


Figure 6.3 (A-C). Crab larval released in three consecutive ebb tides from saltmarsh at Towra Point, Botany Bay, 2001.

6.3.6 Data analysis: Main study

Differences in the zooplankton assemblages between incoming and outgoing tides were examined using the Bray-Curtis measures of dissimilarity (Bray and Curtis 1957) using square root transformed data. Non-metric multidimensional scaling (nMDS) diagrams were used to display the patterns of zooplankton assemblages in different months between flood and ebb tides within saltmarsh at Towra Point, and between saltmarsh and mangrove environments and across sites (Clarke and Warwick 2001). Multivariate techniques such as ANOSIM (Clarke and Warwick. 2001) were used to test for statistical significance of differences between the zooplankton assemblages within tides, and habitats and between sites. The contribution made by a particular species to differences in species assemblages was determined using SIMPER (similarity percentages-species contribution, Clarke and Warwick. 2001) for tides, habitats and sites.

Two factor univariate analysis (ANOVA) and *post-hoc* Student-Newmans-Kuels (SNK) tests were performed using GMAV5 (Underwood and Chapman 1989) to determine the significance of differences of crab larva, gastropod larva, copepod, amphipod and other zooplankton abundance between incoming and outgoing tides in different months at Towra Point the main study site, and at the Bicentennial Park and Allens Creek reference sites.

Univariate analyses (ANOVA) were also performed to determine the significance of differences between locations for larval abundance. Univariate analysis (ANOVA) was performed to determine differences in larval abundance between four locations on a transect from the saltmarsh to the bay. Data were square root transformed before analysis to remove heterogeneity of variances. Location was considered in the analysis as a random factor with four levels (1= A, 2= B, 3= C and 4= D) which were orthogonal and fixed.

Three factor univariate analysis (ANOVA) and *post-hoc* Student-Newmans-Kuels (SNK) tests were performed to determine the significance of differences in crab larvae, gastropod larvae, copepod, amphipod and other zooplankton in incoming and outgoing tides across sites and in common sampling months.

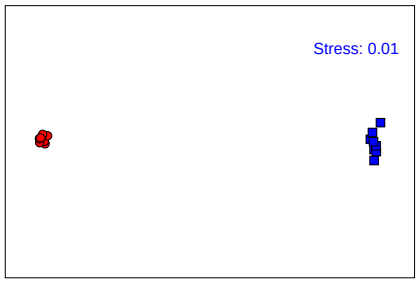
Three factor ANOVA and SNK tests were also performed to determine differences of crab and gastropod larval abundance between incoming and outgoing tides within saltmarsh and mangrove habitats in different months. Tide, the first factor, presented two levels (1= Incoming tide, 2= Outgoing tide), 'Site' as second factor presented two levels (1= saltmarsh, 2= mangrove), and 'Month', as third factor, presented three levels (1= December 01, 2= January 02 and 3= June 02) which were orthogonal and fixed. A Pearson correlation test also performed to examine the correlations between crab and gastropod larval abundance in the out-flowing tidal water.

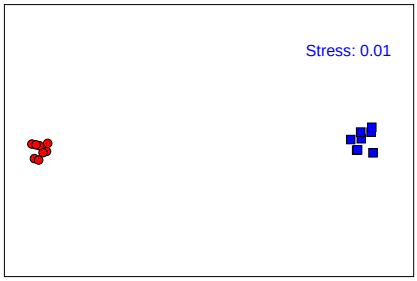
6.4 Results:

6.4.1 Zooplankton assemblages in incoming and outgoing tides in saltmarsh

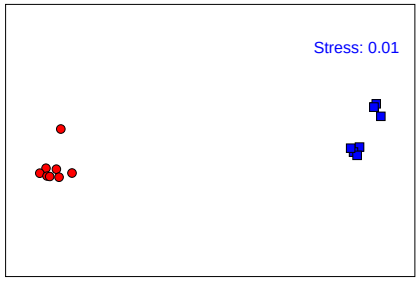
Non-metric multidimensional scaling (nMDS) ordinations in different months showed different assemblages of zooplankton in incoming and outgoing tides at Towra Point in each of the months sampled (Figure 6.4).

March 2001 **April 2001**

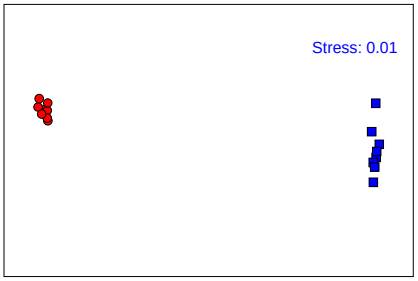




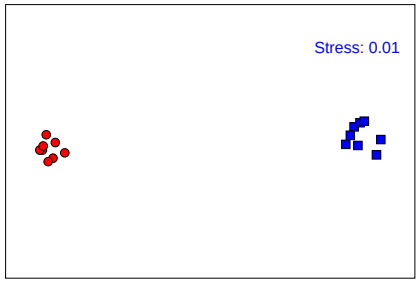
May 01



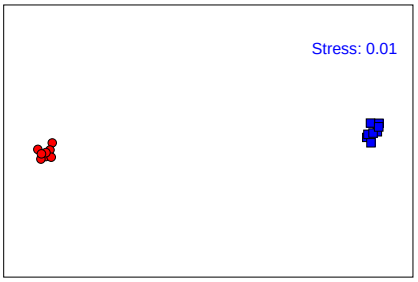
June 01



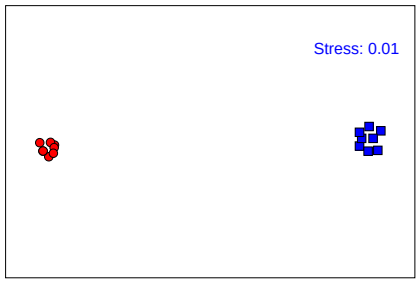
July 01



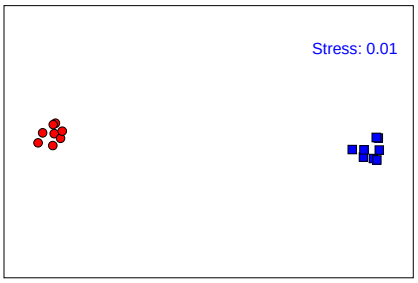
August 01



September 01

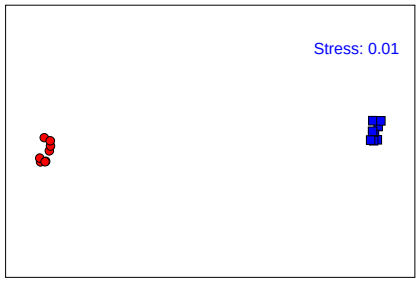


October 01

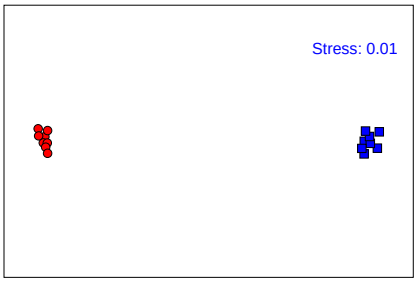


November 01

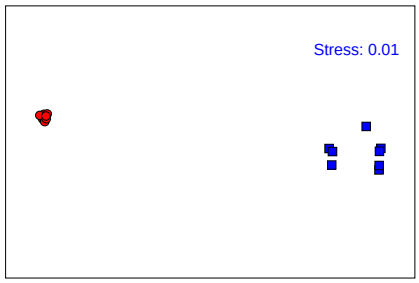
December 01



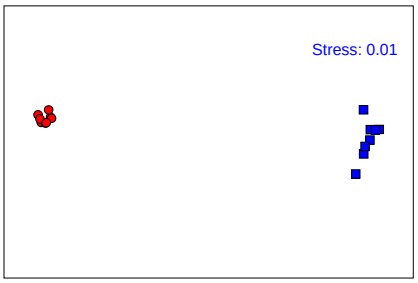
January 02



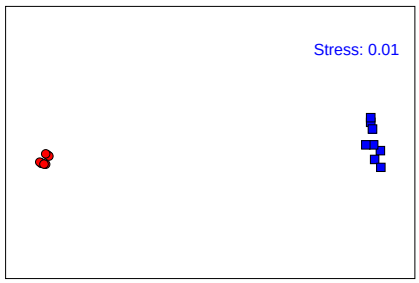
February 02



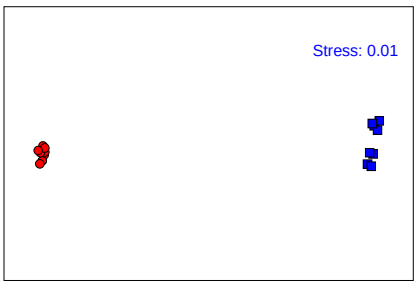
March 02



April 02



May 02



June 02

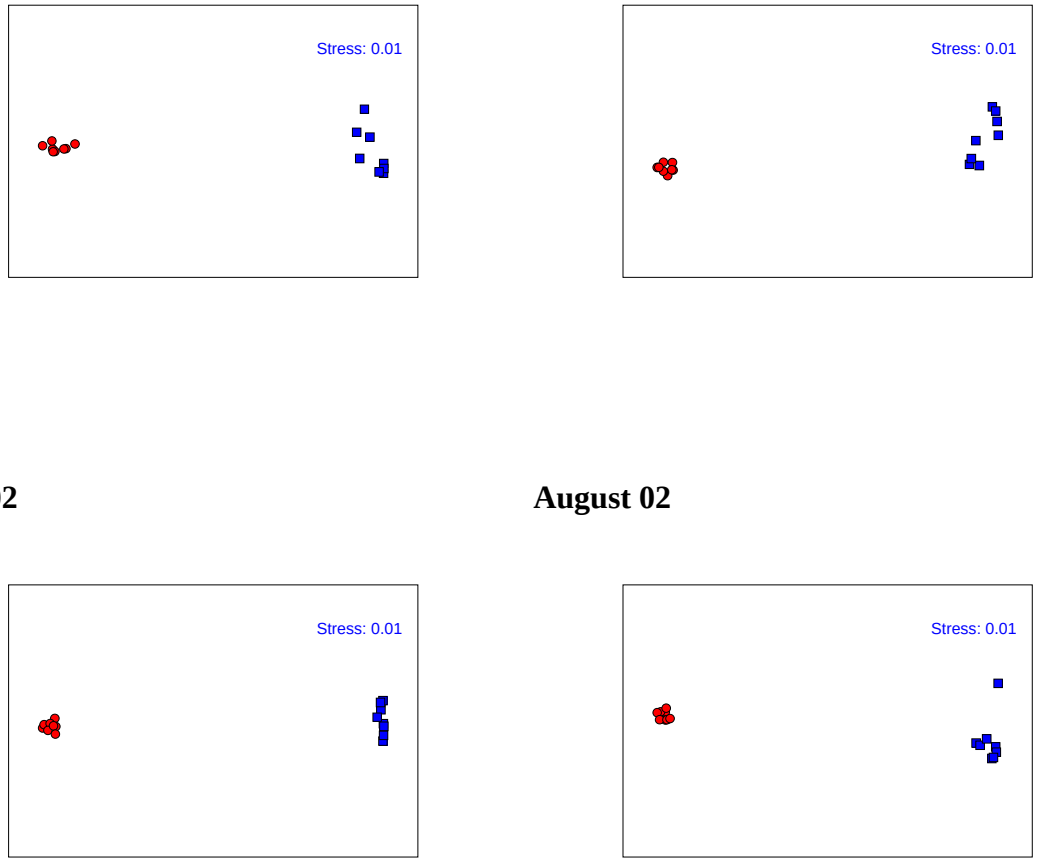


Figure 6.4 Results of an nMDS ordination showing assemblages of zooplankton in incoming and outgoing tides in saltmarsh at Towra Point, Botany Bay, March 2001 to August 02. ■ = Incoming ● = Outgoing

An Analysis of similarities (ANOSIM) showed that zooplankton assemblages between incoming and outgoing tides differed significantly in all sampling months (ANOSIM: P< 0.001) (See Appendix 5.2). Similarity Percentages -species contributions (SIMPER) results showed that the dissimilarity between the two tides was primarily due to the abundance of crab and gastropod larvae in the outgoing tides from saltmarsh and relatively higher abundance of copepod and amphipod in the incoming tides than outgoing tides (Appendix 5.3).

Abundance of crab larva in Towra Point saltmarsh

Results from an ANOVA confirmed that crab larval abundance in incoming and outgoing tides in saltmarsh varied significantly ($P<0.0001$). Crab larval abundance between tidal phase (incoming vs. outgoing) and month also varied significantly ($P<0.0001$) (Table 6.6).

Table 6.6 Results of a Two-way ANOVA of crab larval abundance between tidal phase (incoming and outgoing) and months at Towra Point saltmarsh, Botany Bay, NSW: Cochran's Test C= 0.1410

Source of variation	**DF**	**MS**	**F**	**P**
Tide (incoming & outgoing)	1	3789748.75	498.12	0.0001
Month	17	7209922.95	474.81	0.0001
Tide X Month	17	7177144.70	440.04	0.0001
Residual	252	942.62		
Total	287			

The *post-hoc* SNK test for crab larval abundance between incoming and outgoing tides showed significant differences. Few crab larvae were present in the incoming tide (mean abundance 4^{m-3} water), whereas large numbers of crab larvae were present in the outgoing water (mean abundance 2124.63^{m-3} water). The *post-hoc* SNK test for crab larval abundance between incoming and outgoing tides in saltmarsh in different months showed significantly higher numbers of crab larvae in the outgoing tide compared to incoming tide in all months (Figure 6.5), with the exception noticed in December 01, when no crab larvae ware found in the incoming or outgoing tides.

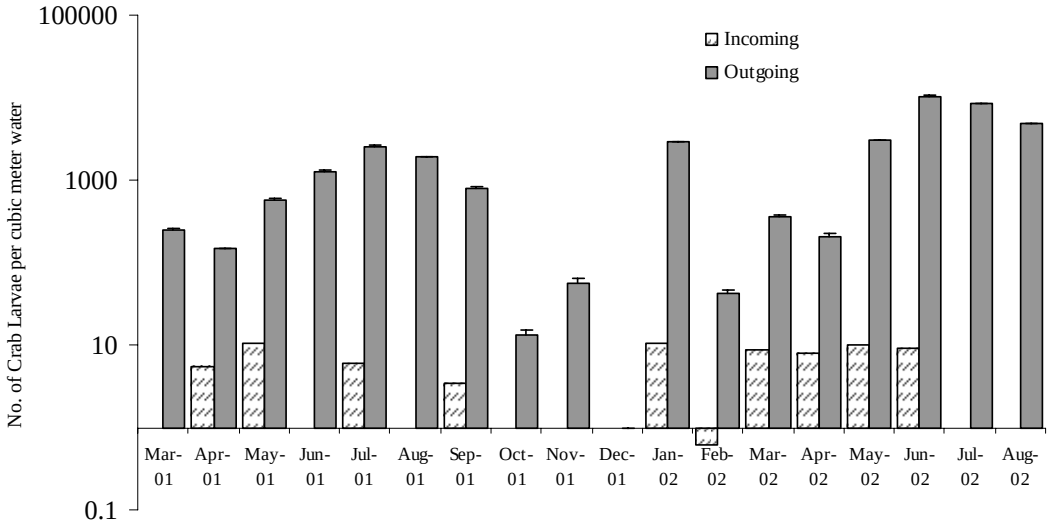


Figure 6.5 The mean (+SE) abundance of crab larva in in-flowing and out-flowing tidal waters of saltmarsh at Towra Point, 2001/02. Logarithmic scale shown.

Abundance of gastropod larva in tidal water at Towra Point saltmarsh

Results from an ANOVA for gastropod larval abundance between incoming and outgoing tides in saltmarsh showed a significant ($P<0.0001$) difference. Gastropod larval varied significantly between months ($P<0.0001$) (Table 6.7).

Table 6.7 Results of a Two way analysis of gastropod larval abundance between tidal phase (incoming and outgoing) and months at Towra Point saltmarsh, Botany Bay, NSW: Cochran's Test C= 0.0800.

Source of variation	DF	MS	F	P
Tide (incoming & outgoing)	1	9950716.00	577.61	0.0001
Month	17	3459354.59	569.16	0.0001
Tide X Month	17	0850548.27	388.26	0.0001
Residual	252	1196.20		
Total	287			

The *post-hoc* SNK tests for gastropod larval abundance between tidal episode showed that ther were significantly higher numbers of gastropod larvae (3764.94^{m-3} water) were present in the outgoing tide compared to incoming tide (56.93^{m-3} water). The *post-hoc* SNK test for gastropod larval abundance between incoming and outgoing tides in different months showed significantly higher numbers of gastropod larvae in the outgoing tide in all months (Figure 6.6).

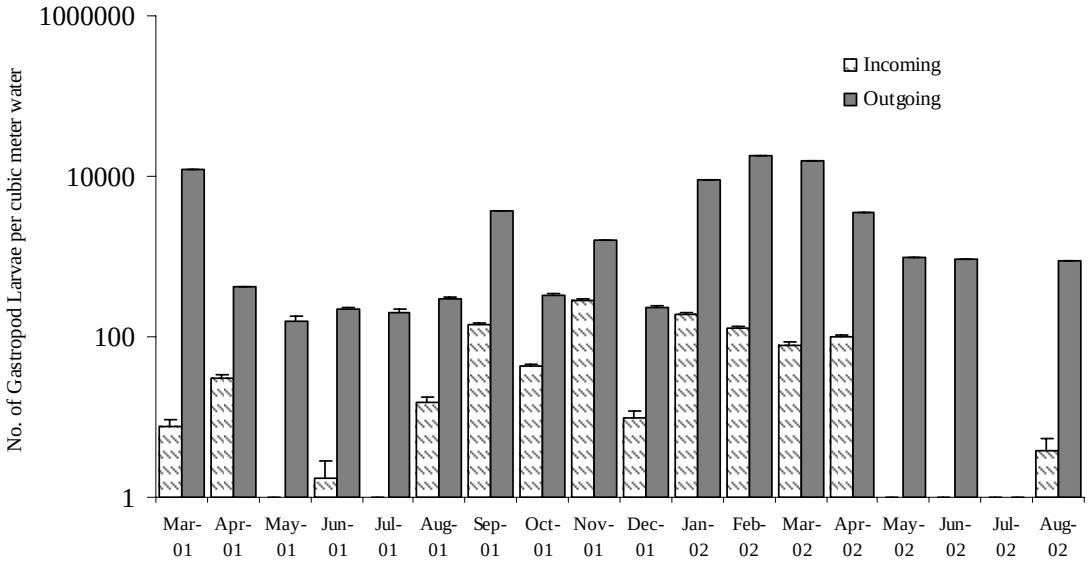


Figure 6.6 The mean (+SE) abundance of gastropod larva in in-flowing and out-flowing tidal waters of saltmarsh at Towra Point, 2001/02.

Abundance of copepods in tidal water at Towra Point saltmarsh

Results from an ANOVA test for differences in copepod abundance between incoming and outgoing tides in saltmarsh showed significant ($P<0.0001$) differences between tides. Significant differences in copepod abundance between tidal episode were also identified between months ($P<0.0001$) difference (Table 6.8).

Table 6.8 Results of a Two way analysis for copepod abundance between tidal episode (incoming and outgoing) and months at Towra Point saltmarsh, Botany Bay, NSW: Cochran's Test C= 0.6488.

Source of variation	DF	MS	F	P
Tide (incoming & outgoing)	1	2362775.68	477.68	0.0001
Month	17	4152401.16	839.49	0.0001
Tide X Month	17	199812.61	40.40	0.0001
Residual	252	4946.31		
Total	287			

The *post-hoc* SNK test for copepod abundance between incoming and outgoing tides in different months found significantly higher abundance of copepod in incoming tide, compared to outgoing tide, in May 01, August 01, September 01, October 01, November 01, January 02, February 02, March 02, April 02, May 02, June 02, July 02, and August 02 (Figure 6.7). On average, 26.03% copepods were removed from the tidal water in the saltmarsh.

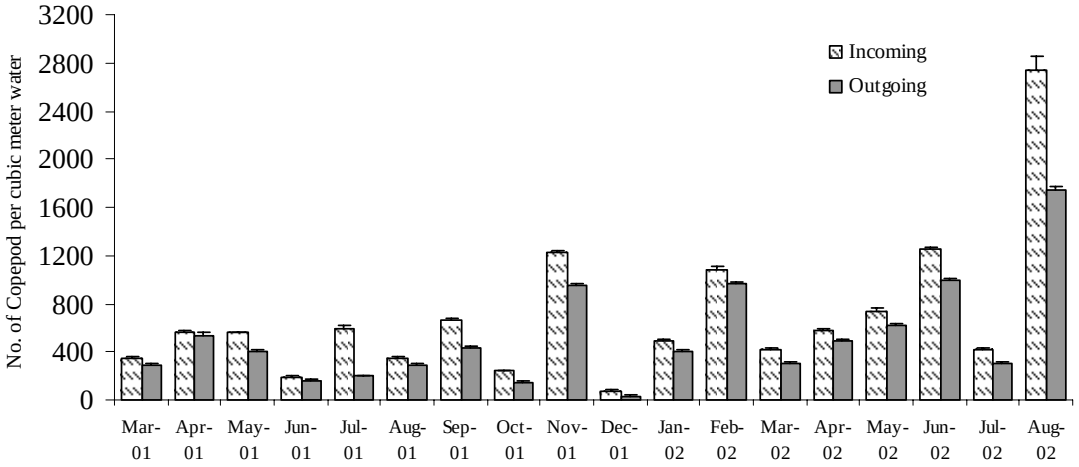


Figure 6.7 The mean (+SE) abundance of copepod in in-flowing and out-flowing tidal waters of saltmarsh at Towra Point, 2001/02.

Abundance of amphipods in tidal water at Towra Point saltmarsh

Results from an ANOVA test for differences in amphipod abundance within incoming and outgoing tides in saltmarsh showed significant ($P<0.0001$) difference. Amphipod abundance also varied significantly ($P<0.0001$) within tidal episode, and between months (Table 6.9).

Table 6.9. Results of a Two way analysis results for amphipod abundance between tidal episode (incoming and outgoing) and months at Towra Point saltmarsh, Botany Bay, NSW: Cochran's Test C= 0.2708

Source of variation	DF	MS	F	P
Tide (incoming & outgoing)	1	174886.83	233.38	0.0001
Month	17	197208.00	263.16	0.0001
Tide X Month	17	5674.71	7.57	0.0001
Residual	252	749.37		
Total	287			

The *post-hoc* SNK test for amphipod abundance between incoming and outgoing tides in different months found a significantly higher abundance of amphipods in incoming tide in April 01, May 01, June 01, July 01, August 01, December 01, February 02, March 02, April 02, July 02, and August 02 (Figure 6.8). On average, 32.63% amphipods were removed from the tidal water in the saltmarsh.

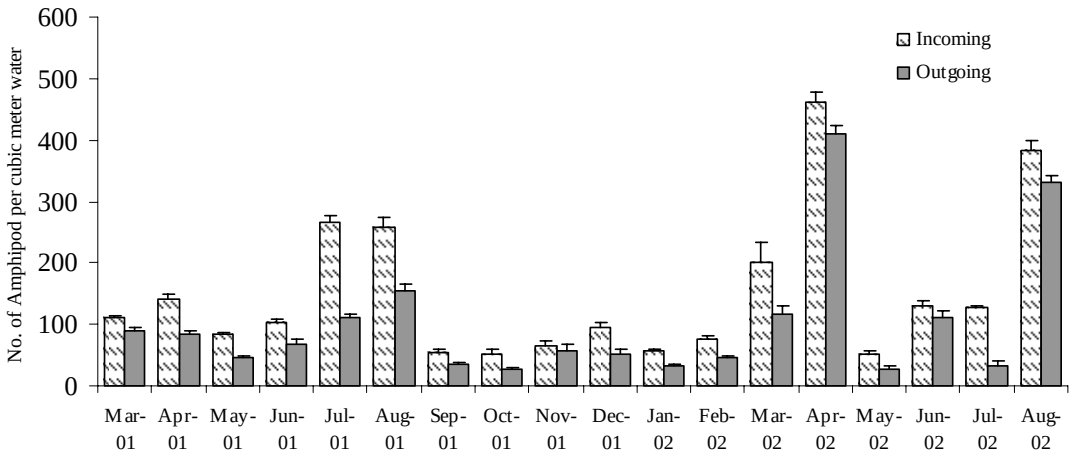


Figure 6.8 The mean (+SE) abundance of amphipods in in-flowing and out-flowing tidal waters of saltmarsh at Towra Point, 2001/02.

Correlations between crab and gastropod larval release

A Pearson correlation test between crab and gastropod larval abundance in outgoing tidal water in saltmarsh found no significant correlation (P=0.468). Gastropods and crabs appear to release larvae in different phase, with a late summer peak for gastropod and winter peak for crabs (Appendix 5.4, Figure 6.9).

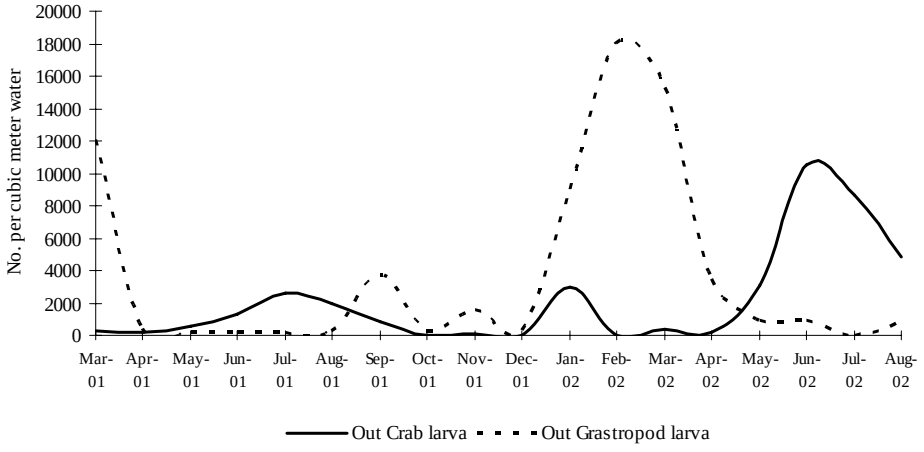


Figure 6.9 The mean export of crab and gastropod larva from the saltmarsh during ebb tide at Towra Point, Botany Bay, NSW, 2001/02.

6.4.2 Zooplankton assemblages across sites

A non-metric multidimensional scaling (nMDS) ordination (Figure 6.10) showed no significant difference in zooplankton assemblages within incoming tides between the Towra Point and Bicentennial Park (ANOSIM: P=0.64) and Towra Point and Allens Creek (ANOSIM: P=0.95). Differences in zooplankton assemblage in the incoming tides were only found between the Bicentennial Park and Allens Creek sites (ANOSIM: P=0.01) (Appendix 5.5).

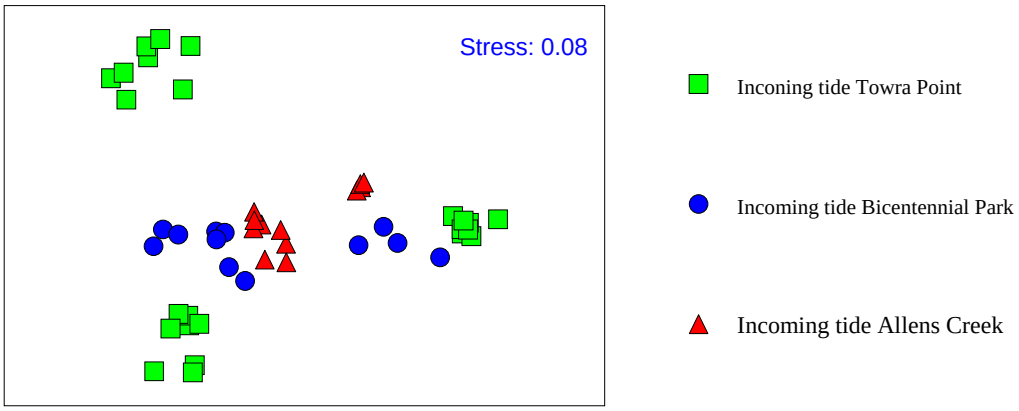


Figure 6.10 Results of an nMDS ordination showing assemblages of zooplankton within incoming tides comparing Towra Point, Bicentennial Park and Allens Creek in December 2001, January and August 2002.

Species percentage (SIMPER) results demonstrate that the dissimilarity between Bicentennial Park and Allens Creek incoming tides appears primarily due to the higher abundance of copepod in Bicentennial Park incoming tides compared to Allens Creek, and the relatively higher abundance of amphipods and other zooplankton present in Allens Creek incoming tides compared to Bicentennial Park (Appendix 5.5).

A non-metric multidimensional scaling (nMDS) ordination (Figure 6.11) showed

differences in zooplankton assemblages in outgoing tides between the Towra Point and Bicentennial Park (ANOSIM: P=0.002) and Bicentennial Park and Allens Creek (ANOSIM: P<0.01). No difference in zooplankton assemblages in the outgoing tides was found between the Towra Point and Allens Creek (ANOSIM: P=0.12) (Appendix 5.5).

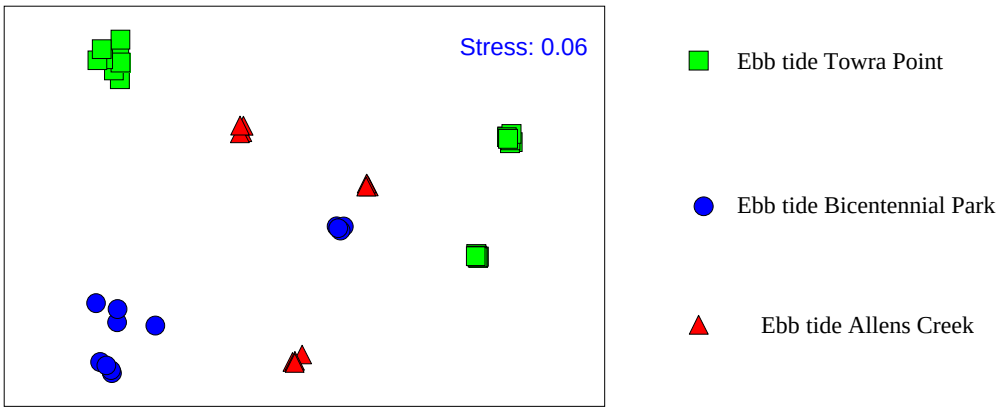


Figure 6.11 Results of an nMDS ordination showing the assemblages of zooplankton within ebb tides between Towra Point, Bicentennial Park and Allens Creek in December 2001, January and August 2002.

The dissimilarity in zooplankton between Towra Point and Bicentennial Park outgoing tides was primarily due to the larger abundance of gastropod larvae, crab larvae and copepod in Towra Point than Bicentennial Park (Table 6.10). The dissimilarity between Bicentennial Park and Allens Creek appears primarily due to higher abundance of gastropod larvae, crab larvae and amphipod in Allens Creek outgoing tides and relatively higher abundance of copepod in Bicentennial Park outgoing tides than Allens Creek (Table 6.10).

Table 6.10 Contribution of zooplankton to differentiation ebb tides across sites at Towra Point, Bicentennial Park and Allens Creek during December 2001, January and August 2002.

Towra Point outgoing Vs Bicentennial Park outgoing				**Bicentennial Park outgoing Vs. Allens Creek outgoing**				**Towra Point outgoing Vs. Allens Creek outgoing**			
Species	Av. Abund TP	Av. Abund BP	% contrib to dissim.	Species	Av. Abund BP	Av. Abund AC	% contrib to dissim.	Species	Av. Abund TP	Av. Abund AC	% contrib to dissim.
Gastropod larva	3371.92	195.75	38.37	Gastropod larva	195.75	962.67	43.93	Gastropod larva	3371.92	962.67	36.51
Crab larva	2607.96	240.08	33.91	Crab larva	240.08	432.75	26.38	Crab larva	2607.96	432.75	36.49
Copepod	728.29	685.42	18.63	Copepod	685.42	559.33	16.27	Copepod	728.29	559.33	17.92
				Amphipod	29.42	77.25	7.16				

Crab larval abundance across sites

Crab larval abundance between incoming and outgoing tides, between sites (Towra Point, Bicentennial Park and Allens Creek) varied significantly ($P<0.0001$, tested by ANOVA). Crab larval abundance in incoming and outgoing tides across sites and months also varied significantly ($P<0.0001$) (Appendix.5.6)

Results from a three factor ANOVA showed significant differences between sites, month and tidal phase (incoming vs. outgoing) for crab larval abundance. There were significant interactions terms for tidal phase by site, tidal phase by month and the 3-way interactions of tidal phase by site by month. Figure 6.12 assist in the interpretation of these interactions. No month showed peak discharge at all sites (Appendix 5.6).

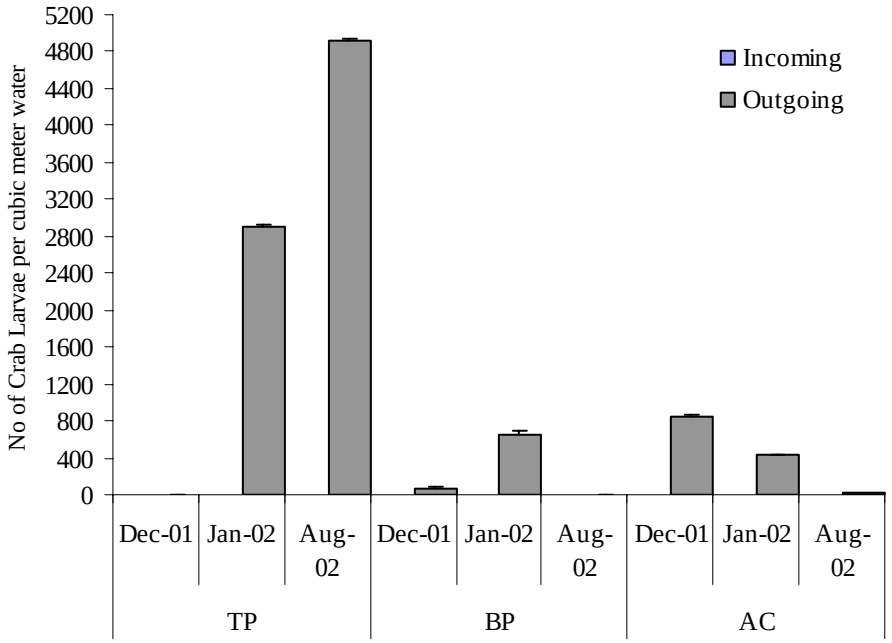


Figure 6.12 The mean (+SE) abundance of crab larvae in in-flowing and out-flowing tidal waters of Towra Point (TP), Bicentennial Park (BP) and Allens Creek (AC) in December 01, January 02 and August 02.

Results from a *post-hoc* SNK test for differences in crab larval abundance in incoming and outgoing tides in different months across Towra Point (TP), Bicentennial Park (BP) and Allens Creek (AC) showed significantly higher numbers of crab larvae in the outgoing tide from TP in January and August 02 (Figure 6.14). Significantly higher crab larval abundance in outgoing tide was observed in Bicentennial Park, and Allens Creek in December 01 and January 02 (Figure 6.12).

Gastropod larval abundance across sites

Results from a three way analysis of variance showed that gastropod larval abundance within incoming and outgoing tides, between sites (Towra Point, Bicentennial Park and Allens Creek) varied significantly ($P<0.0001$). Gastropod larval abundance in incoming and outgoing tides between sites and months also varied significantly ($P<0.0001$).

Results from a three factor ANOVA showed significant difference between sites, month and tidal phase (incoming vs. outgoing) for gastropods larvae. There were significant interactions terms for tidal phase by site, tidal phase by month and the 3-way interactions of tidal phase by site by month. Figure 6.13 assist in the interpretation of these interactions (Appendix 5.7).

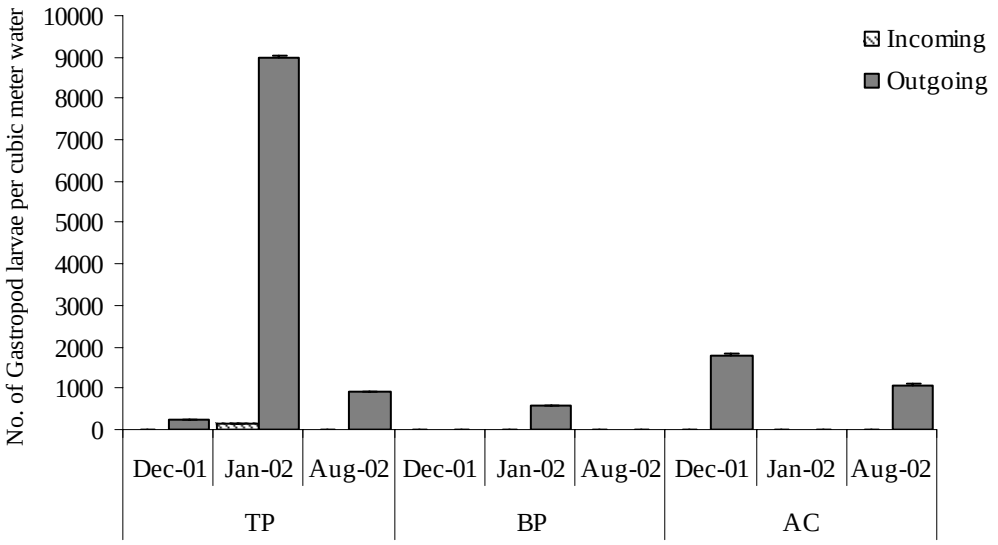


Figure 6.13 Mean (+SE) abundance of gastropod larvae in in-flowing and out-flowing tidal waters of Towra Point (TP), Bicentennial Park (BP) and Allens Creek (AC) in December 01, January 02 and August 02.

The *post-hoc* SNK test for gastropod larval abundance comparing incoming and outgoing tides at Towra Point (TP), Bicentennial Park (BP) and Allens Creek (AC) showed significantly higher numbers of gastropod larvae in the outgoing tide from TP in all months. (Figure6.13). At Bicentennial Park significantly higher abundance of gastropod larvae in the outgoing tide was observed in August 02 only. In Allens Creek significantly higher abundance of gastropod larvae in the outgoing tide observed in December 01 and August 02.

Copepod abundance across sites

The trend of higher copepod abundance in incoming tidal water held across sites and months ($P<0.0001$) (Appendix 5.8).

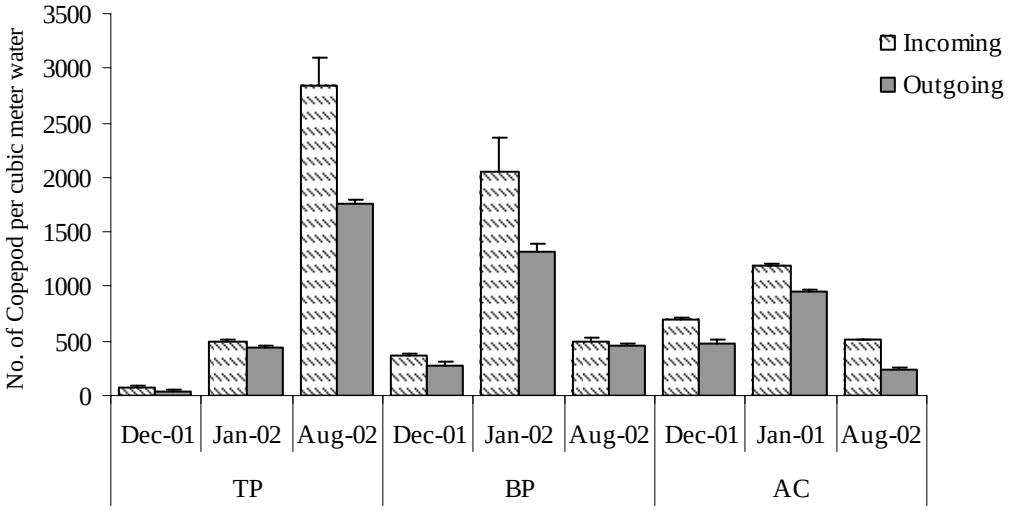


Figure 6.14 Mean (+SE) abundance of copepod in in-flowing and out-flowing tidal waters of Towra Point (TP), Bicentennial Park (BP) and Allens Creek (AC) in December 01, January 02 and August 02.

The *post-hoc* SNK test for copepod abundance in incoming and outgoing tides at Towra Point (TP), Bicentennial Park (BP) and Allens Creek (AC) showed significantly higher abundance of copepods present in the incoming tide in Towra Point in August 02 (Figure 6.14) and Bicentennial Park in January 02. At Allens Creek there was no significance difference between incoming and outgoing tides in any month in copepod abundance (Figure 6.14).

Amphipod abundance across sites

Results from a three way analysis of variance (ANOVA) for difference in amphipod abundances showed that within incoming and outgoing tides across sites and months did not vary significantly (P=0.0941) (Appendix 5.9).

The *post-hoc* SNK test for amphipod abundance in incoming and outgoing tides at Towra Point (TP), Bicentennial Park (BP) and Allens Creek (AC) showed that there was a

significantly higher abundance of amphipods in the incoming tide at Towra Point and Allens creek in all months (Figure 6.15). In Bicentennial Park significantly higher abundance of amphipods was found in the incoming tide in January 02 only (Figure 6.15).

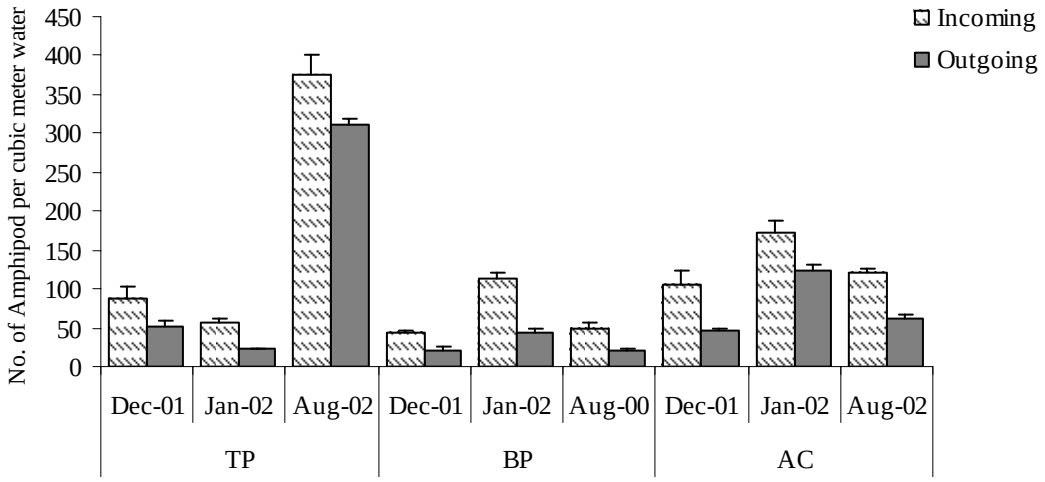
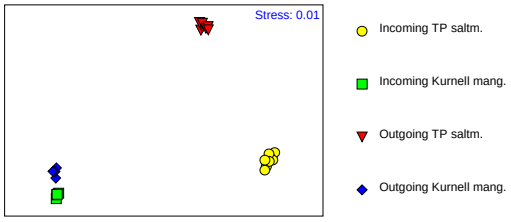


Figure 6.15 Mean (+SE) abundance of amphipod in in-flowing and out-flowing tidal waters of Towra Point (TP), Bicentennial Park (BP) and Allens Creek (AC) in December 01, January 02 and August 02.

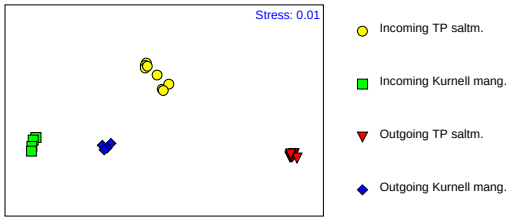
6.4.3 Zooplankton assemblages in saltmarsh and mangrove

Incoming and outgoing zooplankton assemblages sampled in December 01, January 02 and June 02 at the Towra Point saltmarsh and the Kurnell mangrove site showed significant differences. A non-metric multidimensional scaling (nMDS) ordination (Figure 6.16) showed different assemblages of zooplankton in the incoming and outgoing tides between saltmarsh (Towra) and mangrove (Kurnell) in December (ANOSIM: P=0.002), in January (ANOSIM: P=0.002) and June (ANOSIM: P=0.002),

A. December 2001



B. January 2002



C. June 2002

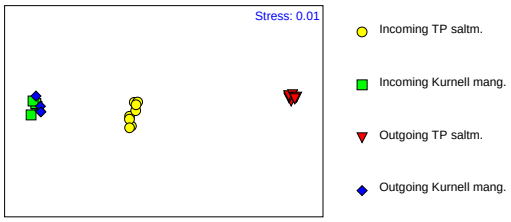


Figure 6.16 Results from an nMDS ordination showing assemblages of zooplankton within incoming and outgoing tides between Towra Point saltmarsh and Kurnell mangrove, Botany Bay, in December 2001, January and June 2002.

SIMPER results shows that the dissimilarity between saltmarsh and mangrove incoming tides in December and June appears primarily due to higher abundance of copepod, amphipod and other zooplankton in Kurnell mangrove than at the Towra Point saltmarsh. In January the dissimilarity appears primarily due to higher abundance of copepod, amphipod and other zooplankton in the Kurnell mangrove and the abundance of gastropod larvae in Towra Point saltmarsh and its absence in Kurnell mangrove (Appendix 5.10).

The dissimilarity between saltmarsh and mangrove outgoing tides in December appears primarily due to the abundance of crab larvae in Kurnell mangrove and absence in Towra

Point saltmarsh and higher abundance of copepod, amphipod and other zooplankton in Kurnell mangrove than Towra Point saltmarsh (Table 6.11). In January and June, the dissimilarity between saltmarsh and mangrove outgoing tides appears primarily due to higher abundance of crab and gastropod larvae in Towra Point saltmarsh than in the Kurnell mangrove and higher abundance of copepod and other zooplankton in Kurnell mangrove compared to the Towra Point saltmarsh (Table 6.11).

Table 6.11 Contribution of zooplankton to differentiation ebb tides between Towra Point saltmarsh and Kurnell mangrove, Botany Bay during December 2001, January and June 2002.

Outgoing Towra Point saltmarsh Vs outgoing Kurnell mangrove				**Outgoing Towra Point saltmarsh Vs outgoing Kurnell mangrove**				**Outgoing Towra Point saltmarsh Vs outgoing Kurnell mangrove**			
December 01				**January 02**				**June 02**			
Species	Av. Abund saltm.	Av. Abund mang.	% contrib to dissim.	Species	Av. Abund saltm.	Av. Abund mang.	% contrib to dissim.	Species	Av. Abund saltm.	Av. Abund Mang.	% contrib to dissim.
Crab larvae	0.00	50.00	7.24	Gastropod larva	9012.38	202.00	41.10	Crab larva	10474.00	00.00	60.79
Copepod	35.75	5021.25	68.24	Crab larva	2914.50	100	22.55	Gastropod larva	911.38	0.00	17.92
Amphipod	52.88	304.00	10.74	Copepod	398.62	5312.00	26.91	Copepod	998.50	2384.00	10.21
Other zooplankton	71.38	344.00	10.64					Other zooplankton	12.38	274.00	7.81

Crab larval abundance in saltmarsh and mangrove

Crab larval abundance varied between tidal phase (incoming and outgoing tides), habitat (saltmarsh and mangrove) and month in a comparison of the Towra Point saltmarsh and the Kurnell mangrove.

Significant interactions were found between tidal phase and site, tidal phase, site and month and 3-way interactions of tidal phase, site and month (Appendix 5.11). Figure 6.17, illustrates these interactions, with higher release of crab larvae from saltmarsh outgoing in different months to that of mangrove.

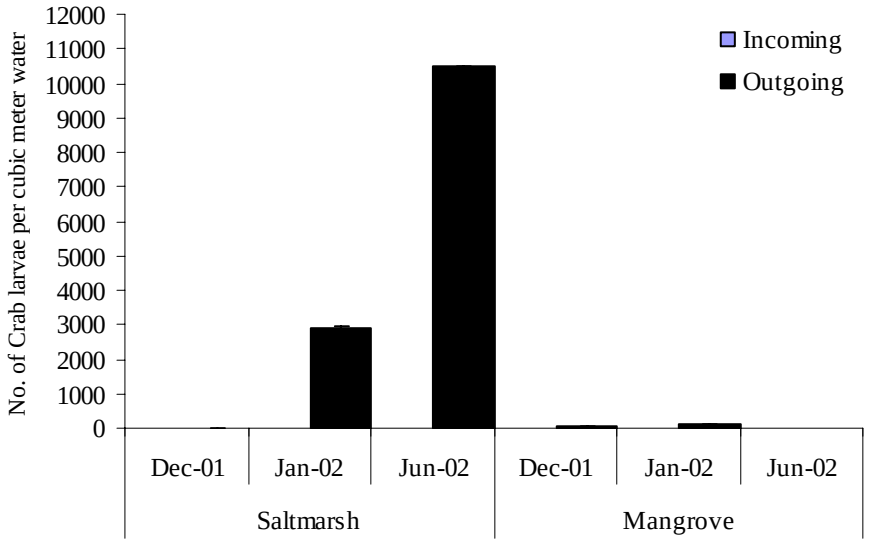


Figure 6.17 The mean (+SE) abundance of crab larvae in in-flowing and out-flowing tidal waters of Towra Point saltmarsh and Kurnell Mangrove at Botany Bay, NSW, in December 01, January 02 and June 02.

The *post-hoc* SNK test for crab larval abundance in incoming and outgoing tides in different months between saltmarsh and mangrove showed significantly higher quantity of crab larvae present in the outgoing tide from saltmarsh in January and June 02 (Figure

6.17). While in the mangrove, significantly higher abundance of crab larvae were found in outgoing tide in December 01 and January 02 (Figure 6.17). No crab larvae were found in the incoming tide in saltmarsh and mangrove during the sampling months.

Gastropod larval abundance in saltmarsh and mangrove

Results of a three way analysis of variance (ANOVA) showed difference in gastropod larval abundance between incoming and outgoing tides ($P<0.0001$), between saltmarsh and mangrove (Towra Point saltmarsh and Kurnell mangrove at Botany Bay) and between months (Appendix 5.12), Figure 6.18.

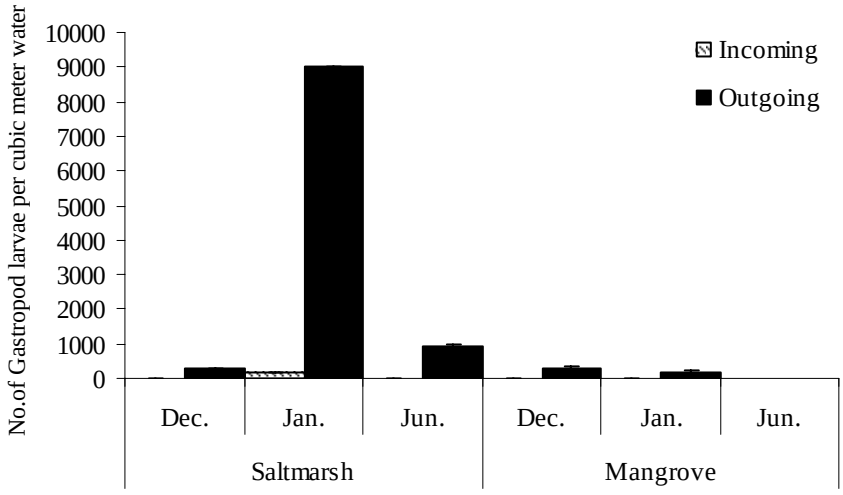


Figure 6.18 Mean (+SE) abundance of gastropod larvae in in-flowing and out-flowing tidal waters of the Towra Point saltmarsh and Kurnell Mangrove at Botany Bay, NSW, in December 01, January 02 and June 02.

The *post-hoc* SNK test for gastropod larval abundance within incoming and outgoing tides in different months between saltmarsh and mangrove showed that there were significantly higher numbers of gastropod larvae present in the outgoing tide from

saltmarsh in all sampling months (Figure 6.18). In mangrove forest on the other hand, significantly higher numbers of gastropod larvae were present in outgoing compared to incoming tide in December 01 and January 02 (Figure 6.18).

6.4.4 Larval abundance across four shallow-water habitats

Along the shore-normal transect, the mean number of crab larvae was always higher in saltmarsh (location A) and then consistently decreased towards the bay (Figure 6.19). The mean concentration of all zooplankton found was also higher in saltmarsh (location A) (8924.25^{m-3}) due to crab larval addition, followed by mangrove forest (location B) (3062.25^{m-3}), seagrass (location C) (2516^{m-3}) and open bay (location D) (2285.75^{m-3}), respectively. Results from an ANOVA showed that the crab larval abundance between locations A, B, C and D varied significantly ($P<0.0001$) (Appendix 5.13).

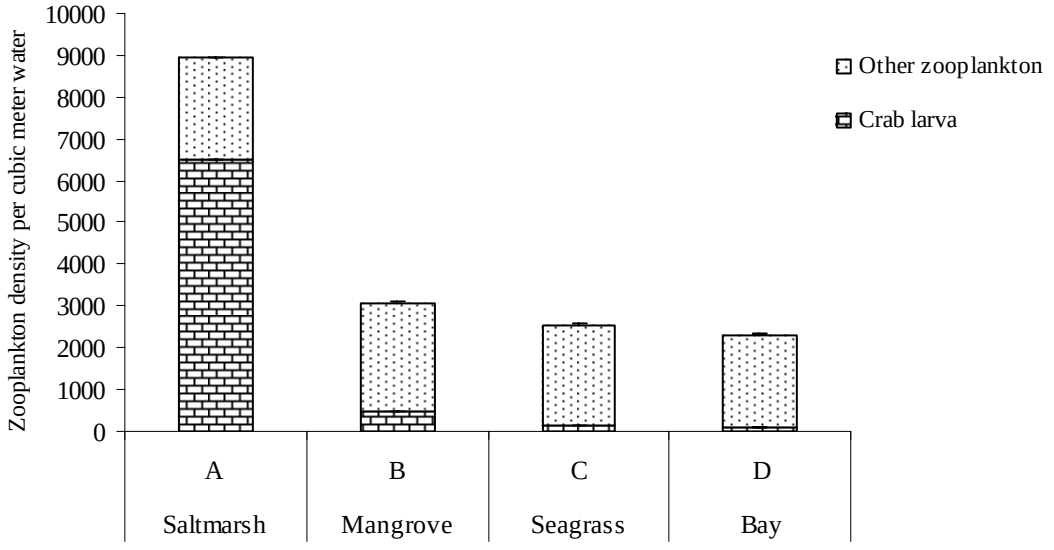


Figure 6.19 Mean (+SE) zooplankton abundance in different locations towards the Bay at Towra Point in September 2002.

The *post-hoc* SNK test showed that crab larval density at location A was significantly higher than location B, which in turn was significantly higher than the density at C. No significant difference was found in the density of crab larvae between points C and D.

A non-metric multidimensional scaling (nMDS) ordination showed that when crab larvae was removed from the analysis (Figure 6.20) differences still emerged between the habitats (ANOSIM: P=0.029).

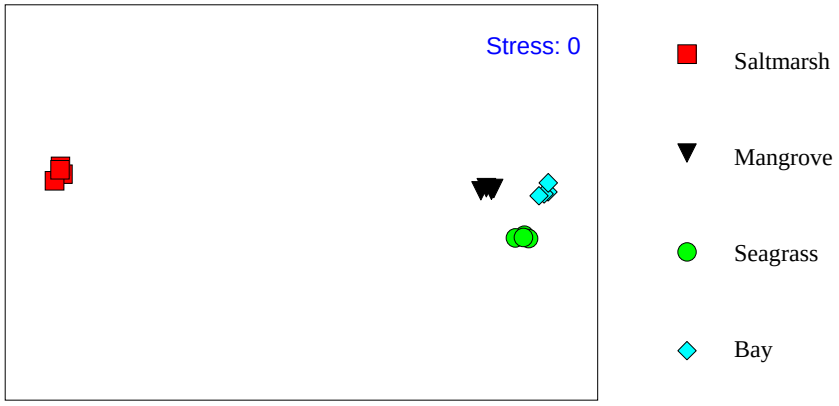


Figure 6.20 Results of an nMDS ordination showing the assemblages of other zooplankton (except crab larvae) during ebb tide within saltmarsh, mangrove, seagrass and bay habitats at Towra Point, September 2002.

Considering zooplankton other then crab larvae, the SIMPER test results demonstrated that the dissimilarity among near shore habitats during ebb tides appears primarily due to higher abundance of gastropod larvae and relatively lower abundance of copepods in saltmarsh than mangrove, seagrass and bay waters (Appendix 5.14).

6.5 Discussion

The results of this study demonstrate that crabs living in the saltmarsh release considerable quantities of larvae almost every month during ebb tides, regardless of day or night episode with a pronounced peak in winter during nocturnal tides. Forward (1987) found that egg hatching and the release of fiddler crab larvae usually occurs near nocturnal high tides on the days of the lunar month when nocturnal ebb tides are at maximum. Epifanio *et al*. (1984) also found that gravid females are concentrated in the shallow areas of the bay and release zoae on ebbing tides.

The pronounced release of crab larvae from the saltmarsh in almost every month highlights the fact that crabs in saltmarsh only have few available tides each month to release larvae. Crabs used these tides to export their larvae to the estuary for further development, because the saltmarsh remains dry for most of the month. Studies conducted by Epifanio *et al*. (1988) showed that newly hatched larvae of fiddler crabs rapidly carried into coastal water where further development occurs. Zoeal development takes place in the lower regions of the large estuaries (Sandifer 1975, Dittle and Epifanio 1982) or on the adjacent continental shelf (Christy & Stancyk 1982). This study also demonstrated that the strong winter peak and a smaller summer peak, in export corresponded to times in which *Helograpsus haswellianus* and *Sesarma erythrodactyla*, respectively, are in berry (Mazumder and Saintilan 2003). *Helograpsus haswellianus* is a saltmarsh specialist and is not found in the mangrove forest at Towra Point that has prolonged breeding period from March, to October (Chapter 5).

This study demonstrated that gastropods (*Assiminea tasmanica*, *Salinator solida*, *Littoraria luteola and Ophicardelus sp*.) living in the saltmarsh (Morrisey1995) also export larvae in almost all months and had a late summer peak. The difference in zooplankton assemblages in the incoming and outgoing tides is mainly due to the export of crab and gastropod larvae from the saltmarsh. If crab larvae were released from mangrove, then it is not occurring during the flood tide, very little crab larvae were found entering the saltmarsh from the mangrove habitat. Crabs occupying the mangrove may be selecting the ebb tide so that larvae move to the estuary, rather than from the saltmarsh

for further development. Christy (1989) found that adult fiddler crabs produce large pulses of zoeae that are rapidly transported to the coastal ocean where larval development is completed; megalopae re-enter the estuary and recruit to adult habitats. The larvae of fiddler crabs (genus *Uca*) do not developed near adult populations, stage 1 zoeae were transported rapidly away from the adult habitat for development (Feest 1969, Salmon *et al*. 1986).

This study also revealed differences between the transport of larvae from saltmarsh and mangrove habitats. With the exception of a single month (December 01), higher concentrations of crab larvae were released from the Towra Point saltmarsh (average 4461.75^{m-3}) in comparison the mangrove forest at Kurnell (average 50^{m-3} water) in the same tide. Release of crab larvae from mangrove in summer corresponded to times in which *Sesarma erythrodactyla* was in berry a crab present in both the saltmarsh and mangrove habitat (Chapter 5). Lower concentrations of larval released from mangrove in any given tide may be due to the greater number of inundating tides in the mangrove which are available to crabs, or the presence of a higher volume of water due to the greater inundation depth.

Transect data demonstrated that zooplankton densities were substantially higher in the saltmarsh than in other habitats due to the introduction of newly hatched crab larvae from *Helograpsus haswellianus* which lives only in saltmarsh. The lesser densities in the mangrove, seagrass and open water habitats may be the result of dilution at the point of sampling (1.2 m as opposed to 40 cm in saltmarsh), as well lower production of crab larvae from these habitats. The transect study also demonstrated the distribution of newly hatched crab larvae within nearshore habitats. Although this study examined only the surficial distribution of larva, other research suggests that stage 1 zoea larvae of blue crabs are most abundant in surface water as compared to mid depth and near bottom waters (Epifanio *et al.* 1984), a behavior also revealed in laboratory studies (Sulkin *et al*. 1980).

The study contained a number of inherent limitations. I did not examine the vertical

distribution of larvae within nearshore habitats, though larvae entering and exiting the saltmarsh via small levee breaks are likely to be well mixed. A further limitation was that collecting samples simultaneously from different sites prevented continuous sampling.

Whatever the fate of the larvae, the results are of significance to estuarine ecology in that the highest concentration of larvae across a series of shallow water habitats were found within the saltmarsh, and represent an optimal feeding environment. It is hypothesised that fish are attracted to these environments during the spring tide cycle because of the abundance of crab larvae. Robertson *et al.* (1988) found that brachyuran zoea were an order of magnitude more abundant in north-east Australian mangrove habitats in summer, when a number of species of juvenile fish were recruited into the tidal creeks.

Table 6.12 Summary of results for Chapter 6 (Export of zooplankton from saltmarsh to estuary).

Findings	**Test**	**Differences**
Zooplankton assemblages between incoming and outgoing tides in saltmarsh	Analysis of similarities (ANOSIM)	Significant ($P<0.001$)
Zooplankton assemblages between saltmarsh and mangrove habitats	Analysis of similarities (ANOSIM)	Significant ($P=0.002$)
Zooplankton abundance between saltmarsh and mangrove outgoing tides	Similarity percentages-species contribution (SIMPER)	Higher abundance of crab and gastropod larvae in saltmarsh than mangrove habitat
Crab larval export from saltmarsh	Analysis of varience (ANOVA)	Significant ($P<0.0001$) export of crab larvae from saltmarsh through ebb tides
Gastropod larval export from saltmarsh	Analysis of varience (ANOVA)	Significant ($P<0.0001$) export of gastropod larvae from saltmarsh through ebb tides
Crab larval abundance between saltmarsh and	Analysis of varience (ANOVA)	Significant ($P<0.00001$)

mangrove outgoing tides		
Gastropod larval abundance between saltmarsh and mangrove outgoing tides	Analysis of varience (ANOVA)	Significant ($P<0.0001$)
Crab larval density across shallow-water habitats	*Post-hoc* SNK	Crab larval density significantly higher in saltmarsh than mangrove, seagrass and open bay

CHAPTER SEVEN

TROPHIC INTERRELATIONS

7.1 Summary

The main aim of this chapter is to explore the trophic links between the saltmarsh environment and itinerant fish, and to investigate whether saltmarsh plants contribute to the diet of crabs which are keystone species in this environment. Results from a stomach content analysis demonstrated that high percentages of crab larva are present in the gut of glassfish (*Ambassis jacksoniensis*), flat tail mullet (*Liza argentea*), and blue eye (*Pseudomugil signifer*). It also appears that the selection of crab larvae as a food item did not correspond to the size of fish. The result indicated a direct trophic link between saltmarsh and the itinerant fish.

It appears from the stable carbon and nitrogen isotope study that diet of *Sesarma erythrodactyla* and *Helograpsus haswellianus* in the saltmarsh is identical and that this differs slightly from the diet of *S. erythrodactyla* in the mangrove. The results of an analysis of the stable isotopes in predators and prey suggests that crabs living in the saltmarsh do not seem to be dependent on any of the common species of saltmarsh plant, but depend on particulate organic matter (POM) derived from local and other sources.

7.2 Introduction

A relatively high density of fish was found in the saltmarsh flats of Towra Point and Allens Creek during spring tides (Chapters 3 and 4). The study to quantified the significant amount of larvae released by saltmarsh crabs during ebbing tide (Chapter 6). The trophic interaction between fish and crab larvae is worthy, therefore, of examination. Research findings from elsewhere suggest that many fishes enter estuaries to feed and spawn during summer when crab larvae hatch and develop (Pearcy and Richards 1962, Weinstein 1979, Kneib 1984, Rozas and Hackney 1984, Talbot and Able 1984). Allen *et al*. (1995) found crab larvae are the dominant component of the diet of the bay anchovies, *Anchoa mitchilli*, and rough silversides, *Membras martinica*, in Town creek of North inlet, South Carolina, USA. Morton *et al*. (1987) similarly reported crab zoeae and megalopae in the diets of *Ambassis marianus* and *Liza argentea* during autumn and winter in Southern Moreton Bay, Queensland, Australia. Depending on the time of the year, copepods and brachyuran zoea supported between 8% and 90% of the total number of juvenile fish captured in mangrove creek at Northern Queensland, Australia (Robertson *et al*. 1988). The present study used gut content analysis to determine whether fish were consuming crab larvae when visiting the saltmarsh flat.

Four crab species: *Helograpsus haswellianus*, *Sesarma erythrodactyla*, *Paragrapsus laevis* and *Helocious cordiformis*, occupy the Towra Point saltmarsh (Chapter 5; Mazumder and Saintilan in press). These species are recognized as potentially keystone species in saltmarsh and it is important to understand the extent to which their diet relies on saltmarsh and mangrove autrotrophic production. Research in Australia, South-east

Asia, Africa, the Caribbean and South America has demonstrated the consumption of mangrove leaf material by crabs occupying the mangrove habitat (Robertson 1986, Robertson and Daniel 1989, Smith and Daniel 1989, Sasekumar and Loi, 1983, Loke 1984, Lee 1989, Japar 1989, Smith *et al*. 1989, Micheli *et al*. 1991). Rodelli *et al*. (1984) reported several commercially important species of bivalves, shrimp, crabs and fish obtained carbon from mangrove trees. Similarly Bullion *et al*. (2002) also reported that mangrove carbon was assimilated to sesarmid crabs in the intertidal mangrove ecosystem in India.

On the other hand the contribution of saltmarsh vegetation to the diet of crabs not been understood clearly. Guest *et al* (2003) noted a relationship between the isotope signatures of saltmarsh-dwelling crabs in SW Queensland and the saltmarsh vegetation. The present study sought to clarify the contribution of saltmarsh and mangrove vegetation to the diet of crabs at Towra Point through the use of carbon and nitrogen isotopes. Stable isotopes such as $\delta^{13}C$ and $\delta^{15}N$, and to lesser extent, $\delta^{34}S$, have been most commonly used to analyse aquatic food webs (Peterson *et al.* 1980, Sullivan & Moncreiff 1990, Bunn & Boon 1993, Thayer *et al*. 1978, Fry *et al*. 1978, Fry 1981). In this work I determined the stable $\delta^{13}C$ and $\delta^{15}N$ isotope ratio of crab muscle tissue and compared that with the major primary food sources (*Sarcocornia quinqueflora*, *Sporobolus virginicus*, *Juncus krausii* and *Avicennia marina* leaves) for Towra Point, provided by Dr Pia Laegdsgaard of the Department of Infrastructure, Planning and Natural Resources (DIPNR).

The work presented in this chapter, therefore has two major objectives:

1) to explore whether a trophic link exist between the saltmarsh environment and itinerant fish through the consumption of crab larvae and,

2) to investigate whether species of saltmarsh plants contribute to the diet of crabs.

7.3 Study Site and Methods

7.3.1 Towra Point

This study was conducted in the saltmarsh of Towra Point, Botany Bay, Australia the site of the ecological investigations of Chapters 2-6.

7.3.2 Fish collection for gut content analysis

Fish leaving the Towra Point saltmarsh on the ebbing spring tide were collected from the small tidal channel by means of fixed-seine net (mesh size 2 mm) monthly from April 2002 to September 2002. This net was deployed for approximately half an hour in the small break in the levee in the border of the saltmarsh and mangrove zones. The net covered approximately 10 m^2. Seven individuals from each of the most common species trapped in the net were collected for stomach content analysis. Species selected were glassfish (*Ambassis jacksoniensis*), flat tail mullet (*Liza argenta*), blue eye (*Pseudomugil signafer*), mangrove goby (*Mugilogobious paludis*), bream (*Acanthopagrus australis*) and blue spot goby (*Pseudogobious olorum*). All other fish were released. The sample fishes were then preserved on site in 10% formaldehyde solution for laboratory analysis.

7.3.3 Gut content analysis

The main aim of the gut content analysis was to investigate whether fish consumed crab larva while visiting the saltmarsh. The gut content of each fish was sorted under a dissecting microscope, and grouped in three major categories: crab larva, crab and or fish body parts, and "other" food items including insects, detritus, zooplankton other than crab larvae and plant materials. Numerical methods of calculating food categories in the gut (Crisp *et al.* 1978, Dewet *et al*. 1990, Sanchez-Jerez *et al*. 2002) were followed with some modification. The food items in each gut were expressed as percentages of the total number of items in the stomach.

7.3.4 Sample preparation for stable Carbon and Nitrogen Isotopes

Seven individuals from two crab species; *Helograpsus haswellianus* and *Sesarma erythrodactyla,* were collected from the *Sarcocornia*/*Sporobolus* zone of saltmarsh, and six individuals of *S. erythrodactyla* were collected from the mangrove using a Pit-trap (Salmon and Hyatt 1983) as described Chapter 5. Individuals of *H. haswellianus* collected had an average carapice width of 15mm, while individuals of *S. erythrodactyla* collected had an average carapace width of 12mm. Sample collection was performed in daylight hours during August 2002.

Crabs were cleaned by tap water before collecting muscle tissues. Muscle tissues were collected from claws and carapace following removal of the exoskeleton. Enough tissue was collected from each crab to make 1 mg of dry powder for isotope analysis. The powder was poured into a small glass vial, freeze-dried for 72 hours, and subsequently stored in a desiccator to prevent the uptake of moisture. Samples were then submitted to the CSIRO Land and Water isotope laboratory in Adelaide, South Australia for continuous flow isotope ratio mass spectrometry analysis. The samples ranged between 1 and 1.5 mg with a total of 21 crab muscle tissues sampled.

7.3.5 Data analysis

The gut content data were analysed by single factor analysis of variance (Underwood and Chapman 1989) and *post-hoc* Student-Newmans-Kuels (SNK) tests were performed to clarify significant differences between species of fish species in regard to the proportion of crab larva present in the stomach. An ANOVA was also conducted to test for differences between month and species in the proportion of crab larvae in the stomach. Data were square root transformed where necessary before analysis to remove heterogeneity of variances. Pearson correlation tests between crab larval abundance in water and consumption by visiting fish in saltmarsh were conducted using SPSS. An ANOVA and *post-hoc* Student-Newmans-Kuels (SNK) tests were also performed to

determine the significance difference between crabs for $\delta^{13}C$ and $\delta^{15}N$ ratios.

7.4 Results

7.4.1 Size of fish examined for gut content

The mean length of *M. paludis* individuals examined for gut content was 43.17 mm (ranging from 37 mm to 56 mm), *P. signifer* 25.17 mm (ranging from 20 to 29 mm), *A. jacksoniensis* 38 mm (ranging from 29 to 44 mm), *L. argenta* 52.5 mm (ranging from 45 to 61 mm), *P. olorum* 30.67 mm (ranging from 29 to 32 mm) and *A. australis* 58.83 mm (ranging from 43 to 78 mm, Figure 7.1).

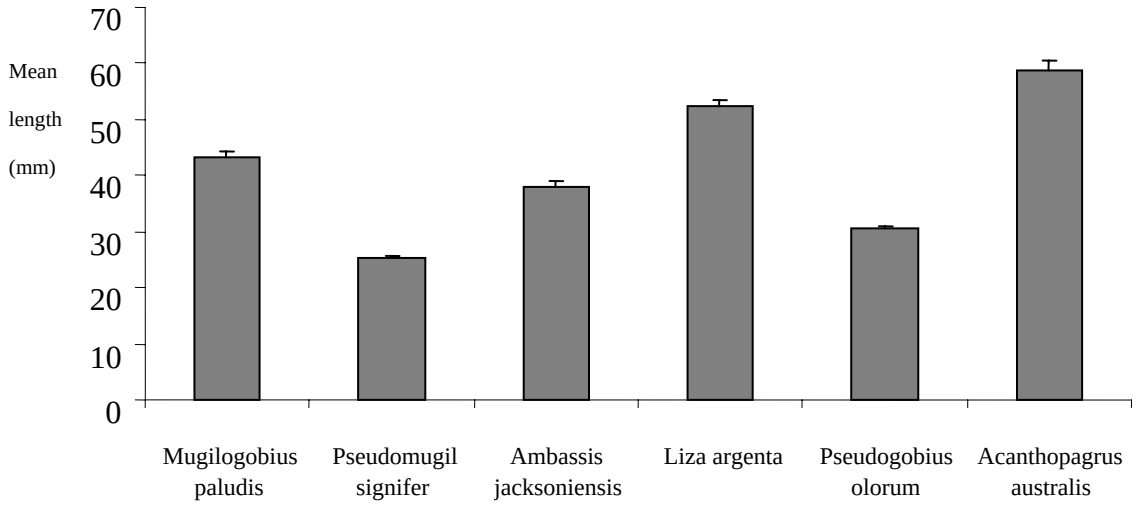


Figure 7.1 Mean (+SE) length of fish species captured from saltmarsh for gut content analysis, Towra Point, Botany Bay, 2002

7.4.2 Diet of fish visiting saltmarsh

Stomach content analyses of six fish species captured in saltmarsh suggested that crab

larva is an important component of the diet of many of these species. The results of a ANOVA demonstrate (Appendix 6.1) significant differences between mangrove goby (*M. paludis*), blue eye (*P. signifer*), glassfish (*A. jacksoniensis*) and flat tail mullet (*L. argenta*) in the proportion of stomach content consisting of crab larvae (P<0.0001), with *A. jacksoniensis* the highest, followed by the *L. argenta*, *P. signifer*, and *M. paludis*. Blue spot goby (*P. olorum*) and yellow fin bream (*A. australis*) were found not to consume crab larvae, though bream consumed post-larval crabs, along with insects, juvenile fish and other forms of zooplankton (Figure 7.2). Blue spot goby consumed insects, detritus, plant materials and other forms of zooplankton (Figure 7.2).

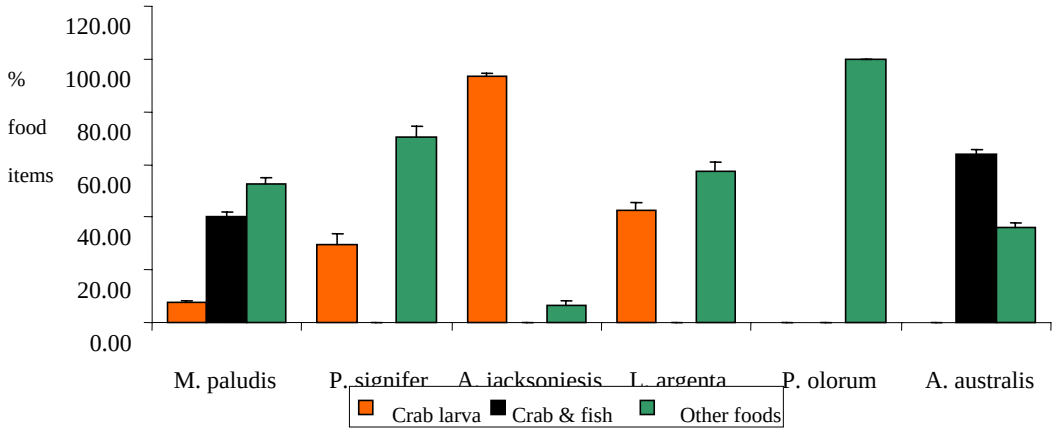


Figure 7.2 The contribution of crab larva in the diet of different fish species visiting saltmarsh at Towra Point, Botany Bay, 2002.

7.4.3 Temporal variation on crab larval consumption

The results of a ANOVA demonstrated that crab larval consumption between months varied significantly (P<0.0001) for *M. paludis*, *P. signiafer*, *A. jacksoniensis* and *L. argenta* (Appendix 6.2).

The *post-hoc* SNK test for differences in crab larval consumption in different months by *M. paludis* showed significantly higher consumption of crab larvae in April than other month. Pearson correlation tests between crab larval abundance in water and consumption by *M. paludis* showed no correlation (P=0.319) (Figure 7.3) (Appendix 6.3).

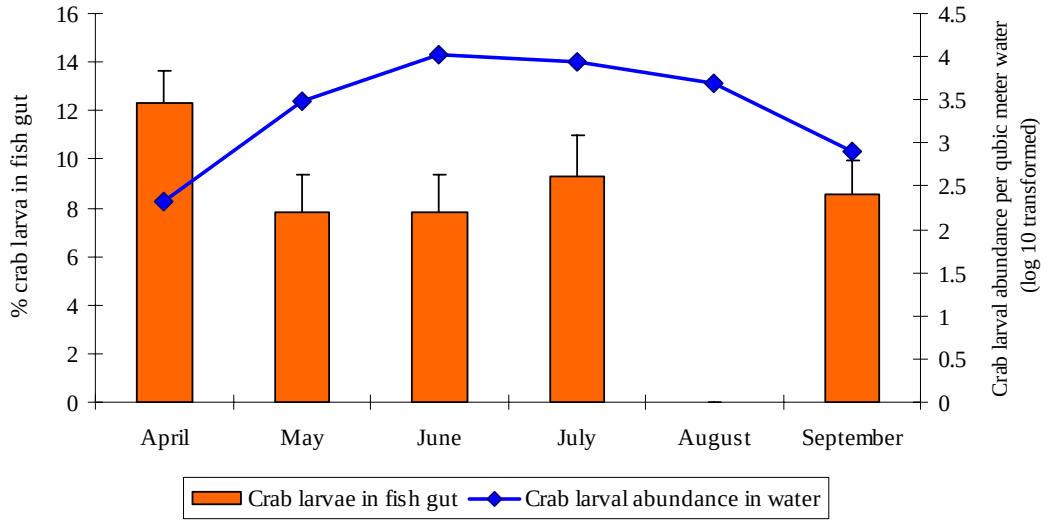


Figure7.3 The consumption of crab larvae (Mean +SE) by mangrove goby (*M. paludis)* in relation to the larval availability (Data Log10 transformed) in ebb tides from Towra Point saltmarsh.

The *post-hoc* SNK test for crab larval consumption by blue eye (*P signafer*) showed significantly higher consumption of crab larvae in July than other months, although no correlation (P=0.256) found between larval abundance in tidal water and consumption (Figure 7.4).

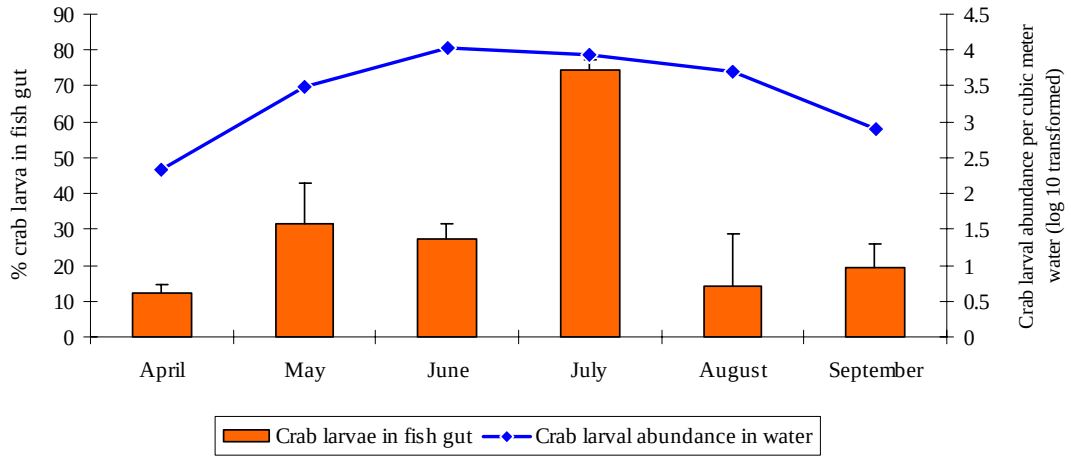


Figure 7.4 The consumption of crab larvae (Mean +SE) by blue eye (*Pseudomugil signifer*) in relation to the larval availability (Data Log10 transformed) in ebb tides from Towra Point saltmarsh.

The *post-hoc* SNK test for crab larval consumption by *A. jacksoniensis* found significant differences between most of the months (August and June, August and May, September and June, August and April, May and September, July and September, April and September, August and September and July and September). A positive correlation (P=0.950) also observed between larval abundance in tidal water and consumption by *A. jacksoniensis* (Figure 7.5).

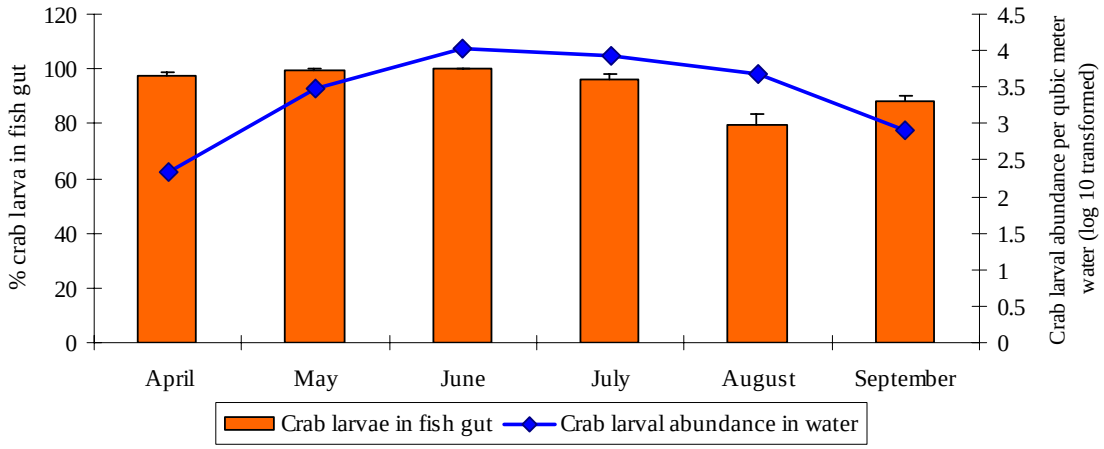


Figure 7.5 The consumption of crab larvae (Mean +SE) by glassfish (*Ambassis jacksoniensis*) in relation to the larval availability (Data Log10 transformed) in ebb tides from Towra Point saltmarsh.

The *post-hoc* SNK test for crab larval consumption by *L. argenta* found significant difference between April and June, April and September, May and June, May and September, and June and July. No correlation (P=0.370) found between consumption and crab larval abundance in tidal water (Figure 7.6).

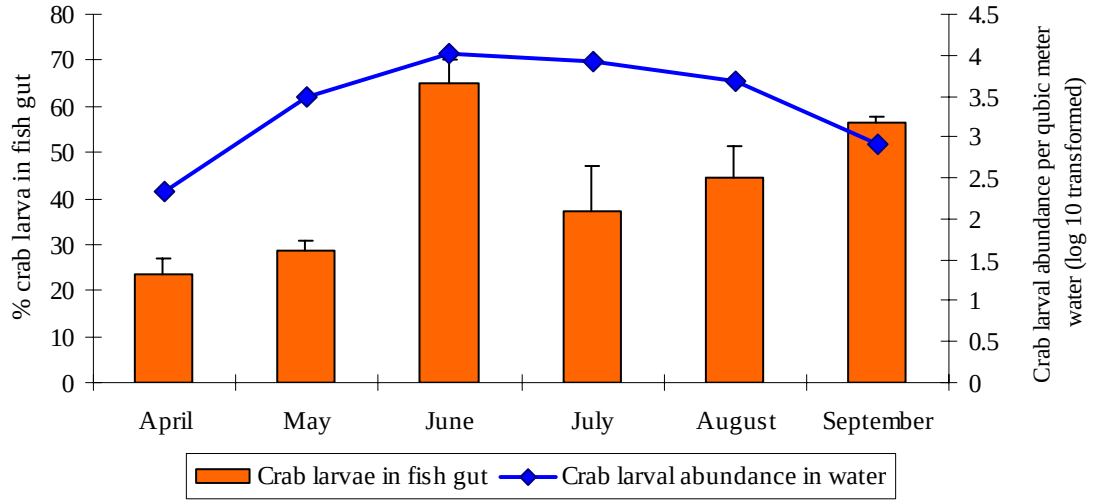


Figure 7.6 The consumption of crab larvae (Mean +SE) by flat tail mullet (*Liza argenta*) in relation to the larval availability (Data Log10 transformed) in ebb tides from Towra Point saltmarsh.

7.4.4 Diet of crabs inhabiting saltmarsh and mangrove

Delta carbon and nitrogen ratios for *H. haswellianus* and *S. erythrodactyla* living in the saltmarsh and mangrove are shown in the Table 7.1.

Table 7.1 Delta carbon and nitrogen ratios for *Helograpsus haswellianus* and *Sesarma erythrodactyla* living in the saltmarsh and mangrove at Towra Point, Botany Bay, NSW

No of samples	***Helograpsus haswellianus* (Saltmarsh)**		***Sesarma erythrodactyla* (Saltmarsh)**		***Sesarma erythrodactyla* (Mangrove)**	
	$\delta^{13}C$	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**
1	-21.1	7.1	-19.9	8.3	-21.3	6.6
2	-19	8.4	-19.9	8.1	-22.5	7.8
3	-20.4	8.2	-19.6	8.1	-23.2	7.5
4	-18.1	8.1	-18.6	8.8	-22.4	7.6
5	-19.6	7.2	-19.5	7.9	-20.2	8
6	-15.5	8.2	-18.6	8	-17.3	7
7	-17.7	8.4	-22.3	7.2	NA	NA
Mean	**-18.77**	**7.94**	**-19.77**	**8.05**	**-21.98**	**7.45**
SE	**0.70**	**0.20**	**0.46**	**0.18**	**0.432**	**0.02**

A One-way ANOVA of $\delta^{13}C$ values for *Helograpsus haswellianus* and *Sesarma erythrodactyla* in saltmarsh showed no significant difference (Table 7.2).

Table 7.2 Results from ANOVA for differences in $\delta^{13}C$ values between *Helograpsus haswellianus* and *Sesarma erythrodactyla* living in saltmarsh at Towra Point, Botany Bay, NSW: Cochran's Test C= 0.6948

Source of variation	**DF**	**MS**	**F**	**P**
Crab species	1	3.50	1.38	0.26
Residual	12	2.53		
Total	13			

An ANOVA comparing $\delta^{15}N$ values for *Helograpsus haswellianus* and *Sesarma erythrodactyla* in saltmarsh also showed no significant difference (Table 7.3).

Table 7.3 Results from ANOVA for differences in $\delta^{15}N$ values between *Helograpsus haswellianus* and *Sesarma erythrodactyla* living in saltmarsh at Towra Point, Botany Bay, NSW: Cochran's Test C= 0.5716

Source of variation	DF	MS	F	P
Crab species	1	0.04	0.17	0.68
Residual	12	0.26		
Total	13			

ANOVA results comparing $\delta^{13}C$ values for *Sesarma erythrodactyla* showed significant difference between saltmarsh and mangrove (Table 7.4).

Table 7.4 Results from ANOVA for differences in $\delta^{13}C$ values for *Sesarma erythrodactyla* between saltmarsh and mangrove at Towra Point, Botany Bay, NSW: Cochran's Test C= 0.7575

Source of variation	DF	MS	F	P
Crab species	1	20.80	27.80	0.0004
Residual	10	0.74		
Total	11			

ANOVA results comparing $\delta^{15}N$ values for *Sesarma erythrodactyla* showed significant between saltmarsh and mangrove (Table 7.5).

Table 7.5 Results from ANOVA for differences in $\delta^{15}N$ values for *Sesarma erythrodactyla* between saltmarsh and mangrove at Towra Point, Botany Bay, NSW: Cochran's Test C= 0.7037

Source of variation	DF	MS	F	P
Crab species	1	1.68	9.62	0.0112
Residual	10	0.17		
Total	11			

The *Post-hoc* NSK test for isotopic values for crabs in saltmarsh and mangrove showed $\delta^{13}C$ value of *S. erythrodactyla* (-19.77) in saltmarsh significantly higher than the values of *S. erythrodactyla* (-21.98) living in the mangrove. The $\delta^{15}N$ value of *S. erythrodactyla* (8.05) living in saltmarsh also higher significantly than the value of *S. erythrodactyla* (7.45) living in mangrove. The $\delta^{13}C$ (-18.77) and $\delta^{15}N$ (7.94) value of *H. haswellianus* found close to the $\delta^{13}C$ (-19.77) and $\delta^{15}N$ (8.05) value of *S. erythrodactyla* in saltmarsh.

7.5 Discussion

7.5.1 Diet of fish

The results of stomach content analysis demonstrate that many species of fish visiting the Towra saltmarsh during high spring tide prey upon crab larva. High percentages of crab larva are present in the gut of glassfish (*A. jacksoniensis*), flat tail mullet (*L. argenta*), and blue eye (*P. signifer*). Little crab larvae are found in water entering the saltmarsh (Chapter 6), which indicates that the larvae was consumed while the fish were resident in the saltmarsh.

Morton *et al*. (1987) reported that crab zoeae and megalopae were a major component of diets of fishes during autumn and winter in tidal inlet in southern Moreton Bay, Queensland. Robertson *et al.* (1988) found that brachyuran zoea, a major prey of fish in Northeastern Australia, were an order of magnitude more abundant in mangrove forest than in seagrass habitats in summer (December to February). The stomach content analyses also suggested that yellow fin bream (*A. australis*) and mangrove goby (*M.*

paludis) move to saltmarsh and consume crabs inhabiting saltmarsh and juvenile fishes concentrated there. Morton *et al.* (1987) also found that terrestrial invertebrates formed a component of the diet of fishes that accessed in the saltmarsh in Moreton Bay, Southern Queensland.

The result indicated a direct trophic link between saltmarsh and the itinerant fish. Within the saltmarsh a greater efficiency of energy is transferred to estuarine fish due to the higher concentration of crab larvae and total zooplankton in the saltmarsh than in any other shallow near-shore environment measured (Chapter 6).

There was also a degree of variability in the consumption of crab larvae, with some species (*A. jacksoniensis* and *M. paludis*) showing lower levels of consumption in August. However, these patterns show no relationship to the availability of larvae. It also appears that the selection of crab larvae as a food item did not correspond to the size of fish. Of the larger species, some consumed larvae (*L. argenta*) and some did not (eg. *A. australis*), while of the smaller species a similar variability in dietary preference was observed (*P. olorum* was not observed to consume crab larvae, while *A. jacksoniensis*, *M. paludis* and *P.signafer* all consumed larvae). The results also suggest that the diet of fish in estuarine situations changes profoundly as they grow to maturity, as *L. argenta* is known to be an omnivore (Thomson 1954, Burchmore 1976, SPCC 1981).

7.5.2 Diet of crabs

Crabs of two species occupying the saltmarsh of Towra Point showed identical stable isotope ratios for $\delta^{13}C$ and $\delta^{15}N$, suggesting a similarity of diet. However, considerable differences were found between the $\delta^{13}C$ and $\delta^{15}N$ values of these species and the saltmarsh vegetation available (Figure 7.7). For example, the $\delta^{13}C$ and $\delta^{15}N$ values for the crab *Helograpsus haswellianus* (-18.77 and 7.94 respectively) are less depleted than those of *Sarcocornia quinqueflora* (-23.35 and -0.4, respectively) and *Juncus krausii* (-26.86 and 4.25 respectively). $\delta^{13}C$ fractionations between producers and consumers are

generally less than 1‰ (DeNiro and Epstein 1978).

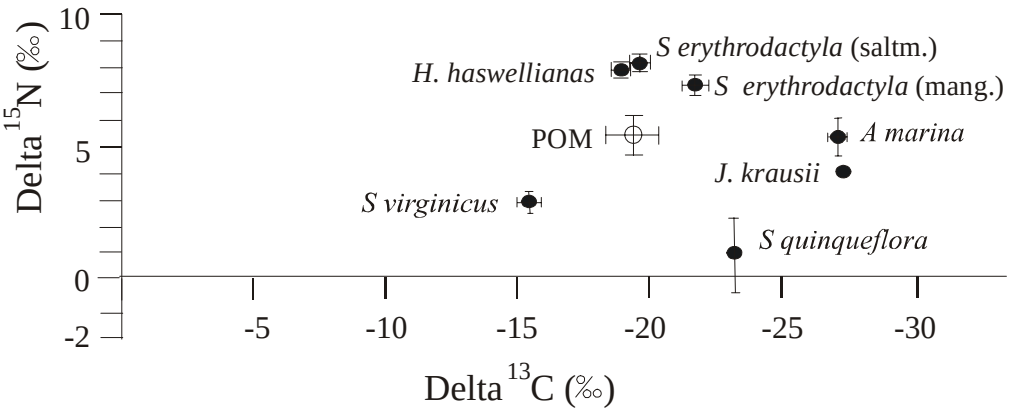


Figure 7.7 Carbon and nitrogen isotope ratios for four categories of primary producers (*Sarcocornia*, *Sporobolus*, *Juncus* and mangrove) and two crab species *H. haswellianus* living in saltmarsh and *S. erythrodactyla* living in both saltmarsh and mangrove habitats. Data of each primary producer represents means of 5 replicates of species, with data provided by Pia Laegsdgaard, Department of Infrastructure and Natural Resources (DIPNR) and data for particulate organic matter (POM) from Melville and Connolly (2003).

The stable carbon and nitrogen values for *S. erythrodactyla* varied between saltmarsh and mangrove. The stable isotope signatures for *S. erythrodactyla* sampled in the mangrove (δ^{13}C of -21.98 and δ^{15}N of 7.45) were closer to those of *A. marina (*δ^{13}C of -27.36 and δ^{15}N of 5.13) than were the crabs sampled in the saltmarsh.

Taken alone, the $\delta^{13}C$ ratios for crab species at Towra Point could reflect a combination of mangrove and saltmarsh detrital sources, occurring mid-way between the signatures of *Avicennia marina* and *Sporobolus virginicus*. However, the $\delta^{15}N$ ratios of all plant sources measured were significantly depleted compared to the values obtained from the crab muscle tissue, even after allowing for the fractionation between producer and consumer of 2.6 ‰ (Owens 1987) to 3.4 ‰ (Minagawa and Wada 1984).

Isotope signatures for particulate organic matter (POM) published by Melville and Connolly (2003) of –19 to –20 for $\delta^{13}C$ and 6 for $\delta^{15}N$, are precisely what would be expected if POM were the food source for saltmarsh crabs at Towra Point. The consumption of POM as a primary food source for crabs in the Sydney region is consistent with the observations of Saintilan *et al.* (2000), who found little evidence of herbivory at two sites in the Sydney region.

The diet of *S. erythrodactyla* in mangrove is closer to mangrove (*A. marina*) $\delta^{13}C$ and $\delta^{15}N$ ratios but not identical. The diet of *Sesarma sp*. in mangrove may depend to some extent on the mangrove leaves is that the species exhibited depleted $\delta^{13}C$ ratios compared to the same species in the saltmarsh, although equally the result could reflect a variety of food sources. Boullion *et al*. (2002) reported mangrove invertebrate groups assimilated mangrove carbon as well as imported organic matter and microphytobenthos. Several authors e.g., Saintilan *et al.* (2000) suggested lower rates of crab herbivory on mangrove leaves in the Sydney region than corresponding tropical environments.

It appears from the stable carbon and nitrogen isotope study that diet of *S. erythrodactyla* and *H. haswellianus* in the saltmarsh is identical and that this differs slightly to the diet of *S. erythrodactyla* in the mangrove. The result suggested species of crabs living in the saltmarsh are reliant on the same source of food for their nutrition (Figure 7.7).

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Avicennia marina and *Sporobolus virginicus*. However, the $\delta^{15}N$ ratios of all plant sources measured were significantly depleted compared to the values obtained from the crab muscle tissue, even allowing for the fractionation between producer and consumer of 2.6 ‰ (Owens 1987) to 3.4 ‰ (Minagawa and Wada 1984).

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Several authors (e.g., Micheli 1993 and Lee 1997) also reported that the Sesarma spp. exploited a wide range of foods under natural conditions. Isotopic results for the crab *Carcinus maenas* in Aiguillon Bay saltmarsh at France revealed complex trophic relationships suggested a high diversity of food sources (Riera *et al*. 1999).

To summarize, the saltmarsh is clearly of importance to the diet of small fish visiting this environment during the spring tide. Many species of fish consume the crab larvae found at particularly high concentrations in this environment at this time. While the diet the crabs producing this larvae seems dependant on the saltmarsh environment (given the contrasting signatures of *S. erythrodactyla* in saltmarsh and mangrove, and the similarlity

of signatures in the saltmarsh for *S. erythrodactyla* and *H. haswellianus*) the crabs do not seem to be dependent on any of the common species of saltmarsh plant, but rather depends on particulate organic matter derived from local and other sources. Deegan & Garritt (1997) reported the utilisation of local organic matter by benthic invertebrates in coastal marshes. Studies conducted elsewhere have demonstrated the trophic importance of imported phytoplankton and local micro-algae to saltmarsh macroconsumers (Creach *et al*. 1997, Page 1997, Currin *et al*. 1995, Sullivan and Moncreiff 1990) which could be explored further.

CHAPTER EIGHT

GENERAL DISCUSSION

8.1 Introduction

The contribution played by saltmarshes to estuarine fish is an important question to be asking at the present time. Photogrammetric surveys of the previous five decades have revealed a pattern of saltmarsh loss to both development and mangrove transgression (Saintilan and Williams 1999). In most of the twenty-seven estuaries studied in southeastern Australia by Saintilan and Williams (2001), the losses of saltmarshes were on the order of 20-50% of the total area lost since the 1940's. Pressure to clear saltmarshes is increasing, due both to development pressure and controversy surrounding the contribution made by saltmarshes to the propagation of mosquitoes.

Because the principal source of saltmarsh loss has been their replacement by mangroves, it is important to distinguish between the relative contribution made by mangroves and saltmarshes to estuarine fish in southeastern Australia. Results from other studies suggested that, while the saltmarsh plain is not an important habitat for commercially important fish species (Connolly *et al*. 1997), juveniles of commercially important species are to be found in the creeks draining saltmarsh plains (Gibbs 1986, Morton *et al*. 1987, Davis 1988). A recent study conducted by Thomas and Connolly (2001) in subtropical Queensland confirmed the widespread use of saltmarshes by fish. The investigations were conducted as part of this study and explored the contribution of temperate saltmarshes to estuarine fish.

8.2 Saltmarsh as habitat for fish

This research has shown that fish assemblages differ between saltmarsh and mangrove habitats, primarily because of the higher abundances of *Ambassis jacksoniensis*, *Gobiopterus semivestitus* and *Pseudomugil signifer* in saltmarshes compared to mangrove habitats and to the higher abundance of *Mugilogobius paludis* in mangroves. The research also found that fish assemblages vary between saltmarshes in different geographical locations. This spatial variability of fish assemblages between locations may be related to geomorphic setting, drainage patterns and other biotic factors, rather than on vegetation type, given the similarity in vegetation between the three sites. Morton *et al*. (1987) found that water depth was positively related to fish abundance in a saltmarsh tidal inlet in Moreton Bay, Queensland, while Louis *et al*. (1995) found that the distribution of species varied across eight mangrove stations sampled in the Bay, of Fort-de-France, Martinique, West Indies. Recent work of Clynick and Chapman (2002) also reported that fish assemblages varied between patches of mangroves from site to site in the same bay, and among bays. Whatever the reasons for this spatial variability, the research strongly suggests that geomorphic location may be a factor to be considered within the context of conservation and management decisions.

Thomas and Connolly (2001) reported that the average density of fish in a subtropical saltmarsh in Queensland was 0.46 fish m^{-2}, and included 23 species of fish. The present study revealed a higher density (0.56 fish m^{-2}) of fish in a temperate saltmarsh, although there was a lower species richness (21 species). There is little to distinguish saltmarsh and mangrove in diversity and abundance during the spring tide. This result also contrasts with results from a South Australian study (Connolly *et al*. 1997), where economically important species were poorly represented in the saltmarsh flats.

The abundance of fish in mangroves is only slightly higher than saltmarsh habitats (mean abundance 0.76 fish m^{-2}). However, the correction of densities for unit volume of water (the average water depth was 1.2 m in mangrove habitat compared to 0.4 m in saltmarsh habitat) yields higher densities in the saltmarsh (0.63 m^{-3} in mangrove compared with 1.9 fish m^{-3} in the saltmarsh). Twenty-five species of fish were found in mangroves among

which 12 species were of commercial importance.

A recent study by Clynick and Chapman (2002) found few differences in fish assemblages in mangroves and unvegetated mudflats. This study showed a higher similarity in diversity and abundance between saltmarsh and mangrove than was expected. Taken together, the two studies suggested that in the temperate situation, mangrove does not play the unique role as a fish habitat that was once attributed to it.

The present study found a strong autumn and spring peaks in the abundance of most common species including *Ambassis jacksoniensis*, *Gobiopterus semivestitus*, *Mugilogobious paludis*, *Pseudomugil signifer Gerres subfasciatus*, *Acanthopagrus australis* with. Previous studies (Robertson and Duke 1987, Bell 1980, Anon 1981, Laegdsgaard and Jonson 1995) found greatest abundance of small fish during summer.

The presence of commercial and recreational fish at high densities in saltmarsh flats during spring tides suggests that the saltmarsh may well be a significant fish habitat during spring tidal cycles. The findings are echoed by some Australian (Davis 1988, Morton *et al*. 1987, Gibbs 1986, Connolly *et al*. 1997), North American (Talbot & Able 1984, Kneib & Wagner 1994, Cain and Dean 1976, Weinstein 1979, Weinstein *et al*. 1980, Weinstein and Brooks 1983) and European studies (Costa *et al*. 1994, 1995). Currently, the value of wetland as fish habitat defined under the Fisheries Management Act (1994) and State Environmental Planning Policy (SEPP) 14 solely by vegetation type, regardless of geomorphological context. Recent studies, of which there is one, would suggest a great deal of spatial heterogeneity in the value of mangrove and saltmarsh as fish habitat, and the possibility that the geographic context is a greater determinant of variability than vegetation type alon. The fish nursery value of seagrass meadows, wetlands and other ecosystems may vary geographically (Beck *et al*. 2001). Recent analysis suggested that seagrass meadows in the tropical Caribbean are more important as nurseries than they are in the Indo-Pacific region (Williams 1991). Other analyses also found that seagrass meadows are more important as nurseries in the United States than in Australia (Edgar Shaw 1995, Butler and Jernakoff 1999, Ward *et al* 1999). Within the United States, seagrass meadows in warm temperate regions may serve as

better nurseries than those in cool temperate regions (Orth and Van Montfrans 1990). Saltmarshes in the Gulf of Mexico found more important as fish nurseries than in the US South Atlantic (Minello 1999). However, a more detailed assessment of the factors that contribute to the value of particular wetlands as fish habitat and nursery is therefore desirable.

8.3 Saltmarsh as habitat for crabs

Four species of crab were found in the saltmarsh: *Heloecius cordiformis, Sesarma erythrodactyla Helograpsus haswellianus* and *Paragrapsus laevis*. Three species of burrowing crabs were found in mangrove: *H. cordiformis, S. erythrodactyla* and *P. laevis*. The most significant difference between mangrove forest and saltmarshes was the absence of *H. haswellians* from the mangrove and the abundance of this species in the saltmarsh. The result contrasts with the analyses of Skilleter and Warren (2000) who reported that *H. haswellians* was the most abundant crab in a subtropical mangrove forest in Moreton Bay, Queensland. Perhaps the substrate conditions are an important factor in determining crab abundance. In case of saltmarsh, dry, less frequently inundated flats are more suitable for *H. haswellians*, and this exerts a greater influence on distribution than vegetation type. Recent studies suggested that tidal inundation, substrate drainage and salinity may exert a strong influence on the fanual composition of saltmarshes (Richardson *et al*. 1997, 1998).

Crab abundance within the saltmarsh, varied between vegetation types with *H. cordiformis* found in greater number in saltmarsh dominated by *Sarcornia quinqueflora* and *H. haswellianus* found in larger numbers in saltmarshes dominated by *Sporobolus virginicus* and *Juncus krausii*. Grapsid and grapsoid crabs, occupy a keystone position (Smith *et al*. 1991) in the ecology of Australian mangrove forests and associated saltmarshes. Burrowing and feeding activity of these crabs enrich the soil through the cycling of organic (Marsh 1982) and inorganic (Williamson *et al*. 1999) material and increase productivity of saltmarsh plants (Davie 1993). But to what extent a particular vegetation community support a wider range of benthic macro-faunal life in a saltmarsh

is beyond the scope of the present study and therefore more detailed investigation is required.

The present study has shown that burrowing crab abundance and species richness in saltmarshes is greater than in the adjacent mangrove forest, suggesting that saltmarshes are potentially as important a habitat for macro-benthic crabs as Northern Hemisphere saltmarshes (Mense & Wenner 1989; Thomas *et al*. 1990; Fitz *et al*. 1991).

8.4 Saltmarsh export live food for fish

Besides fish and crab habitat, part of the conservation value of saltmarshes relies on its role as a net exporter of organic carbon, and the contribution zooplankton including crab larvae may make up the diet of small and juvenile fish. This study has shown that crabs living in saltmarshes release considerable quantities of larva during the ebb tide. There appears to be a strong winter peak and a smaller summer peak, corresponding to times in which *Helograpsus haswellianus* and *Sesarma erythrodactyla*, respectively, are in berry (Chapter 5). Christy (1989) found that adult fiddler crabs produce large pulses of zoeae which are transported to the coastal waters. The present study also found a release of crab larvae from mangrove during summer months. Robertson *et al.* (1988) similarly found that brachyuran zoea were an order of magnitude more abundant in mangrove forest tham in the seagrass habitat during summer months (December to February) in Northeastern Australia. More attention should be given to examine the links between crab reproductive cycle, and the timing of larvae availability and fish recruitment patterns in the estuary.

A relatively lower concentration of crab larvae was released from mangrove during ebb tides when compared to releases from the nearby saltmarsh (Chapter 6). This can in part be explained by the presence of a higher volume of water due to the greater inundation depth, as well as greater number of inundating tides available to the crabs. The highest zooplankton densities sampled in any shallow estuarine environment were found within water draining the saltmarsh. Here zooplankton densities were substantially higher than in other habitats due to the introduction of newly hatched crab larvae. Such a release

would enhance larval distribution within the estuarine water, and this is of potential significance to the availability of organic carbon within the estuary. The high concentration of larvae within the saltmarsh, and to a lesser extent mangrove waters, represents an efficient, if temporary food source for some juveniles and small species.

The present study found that gastropods (*Assiminea tasmanica*, *Salinator solida*, *Littoraria luteola and Ophicardelus sp*.) living in saltmarshes (Morrisey, 1995) also export larvae (on average 3764.94 $^{m-3}$) in almost all months and that this may have potential implications in the estuarine food webs something which is beyond the scope of the current study. The Towra Point saltmarsh acted as a sink for copepods (on average 26.0% were retained) and amphipods (32.6% retained), the most abundant zooplankton components of the incoming tidal water. Whether the loss of such amounts of copepoda and amphipoda in the saltmarsh is due to predation by fish or by other factors is unclear from the present research. Historically the primary value of vegetated marsh habitat to fish has been considered as a carbon source for the production of invertebrate prey that was then utilized by coastal and estuarine-dependent species (Teal 1962, Nixon 1980). Saltmarsh is also considered a high source of primary production (Buzzelli 1996) which is processed by decomposers and detritivores invertebrates before it is available to nekton (Kneib 1997) through which saltmarsh produced energy is exported to deeper water ecosystems via series of predation (Cicchetti and Daiz 2000). The present study found saltmarsh export direct energy in the form of invertebrate larvae that is directly consumed by transient fish and exported to deeper water.

8.5 Fish visit saltmarsh for food

An analysis of the stomach content analysis of fish concluded that fish visiting saltmarshes during high spring tide prey upon crab larva. Studies conducted elsewhere analysing the tidal effects on stomach fullness provides indirect evidence that marsh habitats are preferentially used for feeding (Craig 2000). In the present study a high percentage of crab larva was present in the stomach of glassfish (*Ambassis jacksoniensis*), flat tail mullet (*Liza argenta*) and blue eye (*Pseudomugil signifer*),

suggesting the importance of crab larvae as a component of their diet. Several authors (e.g., Morton *et al*. 1987, Robertson *et al*. 1988 and Allen *et al*. 1995) also reported the consumption of crab larvae by fish. These studies did not clearly trace the source of crab larvae, and therefore trophic links between visiting fish and habitats have been poorly understood. The present study has identified the saltmarsh as an important source of crab larvae, and their consumption by visiting fish during the peak of the spring tide. Stomach content analyses also suggested that yellow fin bream (*Acanthopagrus australis*) and mangrove goby (*Mugilogobius paludis*) move to saltmarshes to eat crabs and juvenile fishes concentrated there for food. Most studies that have examined tidal effects have found that fish have fuller stomachs on ebb tides than on flood tides (Weisberg *et al*. 1981, Klepas and Dean 1983, Rozas and Lasalle 1990, Rountree and Able 1992), suggesting fish move into intertidal creeks and saltmarshes to feed at high tide. The results demonstrate a direct trophic link between saltmarsh and visiting fish, particularly given the low concentration of crab larvae elsewhere in the estuary.

The present study also found that the variability in the consumption of crab larvae by fish was generally independent of the availability of larvae in the water. The result contrasts with the findings of Morton *et al*. (1987) who found crab zoea and megalopae were represented in the diet of fish during autumn and winter in the Moreton Bay, Queensland. Further, the consumption of crab larvae as a food item did not correspond to the size of fish. Both larger and smaller species consumed crab larvae suggesting consumption of crab larvae as food item is mostly species specific regardless of size.

8.6 Diet of crabs

Crabs would appear to be keystone species in saltmarshes, producing a consistently large quantity of plankton which is exported to estuarine water. Results from the analysis of stable isotopes showed very similar $\delta^{13}C$ and $\delta^{15}N$ ratios for *S. erythrodactyla* and *H. haswellianus* in the saltmarsh which differed to the more depleted $\delta^{13}C$ ratio of *S. erythrodactyla* in the mangrove forest. In spite of the correspondence of isotopic

signature and presumably the diet of *S. erythrodactyla* and *H. haswellianus* in the saltmarsh, the stable isotope signatures do not correspond to any of the known signatures of saltmarsh plants. However, the signature corresponded precisely with that of particulate organic matter (POM) for Morton Bay measured by Melville and Connolly (2003), allowing for a 2‰ in $\delta^{15}N$ fractionation between the source and the consumers. The suggestion that crabs in the Sydney region are relying primarily on POM, rather than plant detritus, corresponded to the visual observations of Saintilan *et al*. (2000). Overseas studies of the natural abundance of stable isotopes have demonstrated the trophic linkage of many invertebrate primary consumers to saltmarsh organic matter (Haines and Montague 1979, Peterson *et al*. 1986, Couch 1989, Currin *et al*. 1995). The result should be considered in determining the importance of mangrove and saltmarsh habitats in the diet of fish. Studies using stable isotope to trace trophic dependence of fish on mangrove and saltmarsh detritus could easily neglect the potential importance of crab larvae which, on the basis of these results would not reflect the isotope signatures of the vegetation. However, important food items are none-the-less sourced from these environments. Again, the point is highlighted that it is not the vegetation *per se* which is of fisheries significance, either mangrove or saltmarsh habitats, but the location of the habitat within the estuary and within the tidal plane.

8.7 Management implictions

In the temperate situation, vegetation content does not seem to be a significant factor in defining the importance of a coastal wetland for fish. Fish assemblages are similar between mangrove and mud flat (Clynick and Chapman 2002) and the difference between mangrove and saltmarsh fish communities in this study could be understood from this study as a winnowing of some species from the upper-intertidal zone.

Further, the trophic links between fish and saltmarshes demonstrated in this study was primarily between fish and crabs, specifically crab larvae which are highly abundant in saltmarshes during the spring tide. The crab diet could not related to the plant detrital

material, but did correspond well with isotope values quoted by Melville and Connolly (2003) for particulate organic matter which came from bay water.

The difference between temperate saltmarsh and mangrove habitats for benthic macro-fauna is due the presence of *Helograpsus haswellianus* in saltmarsh. The presence of this crab in saltmarshes may be due to the location of saltmarsh in the estuary, or to the tidal factors, but definitely not plant detritus, as evidenced by the isotopic signatures. *H. haswellianus* was found to be in berry during the winter months when peak larval discharges occurred. Its higher abundance in the saltmarsh may be a key difference in the utility of mangroves and saltmarshes as fish habitat. Driving the periodic productivity of the saltmarsh as a source of zooplankton is the position of the community in the tidal plane rather than the vegetation. Perhaps *H. haswellianus* prefers the better-drained soils, and less frequent inundation. The infrequent inundation, in turn, creates challenges for the timing of larval dispersion, to which *H. haswellianus* responds by discharging larvae profusely into the ebbing winter spring tides. This, in turn, becomes an efficient, if periodic, source of nutrition for fish in the saltmarsh and possibly in the adjacent mangrove. Again, may be the position of the saltmarsh zone in the tidal plain which is of significance, rather than vegetative differences between mangrove and saltmarsh.

These considerations support proposed some policy changes with respect to the Fisheries Management Act (1994) and SEPP14. Clearly, vegetation is of minor significance in determining the fisheries significance of mangrove and saltmarsh. The upper intertidal environment creates a unique set of conditions, leading to high levels of zooplankton availability, a fact not recognised under the Fisheries Management Act, which protects mangrove to the mean tide level. Differences in fish assemblages between mangrove and saltmarsh may be the effect of inundation duration and location, rather than vegetation, which should also be acknowleged in the Act, and lead to greater research on factors responsible for geographic variability in assemblages. The results strongly suggest that emphasis be given to ecosystem-based management for an estuary, rather component (e.g., vegetation) based managed as defined by the Fisheries Management Act (1994) and SEPP14.

REFERENCES

Acosta, C. A. and Butler, M. J. (1997). Role of mangrove habitat as a nursery for juvenile spiny lobster, *Panulirus argus*, in Belize. Marine and Freshwater Research 48: 721-727.

Adam, P. (1990). Saltmarsh Ecology. The University Press, Cambridge.

Adam, P., Wilson, N. C. and B. Huntley. (1988). The phytosociology of coastal saltmarsh vegetation in New South Wales. Wetlands (Australia) 7: 35-84.

Allen, M. D., William, S. Johnson. and Virginia, O. Matthews. (1995). Trophic relationships and seasonal utilization of saltmarsh creeks by zooplanktivorous fishes. Environmental Biology of Fishes. 42: 37-50

Alongi, D. M., Boto, K. G. and Tirendi, F. (1989). Effect of exported mangrove litter on bacterial productivity and dissolved organic carbon fluxes in adjacent tropical nearshore sediments. Marine Ecology Progress Series. 56: 144-189.

Anon. (1981). The ecology of fish in Botany Bay-biology of commercially and recreationally important species. State Pollution Control Commission of New South Wales. Report. No. BBS23B.

Aspey, W. R. (1978). Fiddler crab behaviour ecology: Burrow density in *Uca pugnax* (Smith) and *Uca pugilator* (Bosc) (Decapoda, Brachyura). Crustaceana. 34: 235-244.

Austin, H. M. (1971). A survey of icthyofauna of the mangroves of western Puerto Rico during December, 1967- August 1968. Carib. J. Sci. 11(1-2): 27-39.

Baelde, P. (1990). Difference in the structures of fish assemblages in *Thalassia testudinum* beds in Guadeloupe, French West Indies, and their ecological significance. Marine Biology 105: 163-173.

Baran, E. (2001). Physical environments and variability of the contribution of mangroves to coastal zone production. Workshop presentation on economic valuation of mangrove ecosystems, University Sains Malaysia, 13pp.

Beck, W. M., Heck, L. K. Jr., Able, W. K., Childers, L, D., Eggleston, B, D., Gillanders, M, B., Halpern, B., Hays, G. C., Hoshino, K., Minello, J. T., Orth, J. R., Sheridan, F. P. and Weinstein, P. M. (2001). The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. BioScience 51 (8): 633-641

Bell, J. D. and Worthington, D. C. (1992). Links between estuaries and coastal rocky reefs in the lives of fishes from south-eastern Australia. In proceedings of the Second International Temperate Reef Symposium, Auckland, New Zealand, Battershill, C. N. (ed.). NIWA Marine, Wellington, pp. 85-91.

Bell, J. D. (1980). Aspects of the ecology of fourteen economically important fish species in Botany Bay, New South Wales, with special emphasis on habitat utilisation and a decision of the effects of man-induced habitat changes. M. Sc. Thesis, Macquarie University.

Bell, J. D., Pollard, D. A., Burchmore, J. J., Pease, B. C. and M. J. Middleton. (1984). Structure of a fish community in a temperate tidal mangrove creek in Botany Bay, New South Wales. Australian Journal of Marine and Freshwater Research 35: 33-46.

Blaber, S. J. M. and Blaber, T. G. (1980). Factors affecting the distribution of juvenile estuarine and inshore fish. Journal of Fish Biology 17: 143-162.

Blaber, S. J. M. (2000). Tropical Estuarine Fishes Ecology, Exploitation and Conservation. Fish and Aquatic Resources Series 7, Blackwell Science, 372pp.

Blaber, S. J. M., Brewer, D. T. and Salini, J. P. (1995). Fish communities and the nursery role of shallow inshore waters of a tropical bay in the Gulf of Carpentaria, Australia. Estuarine Coastal and Shelf Science, 40: 177-193.

Blaber, S. J. M., Young, J. W. and Dunning, M. C. (1985). Community structure and zoogeographic affinities of the coastal fishes of the Dampier Region of north-western Australia. Australian Journal of Marine and Freshwater Research. 36: 247-266.

Boorman, L. A. (1999). Salt marshes- present functioning and future change. Mangrove and Salt Marshes 3: 227-241.

Bosech, D. F., Turner, R. E. (1984). Dependency of fishery species on saltmarshes: The role of food and refuge. Estuaries 7 (4A): 460-468.

Boto, K. G. and Bunt, J. S. (1981). Tidal export of particulate organic matter from a northern Australian mangrove system. Estuarine Coastal and Shelf Science 13: 247-255.

Boto, K. G., Bunt, J. S. and Wellington, J. T. (1984). Variation in mangrove forest productivity in northern Australia and Papua New Guinea. Estuarine Coastal and Shelf Science 19: 321-329.

Bouillon, S., Koedam, N., Raman, A. V. and Dehairs, F. (2002). Primary producers sustaining macro-invertibrate communities in intertidal mangrove forests, Oecologia 130: 441-448

Branch, G. M. and Grindley, J. R. (1979). Ecology of the southern African estuaries. Part XI. Mngazana: a mangrove estuary in Transkei. South African Journal of Zoology 14 (3): 149-165.

Bray, J. R. and J. T. Curtis. (1957). An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs 27: 325-349.

Bunn, S. E. and Boon, P. I. (1993). What sources of organic carbon drive food webs in billabongs? A study based on stable isotope analysis. Oecologia. 96: 85-94

Bunt, J. S., Boto, K. G., and Boto, K. (1979). A survey of estimating potential levels of mangrove forest primary production. Marine Biology 52: 123-128.

Burchmore, J. J. (1976). Morphology and growth of the alimentary tract, in relation to phylogeny, food and feeding habitats, in nineteen species of eastern Australian estuarine teleosts. BSc (Hons) Thesis, University of Sydney

Burton, T. (1982). Mangrove changes recorded north of Adelaide. Safic 6: 8-12.

Butler, A. J., Jernakoff, P. (1999). Seagrass in Australia: Strategic Review and Development of an R & D Plan. Collingwood (Australia): CSIRO Publishing.

Buzzelli, C. P. (1996). Integrative analysis of ecosystem processes in the littoral zone of lower Chesapeake Bay: a modeling study of the Goodwin Isalnds National Estuarine Research Reserve. Doctoral Dissertation, The college of William and Mary, Williamsburg, Virginia, USA.

Cain, R. E. and J. M. Dean (1976). Annual occurrence, abundance and diversity of fish in South Carolina intertidal creek, Marine Biology 36: 369-379.

Carr, W. E. S. and Adams, C. A. (1973). Food habitats of juvenile marine fishes occupying seagrass beds in the estuarine zone near Crystal River Florida. Transactions of the American Fisheries Society 102: 511-540.

Chafer, C. J. (1998a). A Spatio-temporal analysis of estuarine vegetation changes in the Minnamurra River 1938-1997. Minnamurra Estuary Management Committee.

Chafer, C. J. (1998b). The effect of temporal geomorphological processes on shorebird populations at Shoalhaven Heads, NSW. Master of Science Thesis, University of

Wollogong.

Chapman, M. G. and Underwood, A. J. (1995). Mangrove forest. In: Underwood, A. J., Chapman, M. G. (eds.) Coastal Marine Ecology of the Temperate Australia. UNSW press, Sydney, pp. 187-204.

Chong, V. C., Sasekumar, A., Leh, M. U. C. and Cruz, A. (1990). The fish and prawn communities of a Malaysian coastal mangrove system, with comparisons to adjacent mud flats and inshore waters. Estuarine Coastal and Shelf Science 31: 703-722.

Christy J. H. (1978). Adaptive significance of reproductive cycles in the fiddler crab *Uca Pugilator*. A hypothesis. Science. 199: 453-455.

Christy, J. and Stancyk, S. E. (1982). Timing of larval production and flux of invertebrate larvae in well-mixed estuary. In Estuarine Comparisons, Kennedy, V. S. (ed.) Accademic Press, New York, pp. 505-520.

Christy, J. H. (1982). Burrow structure and use in the sand fiddler crab. *Uca pugilator* (Bosc). Animal Behaviour 30: 687-694.

Christy, J. H. (1989). Rapid development of megalopae of the fiddler carb *Uca pugilator* reared over sediment: implications for models of larval recruitment. Marine Ecology Progress Series 57: 259-265.

Cicchetti, G., and Diaz, R. J. (2000). Types of saltmarsh edge and export of trophic energy from marshes to dipper habitats. Pages: 515-541. *In* Weinstein, P. M., and Kreeger, A. D. (ed.). Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishers, Netherlands.

Claridge, P. N., Potter, I. C. and Hardisty, M. W. (1986). Seasonal changes in movements, abundance, size compositions and diversity of the fish fauna of the Severn estuary. Journal of Marine Biology Association, U.K. 66: 229-258.

Clark L. D, Hannon, N. J. (1969). The mangrove swamp and saltmarsh communities of the Sydney district: II. The holocoenotic complex with particular reference to physiography. Journal of Ecology 57: 213-244.

Clark, L. D. and Hannon, N. J. (1967). The mangrove swamp and saltmarsh communities of the Sydney district. I. Vegetation, soil and climate. Journal of Ecology 55: 753-771.

Clark, P. and Benson, D. (1988). The natural vegetation of Homebush Bay-two hundred years of changes, Wetlands (Australia). 1: 282pp.

Clarke, K. R. and R. M. Warwick. (2001). Changes in marine communities: An approach to statistical analysis and interpretation, 2nd edition. PRIMER-E; Plymouth, United Kingdom.

Clynick, B. and M. G. Chapman. (2002). Assemblages of small fish in patchy mangrove forest in Sydney Harbour. Marine and Freshwater Research 53: 669-677.

Colby, D. R. and Fonseca, M. S. (1984). Population dynamics, spatial dispersion and somatic growth of the sand fiddler crab Uca pugilator. Marine Ecology Progress Series 16: 269-279.

Connolly M. R. (1994). Comparison of fish catches from a buoyant pop net and beach seine net in a shallow seagrass habitat. Marine Ecology Progress Series 109: 305-309.

Connolly, R. M. (1999). Saltmarsh as habitat for fish and nektonic crustaceans: challenges in sampling designs and methods. Australian Journal of Ecology 24(4): 422-430.

Connolly, R. M. Dalton, A. and Bass, D. A. (1997). Fish use of an inundated saltmarsh flat in a temperate Australian estuary. Australian Journal of Ecology 22: 222-226.

Costa, M. J., Costa, J. L., Almeida, P. R. and Assis, C. (1994). Do eel grass beds and salt

marshes act as preferential nurseries and spawning grounds for fish? An example of the Mira estuary, Portugal. Ecological Engineering 3: 187-195.

Costa, M. J., Lopes, M. T., Domingos, I. M., Almeida, P. R. and Costa, J. L. (1995). Portuguese fauna working group-Tagus and Mira sites. pp. 95-174. In: Lefeuvre, J. C. (ed.), The eEffects of Environmental Change on European Salt Marshes: Structure, Functioning and Exchange Potentialities with Marine Coastal Waters. Vol. 3. University of Rennes, France.

Couch, C. A. (1989). Carbon and nitrogen stable isotopes of meiobenthos and their food resources. Estuarine, Coastal and Shelf Science 28: 433-441.

Craig, K. J. (2000). Factors influencing habitat selection in fishes with a review of marsh ecosystems. Pages: 241-266. *In* Weinstein, P. M., and Kreeger, A. D. (ed.). Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishers, Netherlands.

Crane, J. (1975). Fiddler crabs of the world. Ocypodidae: genus *Uca. Princeton* University Press, New Jersey.

Creach, V., Schrike, M. T., Bertru, G. and Mariotti, A. (1997). Stable isotopes and gut content analysis to determine feeding relationships in saltmarsh macroconsumers. Estuarine Coastal and Shelf Science 44: 599-611.

Crichton, O. W. (1960). Marsh crab: Intertidal tunnel-maker and grass eater. Estuar. Bull 5: 3-10.

Crisp, D. T., Mann, R. H. K. and McCormac, J. C. (1978). The effects of impoundment and regulation upon the stomach contents of fish at Cow Green, Upper Teesdale. Journal of Fish Biology 12: 287-301.

CSIRO Division of Fisheries (1994). Jervis Bay Baseline Studies. Final report, May 1994. Marimon Marine Laboratories, North Beach, Western Australia. 128pp.

Currin, C. A., S. Y. Newell and H. W. Paerl. (1995). The role of standing dead *Spartina alterniflora* and benthic microalgae in salt marsh food webs: considerations based on multiple stable isotope analysis. Marine Ecology Progress Series. 121: 99-116.

Daiber, F. C. (1977). Salt marsh animals: distributions relating to tidal flooding salinity and vegetation. Pp. 79-108. *In*: Chapman, V. J. (ed.), Wet Coastal Ecosystems. Elsevier: Amsterdam.

Dame, R., Chrzanowski, T., Bildstein, K., Kjerfre, B., McKellar, H., Nelson, D., Spurrier, S., Stancyk, S., Stevenson, H., Vernberg, J. and Zingmark, R. (1986). The outwelling hypothesis and North Inlet, South Carolina. Marine Ecology Progress Series 33: 217-229.

Davie, P. (1993). Grabbed by crabs. In Death to Mangroves? Australian Science, Autumn issue.

Davis, T. L. O. (1988). Temporal changes in the fish fauna entering a tidal swamp system in tropical Australia. Environmental Biology of Fish 21: 185-194.

Deegan, L. A., and Garritt, R. H. (1997). Evidence of spital variability in estuarine food webs. Marine Ecology Progress Series 147: 31-47.

DeNiro, M. J. and Epstein, S. (1978). Influence of diet on the distribution of carbon isotopes in animals. Geochim Cosmochin Acta 42: 495-506.

Dewet, P. S. and Marais, J. F. K. (1990). Stomach content analysis of juvenile Cape stumpnose Rhabdosargus holubi in the Swartkops estuary, South Africa. South African Journal of Marine Science 9: 127-133.

Dittle, A. I., and Epifanio, C. E. (1982). Seasonal abundance and vertical distribution of crab larvae in Delaware Bay. Estuaries 5: 197-202.

Dittle, A. I., and Epifanio, C. E. (1990). Seasonal and tidal abundance of crab larvae in a

tropical mangrove system, Gulf of Nicoya, Costa Rica. Marine Ecology Progress Series 65: 25-34.

Dittle, A. I., and Epifanio, C. E., and Lizano, O. (1991). Flux of crab larvae in a mangrove creek in the Gulf of Nicoya, Costa Rica. Marine Ecology Progress Series 65: 25-34.

Duke, N. C. (1982). Mangrove litter fall data from Hichinbrook Island, Northeastern Australia . Australian Institute of Marne Science. Data Report, CS-81-2.

Ebert, S. P. (1995). The geomorphological response to sediment discharge from the Herbert River, North Queensland, 1943-1991. B. Sc. Honours Thesis, Department of Geology, James Cook University, 78pp. plus appendices.

Edgar, G. I., Shaw, C. (1995). The production and trophic ecology of shallow water fish assemblages in southern Australia: Species richness, size structure and production of fishes in Western Port, Victoria. Journal of Experimental Marine Biology and Ecology 194: 53-81.

Edmondson, T. W. and Winberg, G. G. (1971). A Manual on Methods for the Assessment of Secondary Productivity in Fresh Waters. IBP Hand Book No. 17. Blackwell Scientific Publications. 358 pp.

Epifanio, C. E., Valenti, C. C. and Pembroke, A. E. (1984). Dispersal and recruitment of blue Crab Larvae in Delaware Bay, USA. Estuarine, Coastal and Shelf Science 18: 1-12.

Epifanio, C. E., Little, K. T., Rowe, P. M. (1988). Dispersal and recruitment of fiddler crab larvae in the Delaware River estuary. Marine Ecology Progress Series 43: 181-188.

Evans, M. (1997). Historical distribution of estuarine wetlands at Kurnell Peninsula, Botany Bay-the need and potential for rehabilitation B.Sc. Honours Thesis, University of Wollong.

Feest, J. (1969). Morphophysiological studies on the ontogeny and sexual biology of *Uca annulipes* and *Uca triangularis* as compared to *Ilyoplax gangetica*. Forma Functio 1: 159-225.

Fenech, H. (1994). An assessment of the estuarine wetland status within the Sutherland Shire. Unpublished B. Env. Sc. Thesis, Faculty of Science, University of Wollongong.

Finlayson, C. M. and Rea, N. (1999). Reasons for the loss and degradation of Australian wetlands. Wetlands Ecology and Management 7: 1-11.

Fitz, H. C., Wiegert, R. G. (1991). Utilization of the intertidal zone of a saltmarsh by the blue crab *Callinectes sapidus*: density, return frequency and feeding habits. Marine Ecology Progress Series 76: 249-260.

Flores-Verdugo, F. J., Day, J. W., Briseno-Duenas, R. (1987). Structure, litterfall, decomposition and detritus dynamics of mangroves in a Mexican coastal lagoon with an ephemeral inlet. Marine Ecology Progress Series 35: 83-90.

Forward, R.B.Jr. (1987). Larval release rhythms: an overview. Bulletin of Marine Science 41: 165-176.

Fotheringham, C. M. (1994). A vegetation survey of Barker Inlet, Gulf st. Vincent, South Australia. Management Issue and Recommendations. Coastal management Branch, Technical Report 94/1, Department of Environment and Natural Resources.

Fry, B. (1981). Natural stable isotope tag traces Texas shrimp migrations, Fishery Bulletin 79:337-345.

Fry, B., Joern, A. and Parker, P. L. (1978). Grasshopper food web analysis: use of carbon isotope ratios to examine relationships among terrestrial herbivores, Ecology 59: 498-506.

Gibbs, P. J. (1985). The funna and fisheries of Wallis Lake. Wallis Lake- present and future. Australine Marine Science Association (NSW Branch) and Coast and Wetland society, Occasional paper series.

Gibbs, P. J. (1986). The fauna and fishery of Wallis Lake. In: Wallis Lake: Present and Future. Occasional papers of the Australian Marine Science Association, Sydney, NSW. pp. 1-7.

Golley. F., Odum. H. T. and Wilson, R. F. (1962). The structure and metabolism of a Puerto Rican red mangrove forest in May**.** Ecology 43: 9-19.

Gray, C. A. and Bell, J. D. (1986). Consequences of two common techniques for sampling vagile macrofauna associated with the seagrass *Zostera capricornia*. Marine Ecology Progress Series 28: 43-48.

Gray, C. A., McElligot, D. J. and Chick, R. C. (1996). Intra and inter estuary difference in assemblages of fishes associated with shallow seagrass and bare sand. Australian Journal of Marine and Freshwater Research 41: 13-26.

Griffin, D. J. G. (1968). Social and maintenance behaviour in two Australian Ocypodid shore crabs (Crustacea: Brachyura). Journal of Zoology, London 156: 291-305.

Griffin, D. J. G. (1971). The ecological distribution of grapsid and ocypodid shore crabs (Crustacea: Brachyura) in Tasmania. Journal of Animal Ecology 40: 597-621.

Griffiths, S. P. and West, R. J. (1999). Preliminary assessment of shallow water fishes in three small intermittently open estuaries in south eastern Australia. Fisheries Management and Ecology 6: 311-321.

Haedrich, R. L. (1983). Estuarine fishes. Pahges 183-207. *In* B. H. Ketchum, (ed.). Ecosystems of the World. Elsevire, Amsterdam. The Netherlands.

Hagen, H. O. (1993). Waving display in females of *Uca polita* and of other Australian fiddler crabs. Ethology 93: 3-20.

Haines, E. B. and C. L. Montague (1979). Food sources of estuarine invertebrates analyzed using $^{13}C/^{12}C$ ratios. Ecology 60: 48-56.

Halliday, I. A. & W. R. Young. (1996). Density, biomass and species composition of fish in a subtropical Rhizophora stylosa mangrove forest. Marine and Freshwater Research (Australia) 47 (4): 609-615.

Hannan, J. C. and Williams, R. J. (1998). Recruitment of juvenile marine fishes to seagrass habitat in a temperate Australian estuary. Estuaries 21: 29-51.

Harty, C. (1997). Mangroves in New South Wales and Victoria. Vista publications, Melbourne.

Hayland, S. J. and Butler, C. T. (1988). The distribution and modification of mangroves and saltmarsh-claypans in southern Queensland. Queensland Department of Primary Industries, Information Series Q 189004. 74p.

Hettler, W. F. (1989). Nekton use of regularly-flooded saltmarsh cordgrass habitat in North Carolina, USA. Marine Ecology Progress Series 56: 111-118.

Hughes, N. (1998). The changing mangrove saltmarsh boundary: studies in the Sydney district. B. Sc. Honors Thesis, School of Geosciences, University of Sydney.

Hutchings, P. and Seanger, P. (1987). Ecology of Mangroves. University of Queensland Press, St. Lucia 388pp.

Japar, S. B. (1989). Studies on leaf litter decomposition of the mangrove *Rhizophora apiculata* Bl. PhD. Thesis, University Sains Malaysia, 322pp.

Jones, A. R. (1988). Zoobenthic species richness in the Hawkesbury estuary: Pattern and variability associated with major physio-chemical factors: pp. 6-10. *In* Australian Marine Science Association Silver Jubilee Commemorative Volume. Wavelength Press, Chippendale.

Jones, A. R., Watson-Russell, C. J. and Murry, A. (1986). Spatial patterns in the macrobenthic communities of the Hawkesbury Estuary, New South Wales, Australian Journal of Marine and Freshwater Research 37: 521-543.

Jones, D. A. (1984). Crabs of the mangal ecosystem: pp. 89- 109. *In*: Por. F. D., Dor, I. and Junk, W. (eds.), Hydrobiology of the Mangal. The Hague (W. Junk Publisher).

Kathiresan, K. and Bingham, B. L. (2001). Biology of mangroves and mangrove ecosystems. Advances in Marine Biology 40: 81-251.

Kerbs, C. T. and Valiela, I. (1978). Effects of experimentally applied chlorinated hydrocarbons on the biomass of the fiddler crab, *Uca pugnax* (Smith). Estuarine Coastal and Shelf Science 6: 375-386.

Kerwin, J. A. (1971). Distribution of fiddler crab (*Uca minax*) in relation to marsh plants within a Virginia estuary. Chesapeake Science 12: 180-183.

Kleypas, J. and J. M. Dean (1983). Migration and feeding of the predatory fish, *Bairdiella chrysura* Lacepede, in an intertidal creek. Journal of Experimental Marine Biology and Ecology 72: 199-209.

Kneib, R. T. (1997). The role of tidal marshes in the ecology of estuarine nekton. Oceanography and Marine Biology: an Annual Review 35: 163-220.

Kneib, R. T. and S. L. Wagner. (1994). Nekton use of vegetated marsh habitats at different stages of tidal inundation. Marine Ecology Progress Series 106: 227–38.

Kratochvil, M., Hannon, N. J. and Clarke, L. D. (1972). Mangrove swamp and saltmarsh communities in eastern Australia. Proceedings of the Linnaean Society of NSW 97: 262-274.

Laegdsgaard, P. and C. R. Johnson. (1995). Mangrove habitats as nurseries: unique assemblages of juvenile fish in subtropical mangroves in eastern Australia. Marine Ecology Progress Series 126: 67-81.

Laegdsgaard, P. and C. R. Johnson. (2001). Why do juvenile fish utilise mangrove habitats? Journal of Experimental Marine Biology and Ecology 257: 229-253.

Lambert, R. and Epifanio, C. E. (1982). A comparison of dispersal strategies in two genera of brachyuran crab in a secondary estuary. Estuaries 5: 182-188.

Larkum, A. W. D. (1981). Marine primary productivity: pp. 369-385. *In* Marine Botany: an Australian perspective, edited by M. N. Clayton & R. J. King, Longman Cheshire, Melbourne.

Lear, R. and Turner, T. (1977). Mangroves of Australia. University of Queensland Press, Queensland. 82 pp.

Lee, S. Y. (1997). Potential trophic importance of the faecal material of the mangrove sesarmine crab *Sesarma messa*. Marine Ecology Progress Series, 159: 275-284

Lee, Y. S. (1998). Ecological role of grapsid crabs in mangrove ecosystems: a review. Marine and Freshwater Research 49: 335-343.

Lefeuvre, J. C. and Dame, R. F. (1994). Comparative studies of salt marsh processes on the New and Old Worlds: an introduction. pp. 169-179. *In*: Mitsch, W. J. (ed.). Global Wetlands: Old World and New. Elsevier, Amsterdam.

Little, M. C., Reay, P. J. and Grove, S. J. (1988). The fish community of an East African

mangrove creek. Journal of Fish Biology 32: 729-747.

Loke, Y. M. (1984). Energetics of leaf litter production and its pathway through the sesarmid crabs in a mangrove ecosystem. M.Sc. Thesis, University Sains, Malaysia. 140pp.

Louis, M., Bouchon, C. & Bouchon-Navro, Yolande. (1995). Spital and temporal variations of mangrove fish assemblages in Martinique (French Wes Indies). Hydrobiologia 295: 275-284.

MacFarlane, G. R. (2002). Non-destructive sampling techniques for the rapid assessment of population parameters in estuarine shore crabs. Wetlands (Australia) 20:49-54.

MacFarlane, G. R., King, S. A. (2002). Observer presence influences behaviour of semaphore crab, *Heloecious cordiformis*. Animal Behaviour 63: 1191-1194.

Macintosh, D. J. (1988). The ecology and physiology of decapods of mangrove swamps. Symp. Zool. Soc. Lond. 59: 315-341.

MacIntyre, R. J. (1959). Some aspect of ecology of Lake Macquarie, NSW with regard to an alleged deplation of fish. VII The benthic macrofauna. Australian Journal of Marine and Freshwater Research 10: 341-353.

Margalef, R. (1969). Perspectives in Ecological Theory. The University of Chicago Press, Chicago.

Marsh, J. (1982). Aspects of the ecology of three salt-marshes of the Derwent region, and an investigation into the role of the burrowing crab *Helograpsus haswellianus* (Whitelegge, 1889). Honours Thesis, University of Tasmania

Mazumder, D. and Saintilan, N. (2003). A comparison of sampling techniques in the assessment of burrowing crab abundance in saltmarsh and mangrove in temperate

Australia. Wetlands (Australia) 21(1): 1-15.

McGuinness, K. A. (1990). Effects of oil spills on macro-invertebrates and mangrove forests in Botany Bay, New South Wales, Australia. Journal of Experimental Marine Biology and Ecology 142: 121-135.

McGuiness, K. A. (1997). Seed predation in a north Australian mangrove forest: a test of the dominance-predation model. Journal of Tropical Ecology 13: 293-302.

Mcloughlin, L. (1987). Mangrove and grass swamps: Changesin shoreline vegetation of the middle Lane Cove River, 1780's to 1880's. Wetlands (Australia) 7: 13-24.

McTainsh, G., Iles, B and Saffigan, P. (1988). Spaital and temporal patternsof mangroves at Oyster Point Bay, southeast Quensland. 1944-83. Proc. R. Soc. Qld. 99: 83-91.

Meehan, A. (1997). Historical changes in seagrass, mangrove and saltmarsh communities in Meribula Lake and Pambula Lake. B.Sc Honours Thesis, University of Wollongong.

Melville, A. J. and Connolly, R. M. (2003). Spatial analysis of stable isotope data to determine sources of nutrition for fish, Oecologia 136: 499-507.

Mense, D. J., Wenner, E. L. (1989). Distribution and abundance of early life history stages of the blue crab, *Callinectes sapidus*, in tidal marsh creeks near Charleston, South Carolina. Estuaries 12:157-168.

Michael, R. D., Holland, E. L. and Zigler, J. S. (1989). Comparison of fish catches with buoyant pop nets and seines in vegetated and non-vegetated habitats. North American Journal of Fish Management 9: 249-253.

Michaela, G., Connolly, R., and Loneragan, N. (2003). Estuarine food web process: eat home grown or home delivery? Symposium abstracts, Society for Wetland Scientists (Australia), Postgraduate Symposium 28 February 2003, Bicentennial Park, Australian

Catholic University. .

Micheli, F. (1993). Feeding ecology of mangrove crabs in North Eastern Australia: manrove little consumption by *Sesarma messa* and *Sesarma smithii*. Journal of Experimental Marine Biology and Ecology, 171: 165-186

Micheli, F., Gherardi, F., and Vannini, M. (1991). Feeding and burrowing ecology of two East African mangrove crabs. Marine Biology 111:247-254.

Middleton, M. J., Rimmer, M. A. and Williams, R. J. (1985). Structural flood mitigation works and estuarine management in New South Wales-case Study of the Macleay River. Coastal Zone Management Journal 13: 1-23.

Minagawa, W and Wada, E (1984). Stepwise enrichment of ^{15}N along food chains: further evidence and the relation between ^{15}N and animal age. Geochim Cosmochim Acta 48: 1135-1140.

Minello, T. (1999). Nekton densities in shallow estuarine habitats of Texas and Louisina and the identification of essential fish habitat. Pages43-75. *In* Benaka L. R (ed.). Fish Habitat and Rehabilitation. Bethesda (MD): American Fisheries Society.

Mitchell, M. L. and Adam, P. (1989). The decline of saltmarsh in Botany Bay. Wetlands (Australia). 8: 55-60.

Mitsch, W. J. and Gosselink, J. G. (1986). Wetlands. Van Nostrand Reinhold, New York.

Morrisey, D. (1995). Saltmarshes. Coastal and Marine Ecology (eds.) Underwood, A. J. and Chapman, M. G. (eds.), University of New South Wales, 341pp.

Morrison, D. (2001). Historical changes in land cover and predicted distribution of mangrove and saltmarsh in Hexham Swamp. Bachelor of Science Honours Thesis, Discipline of Biological Sciences, University of Newcastle. 106pp.

Morton, M. (1994). Flactuations in wetland extent in southern Moreton Bay. Future marine science in Moreton Bay. pp. 145-150. Greenwood, J. G. and Hall, N. J. (eds.). School of Marine Science University of Queensland.

Morton, R. M (1990). Community structure, density and standing crop of fishes in a subtropical Australian mangrove area. Marine Biology, 105:385-394

Morton, R. M, Pollock, B. R. and Beumer J. P. (1987) The occurrence and diet of fishes in a tidal inlet to a saltmarsh in southern Moreton Bay, Queensland. Australian Journal of Ecology 12: 217-237.

Morton, R. M., Beumer, J. P. and Pollock.B. R. (1988). Fishes of a subtropical Australian saltmarsh and their predation upon mosquitoes. Environmental Biology of Fishes, 21(3): 185- 194.

Nagelkerken, I., Van der Velde, G., Gorrisen, M. W., Meijer, G. J., Van't Hof, T. and Hartog, den, C. (2000). Importance of mangroves, seagrass beds and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. Estuarine Coastal and Shelf Science, 51: 31-44.

Nakasone, Y., (1982). Ecology of the fiddler crab Uca (Thalassuca) *vocans vocans* (Linnaeus) (Decapoda: Ocypodidae) 1. Daily activity in warm and cold seasons. Res. Popul. Ecol. 24: 97-109.

Nixon, S.W. (1980). Between coastal marshes and coastal waters-a review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry. Pages 437-525 *In* P. Hamilton and K. B. MacDonald, editors. Estuarine and wetland process. Plenum, New York, New York, USA.

Nobbs M., McGuinness, K. A. (1999). Developing methods for quantifying the apparent abundance of fiddler crabs (Ocypodidae: Uca) in mangrove habitats. Australian Journal of Ecology. 24: 43-49.

Odum, E. P. (1961). The role of tidal marshes in estuarine production. New York State Conservation 16: 12-15.

Odum, W. E. and Heald, E. J. (1972). Trophic analysis of an estuarine mangrove community. Bulletin of Marine Science 22: 671-738.

Ogden, J. C. and Zieman, J. C. (1977). Ecological aspects of coral reef-seagrass bed contacts in the Caribbean. Proceedings of the Third International Coral Reef Symposium 1: 377-382.

Orth, R. J., van Montfrans, I. (1984). Utilization of marsh and seagrass beds: A review of the influence of plant structure and prey characteristic on predator-prey relationships. Estuaries 7: 339-350.

Osborne, K. and Smith, T. J. III. (1990). Differential predation on mangrove propagules in open and closed canopy forest habitats. Vegatatio 89: 1-6.

Owens, N. J. P. (1987). Natural variations in ^{15}N in the marine environment. Advanced Marine Biology. 24: 389-451

Page, H. M. (1997). Importance of vascular plant and algal production to macro-invertibrate consumers in a southern California saltmarsh. Estuarine Coastal and Shelf Science 45: 823-834.

Pearcy, W. G. and Richards. S. W. (1962). Distribution and ecology of fishes of the Mystic River estuary, Connecticut. Ecology 43: 248-259.

Pease, B. C. (1999). A spatially oriented analysis of estuaries and their associated ommercial fisheries in New South Wales, Australia. Fisheries Research 42: 67-86.

Peterson, B. J., Howarth, R. W., Lipschultz, and F., Ashendorf, D. (1980). Saltmarsh detritus: an alternative interpretation of stable carbon isotope ratios and the fate of

Spartina alterniflora. Oikos. 34: 173-177.

Peterson, B. J., R. W. Howarth and R. H. Garritt. (1986). Sulfur and carbon isotopes as tracers of salt-marsh organic matter flow. Ecology 67: 865-874.

Pollard, D. A. (1984). A review of ecological studies on seagrass-fish communities, with particular reference to recent studies in Australia. Aquatic Botany 18: 3-42.

Pollard, D. A. and Hannan, J. C. (1994). The ecological effects of structural flood mitigation works on fish habitats and fish communities in the lower Clarence River system of south –eastern Australia. Estuaries 17(2): 427-461.

Potter, I. C. and Hyndes, G. A. (1994). Composition of the fish fauna of a permanently open estuary on the southern coast of Australia, and comparisons with a nearby seasonally closed estuary. Marine Biology 121: 199-209.

Potter, I. C. and Hyndes, G. A. (1999). Characteristics of the icthyo-faunas of south-western Australian estuaries, including comparisons with holarctic estuaries and estuaries elsewhere in temperate Australia. Australian Journal of Ecology 24: 395-421.

Powers, L. W. and Cole, J. F. (1976). Temperature variation in fiddler crab microhabitats. Journal of Experimental Marine Biology Ecology 21: 141-157.

Primavera, J. H. (1997). Fish predation on mangrove-associated penaeids: the role of structures and substrate. Journal of Experimental Marine Biology and Ecology 215: 205-216.

Richardson, A. M. M., Swain, R. and Wong, V. (1997). The crustacean and molluscan fauna of Tasmanian salt-marshes. Papers and proceedings of the Royal Society of Tasmania 131: 21-30.

Richardson, A. M. M., Swain, R. and Wong, V. (1998). Relationship between the

crustacean and molluscan assemblages of Tasmanian saltmarshes and the vegetation and soil conditions. Marine and Freshwater Research 49: 785-799.

Riera, P., Stal, L. J., Nieuwenhuize, J., Richard, P., Blanchard, G. and Gentil, F. (1999). Determination of food sources for benthic invertebrates in a saltmarsh (Aiguillon Bay, France) by carbon and nitrogen stable isotopes: importance of locally produced sources. Marine Ecology Progress Series 187: 301-307

Robertson, A. I. (1986). Leaf-burying crabs: their influence in energy flow and export from mixed mangrove forests (Rhizophora spp.) in north eastern Australia. Journal of Experimental Marine Biology and Ecology 102: 237-248.

Robertson, A. I. and Duke, N. C. (1987). Mangrove as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangrove and other near shore habitats in tropical Australia. Marine Biology 96: 193-205.

Robertson, A. I. and Duke, N. C. (1990). Mangrove fish communities in tropical Queensland, Australia: Spatial and temporal patterns in densities, biomass and community structure. Marine Biology 104: 369-379.

Robertson, A. I., and Daniel, P. A. (1989). The influence of crabs on litter processing in high intertidal mangrove forests in tropical Australia. Oecologia. 78: 191-198.

Robertson, A. I., Dixon, P. and Daniel, P. A. (1988). Zooplankton dynamics in mangrove and other near shore habitats in tropical Australia. Marine Ecology Progress Series 43: 139-150.

Robinson, K. I. M., Gibbs, P. J., Barclay, J. B., and May, J. L. (1983). Estuarine flora and fauna of Smiths Lake, New South Wales. Proceedings of the Linnaean Society of New South Wales 107 (1): 19-34.

Rochford, D. J. (1951). Studies in Australian estuarine Hydrology. Introductory and

comperative features. Australian Journal of Marine and Freshwater Research 2: 1-116.

Rodelli, M. R., Gearing, J. N., Gearing, P. J., Marshall, N. and Sasekumar, A. (1984). Stable isotope ration as a taracer of mangrove carbon in Malaysian ecosystems, Oecologia (Berlin) 61: 326-333.

Rogers, K. and Saintilan, N. (2001) Homebush Bay mangrove and saltmarsh monitoring program. Progress report. Coastal Wetland Unit. Australian Catholic University. 15pp.

Rogers, K. and Saintilan, N. (2002). Monitoring the loss of saltmarsh in SE Australian Estuary. Progress report to the Coasts & Clean Seas Initiative, Environment Australia. 73pp.

Rountree, R. A. and Able, K. W. (1992). Fauna of Polyhaline subtidal marsh creeks in southern New Jersey: composition, abundance and biomass, Estuaries 15: 171-185.

Rountree, R. A. and K. W. Able. (1993). Diel variation in decapod crustacean and fish assemblages in New Jersey polyhaline marsh creeks. Estuarine Coastal and Shelf Science 37: 181-201.

Roy, P. S. (1984). New South Wales estuaries-their origin and evaluation. In: Developments in Coastal Geomorphology in Australia B. G. Thom (ed.), Academic Press, New York 99-121.

Roy, P. S. and Boyd, R. (1996). Quaternary geology of southeast Australia: a tectonically stable, wave-dominated, sediment-defficient margin. Field Guide to the Central New South Wales Coast, IGCP Project # 367. International Conference, Sydney, November, 174pp.

Roy, P. S., Williams, R. J., Jones, A. R., Yassini, I., Gibbs, P. J., Coates, B., West, R. J., Scanes, P. R., Hudson, J. P., and Nichol, S. (2001). Structure and function of South-east Australian Estuaries. Estuarine Coastal and Shelf Science 53: 351-384.

Rozas L. P (1992) Bottomless lift net for quantitative sampling nekton on intertidal marshes. Marine Ecology Progress Series 89: 287-292.

Rozas, L. P. and Hackney, C. T. (1984). Use of oligohaline marshes by fishes and macrofaunal crustaceans in North Carolina. Estuaries 7:213-214

Rozas, L. P. and M. W. LaSalle (1990). A comparison of the diets of gulf killifish, *Fundulus grandis* Baird and Girard, entering and leaving a Mississippi brackish marsh. Estuaries 13: 332-336.

Saenger, P. E. (1994). Mangrove and Saltmarsh. Marine Biology. Longman Cheshire Pty Ltd Melbourne, Australia.

Saenger, P., Specht, M. M., Specht, R. L. and Chapman, V. J. (1977). Mangal and coastal saltmarsh communities in Australia: pp. 293-339. In Ecosystems of the World: Wet Coastal Ecosystems. Chapman, V. J. (ed.). Elsevier Scientfic Publishing Company.

Saintilan N. (1996). Mangrove community charactersitics within two east-coast Australian estuaries. Unpublished PhD thesis, University of Sydney.

Saintilan, N. (1998). Photogrammetric survey of the Tweed River wetlands. Wetlands (Australia) 17: 74-82.

Saintilan, N. and Hashimoto, R. (1998). Mangrove-saltmarsh dynamics on a prograding bayhead delta on the Hawkesbury River estuary, New South Wales, Australia. Symposium: Recent Advances in Mangrove Research: Biodiversity, Genetics, Evolutionary and Restoration.8-10th July, Touluse, France.

Saintilan, N. and Williams, R. J. (1999). Mangrove transgression into saltmarsh environments in New South Wales, Australia. Global Ecology and Biogeography 8: 117-124.

Saintilan, N. and Williams, R. J. (2000). The decline of saltmarsh in southeast Australia: result of recent surveys. Wetlands (Australia) 18: 49-54.

Saintilan, N., Griffiths, K., Jaafar, W. and Tibbey, M. (2000). A possible experimental artefact associated with leaf-tethering in crab herbivory experiments. Wetlands (Australia) 18(2): 55-59.

Salmon, M. and Hyatt, G. W. (1983). Spatial and temporal aspects of reduction in North Carolina fiddler crabs (*Uca pugilator* Bosc.). Journal of Experimental Marine Biology Ecology 70: 21-43.

Salmon, M., Seiple, W. H. and Morgan, S. G. (1986). Hatching rythms of fiddler crabs and associated species at Beaufort, North Carolina. Journal of Crustacean Biology. 6: 24-36.

Sanchez-Jerez, P., Gillanders, B. M. and Kingsford, M. J. (2002). Spatial variation in abundance of prey and diet of trumpeter (*Pelates sexlineatus*: Teraponidae) associated with *Zostesra capricorni* seagrass meadows. Austral Ecology. 27: 200-210.

Sandifer, P. A. (1975). The role of pelagic larvae in recruitment to populations of adult decapod crustaceans in the York River estuarie and adjacent lower Chesapeake Bay, Virginia. Estuar. Coast. Mar. Sci. 3: 269-279.

Sasekumar, A. (1974). Distribution of macrofauna on a Malayan mangrove shore. Journal of Animal Ecology 43: 51-69.

Sasekumar, A., and Loi, J. J. (1983). Litter production in three mangrove forest zones in the Malay Peninsular. Aquatic Botany 17: 283-290.

Sasekumar, A., Chong, V. C., Leh, M. U. and D'Cruz, R. (1992). Mangrove as a habitat for fish and prawns. Hydrobiologia 247: 195-207.

Schelske, C. L., and Odum, E. P. (1961). Mechanisms maintaining high productivity in Georgia estuaries. Proc. Gulf. Caribb. Fish. Inst. 14: 75-80.

Sedberry, G. R. and Carter, J. (1993). The fish community of a shallow tropical lagoon in Belize, Central America. Estuaries 16: 198-215.

Seiple, W., and Salmon, M. (1982). Comparative social behaviour of two grapsid crabs. *Sesarma reticulatum* (Say) and *S. cinereum* (Bosa.). Journal of Experimental Marine Biology Ecology 62: 1-24.

Skilleter, G. A. and Warren, S. (2000). Effects of habitat modification in mangroves on the structure of mollusc and crab assemblages. Journal of Experimental Marine Biology Ecology 244: 107-129.

Smith III, T. J., Boto, K. G., Frusher, S. D. and Giddins, R. L. (1991). Keystone species and mangrove forest dynamics: the influence of burrowing by crabs on soil nutrient status and forest productivity. Estuarine, Coastal and Shelf Science 33: 419-432.

Smith K. J, and Able K. W (1994) Salt-marsh tide pools as winter refuges for the mummichog, *Fundulus heteroclitus*, in New Jersey. Estuaries 17:226-34.

Smith, T. J. III (1987). Seed predation in relation to tree dominance and distribution in mangrove forests. Ecology 68: 266-273.

Smith, T. J. III (1991). Keystone species and mangrove forest dynamics: the influence of the burrowing by the crabs on soil nutrient status and forest productivity. Estuarine Coastal and Shelf Science 33: 419-432.

Smith, T. J. III and Daniel, P. A. (1989). The influence of crabs on litter processing in high intertidal mangrove forests in tropical Australia. Oecologia. 78: 191-98

Smith, T. J. III., Chan, H. T., McIvor, C. C., and Roblee, M. B. (1989). Comparisons of

seed predation in tropical tidal forests from three continents. Ecology 70 (1): 146-151.

SPCC (1981). The ecology of fish in Botany Bay - Biology of commercially and recreationally valuable species, Environmental Control Study of Botany Bay, Sydney, Australia, 287pp

Sulkin, S. D., Van Heukelem, W., Kelly, P. and Van Heukelem, L. (1980). The behavioural basis of larval recruitment in the crab Callinectes sapidus Rathbun: A loboratory investigation of ontogenetic changes in geotaxis and barokinesis. Biological Bulletin 159: 402-417.

Sullivan, M. J. and Montcrelff, C. A. (1990). Edaphic algae are an important component of saltmarsh food webs: evidence from multiple stable isotope analyses. Marine Ecology Progress Series. 62: 149-159.

Talbot, C. W. and Able.K. W. (1984). Composition and distribution of larval fishes in New Jersey high marshes. Estuaries 7: 434-443.

Teal, J. M. (1962). Energy floe in the salt marsh ecosystem in Georgia. Ecology 43: 614-624.

Thayer, G. W., Colby, D. R. and Hettler, W. F. Jr. (1987). Utilization of the red mangrove prop root habitat by fishes in south Florida. Marine Ecology Progress Series 35: 25-38.

Thayer, G. W., Parker, P. L., LaCriox, M. W. and Fry, B. (1978). The stable carbon isotope ratio of some components of an eelgrass. *Zostera marina*, bed. Oecologia (Berlin) 35: 1-18

Thomas, E. B. and Connolly, R. M. (2001). Fish use of subtropical saltmarshes in Queensland, Australia: relationships with vegetation, water depth and distance onto the marsh. Marine Ecology Progress Series 209: 275-288.

Thomas, J. L., Zimmerman, R. J., and Minello, T. J. (1990). Abundance patterns of juvenile blue crabs (Callinectes sapidus) in nursery habitats of two Texas bays. Bulletin of Marine Science 46: 115-125.

Thorogood, C. A. (1985). Changes in distribution of mangroves in the Port Jackson Parramatta River estuary from 1930 to 1985. Wetlands (Australia) 5: 91-93.

Thoson, J. M. (1954). The organs of feeding and the food of some Australian Mullet, Australian Journal of Marine and Freshwater Research 6: 328-347

Turner, R. E. (1992). Coastal wetlands and penaeid shrimp habitat. P. 97-104. In R. E. Stroud (ed.) Stemming the Tide of Coastal Fish Habitat Loss. National Coalition for Marine Conservation, Inc., Savannah, GA, USA. Marine Recreational Fisheries Publication 14

Tzeng, W. and Wang, Y. (1992). Structure, composition and seasonal dynamics of the larval and juvenile fish community in the mangrove estuary of Tanshui River, Taiwan. Marine Biology 113: 481-490.

Underwood, A. J. (1997). Experiments in Ecology: Their Ecological Design and Interpretation Using Analysis of Variance. University Press, Cambridge, UK.

Underwood, A. J., Chapman, M. G. (1989). GMAV5 for windows, Institute of Marine Ecology, University of Sydney, Australia.

Vance, D. J. M., Haywood, D. E. and Staples, J. (1990). Use of Mangrove Estuary as a Nursery Area by postlarval and juvenile banana prawns, *Penaeus merguiensis* de Man, in Northern Australia. Estuarine Coastal and Shelf Science 31: 689- 701.

Vance, D. J., Haywood, M. D. E., Heales, D. S., Kenyon, R. A., Loneragan, N. R. and Pendrey, R. C. (1996). How far do prawns and fish move into mangroves? Distribution of juvenile bananna prawns *Penaeus merguiensis* and fish in a tropical mangrove forest in

northern Australia. Marine Ecology Progress Series 131: 115-124.

Vnderzee, M. P. (1988). Changes in saltmarsh vegetation as an early indication of sea-level rise. pp.147-160 in Perman, G. I. (ed.). Greenhouse: Planning for climatic change. CSIRO Australia, Melbourne

Ward, T. I., Vanderklitt, M. A., Nicholas, A. O., Kenchington, R. A. (1999). Selecting marine reserves using habitats and species assemblages as surrogates for biological diversity. Ecological Applications 9: 691-698.

Warner, G. F. (1969). The occurrence and distribution of crabs in a Jamaican mangrove swamp. Journal of Animal Ecology 38: 379-389.

Warren, G. F. (1967). The life history of the mangrove tree crab. *Aratus pisoni*. Journal of Zoology, London. 153: 321-335.

Warren, J. H. (1987). Behavioural ecology of crabs in temperate mangrove swamps. PhD thesis, University of Sydney (unpublished).

Warren, J. H. (1990). The use of open burrows to estimate abundances of intertidal estuarine crabs. Australian Journal of Ecology 15: 277-280.

Weinstein, M. P. (1979). Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina, United States National Marine Fisheries Service. Fishery Bulletin 77: 339-356

Weinstein, M. P. and H. A Brooks. (1983). Comparative ecology of neckton resdining in a tidal creek and adjacent seagrass meadow community composition and structure. Marine Ecology Progress Series 12:15-28.

Weinstein, M. P. and Heck, K. L. (1979). Icthyofauna of seagrass meadows along the Caribbean coast of Panama and in the Gulf of Mexico: composition, structure and

community ecology. Marine Biology 50: 97-107.

Weinstein, M. P., S. L. Weiss and M. F. Walters (1980). Multiple determinants of community structure in shallow marsh habitats, Cape Fear River estuary, North Carolina, USA. Marine Biology 58: 227-243.

Weisberg, S. B., R. Whalen, and V. A. Lotrich (1981). Tidal and diurnal influence on the food consumption of a salt marsh killifish, *Fundulus heteroclitus*. Marine Biology 61: 243-246.

West, R. J. (1985). Mangroves. Agfact F2.0.1. NSW Agriculture and Fisheries, Fisheries Research Institute, Cronulla. 160pp.

West, R. J. (1993). Estuarine Fisheries resources of two south eastern Australian rivers. PhD Thesis, University of New South Wales.

Williams, D. M. (1991). Patterens and processes in the distribution of coral reef fishes. Pages 435- 474. *In* Sale P, (ed.). The ecology of Fishes on Coral Reefs. New York: Academic Press.

Williams, R. J. and Watford, F. A. (1997). Changes in the distribution of mangrove andsaltmarsh in Berowra and Marramrracreeks, 1941-1992. Report to Hornsby Shire Council. 21pp.

Williams, R. J., Hannan, J., Balashov, V. and Watford, F. A. (1996). The changing estuarine fish and decapod crustacean community of western Kooragang Island, NSW, Australia. In Wetlands for the future, INTECOL'S V international wetlands conference. Conference programme and book of abstracts. Encore Productions. WA, Australia, pp. 118-119.

Williams, R. J., Watford, F. A. and Balashov, V. (1999). Kooragang Wetland Rehabilitation Project: Changes in wetland fish habitats of the lower Hunter River. NSW

Fisheries Office of Conservation. Fisheries Research Institute, Cronulla.

Williamson, R., Wilcock, R., Wise, B. and Pickmere, S. (1999). Effect of burrowing by the crab Helice crassa on chemistry of intertidal muddy sediments. Environmental Toxicology and Chemistry 18: 2078-2086.

Wilton, K. (1997). Changes inmangrove nd saltmarsh areas in the Sydney region, with specific reference to Careel Bay, Pittwater. Published abstracts, Conference on the Ecology of Estuaries and soft Sedimant habitats, January 1997, Deakin University.

Wilton, K. (2002). Mangrove and saltmarsh habitat dynamics in selected NSW estuaries. Unpublished PhD thesis, Australian catholic University.

Winning, G. (1990). Lake Macquarie littoral habitats study. Report prepared for Lake Macquarie City Council by Shortlands Wetlands Centre. Unpublished.

Zan, L. P. (1997). Our Sea, Our Future. Major findings of the State of the Marine Environment Report for Australia. Department of Environment, Sport and Territories, Canberra.

CONTENTS

Formatted

1 Appendix

1.1 Appendix

ANOSIM results for fyke and pop net catch at Towra Point saltmarsh

ANOSIM- March 01

One-way Analysis

Factor Values

Factor: Net type
Fyke
Pop

Factor Groups

Sample Net type
TSF1 Fyke
TSF2 Fyke
TSF3 Fyke
TSF4 Fyke
TSP1 Pop
TSP2 Pop
TSP3 Pop
TSP4 Pop

Global Test

Sample statistic (Global R): 0.599
Significance level of sample statistic: 2.9%
Number of permutations: 35 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 1

ANOSIM- April 01

One-way Analysis

Factor Values

Factor: Net type
Fyke
Pop

Factor Groups

Sample Net type
TSF1 Fyke
TSF2 Fyke
TSF3 Fyke
TSF4 Fyke
TSP1 Pop
TSP2 Pop
TSP4 Pop

Global Test

Sample statistic (Global R): 0.833
Significance level of sample statistic: 2.9%
Number of permutations: 35 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 1

ANOSIM- May 01

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet4
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Net type
Fyke
Pop

Factor Groups

Sample Net type
TSF1 Fyke
TSF2 Fyke
TSF3 Fyke
TSF4 Fyke
TSP2 Pop
TSP3 Pop

Global Test

Sample statistic (Global R): 0.893
Significance level of sample statistic: 6.7%
Number of permutations: 15 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 1

ANOSIM- June 01

One-way Analysis

Factor Values

Factor: Net type
Fyke
Pop

Factor Groups

Sample	Net type
TSF1	Fyke
TSF2	Fyke
TSF3	Fyke
TSF4	Fyke
TSP2	Pop
TSP3	Pop
TSP4	Pop

Global Test

Sample statistic (Global R): 0.574
Significance level of sample statistic: 2.9%
Number of permutations: 35 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 1

ANOSIM- July 01

One-way Analysis

Factor Values

Factor: Net type
Fyke
Pop

Factor Groups

Sample	Net type
TSF1	Fyke
TSF2	Fyke
TSF3	Fyke
TSF4	Fyke
TSP2	Pop
TSP3	Pop
TSP4	Pop

Global Test

Sample statistic (Global R): -0.407
Significance level of sample statistic: 100.%
Number of permutations: 35 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 35

ANOSIM- August_01

One-way Analysis

Factor Values

Factor: Net type
Fyke
Pop

Factor Groups

Sample	Net type
TSF1	Fyke
TSF2	Fyke
TSF3	Fyke
TSF4	Fyke
TSP2	Pop
TSP3	Pop
TSP4	Pop

Global Test

Sample statistic (Global R): 0.148
Significance level of sample statistic: 22.9%
Number of permutations: 35 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 8

ANOSIM- September_01

One-way Analysis

Factor Values

Factor: Net type
Fyke
Pop

Factor Groups

Sample	Net type
TSF1	Fyke
TSF2	Fyke
TSF3	Fyke
TSF4	Fyke
TSP1	Pop
TSP2	Pop
TSP3	Pop
TSP4	Pop

Global Test

Sample statistic (Global R): 0.568
Significance level of sample statistic: 2.9%
Number of permutations: 35 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 1

ANOSIM- October_01

One-way Analysis

Factor Values

Factor: Net type
Fyke
Pop

Factor Groups

Sample	Net type
TSF1	Fyke
TSF2	Fyke
TSF3	Fyke
TSF4	Fyke
TSP1	Pop
TSP2	Pop
TSP3	Pop
TSP4	Pop

Global Test

Sample statistic (Global R): 0.677
Significance level of sample statistic: 2.9%
Number of permutations: 35 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 1

ANOSIM- November_01

One-way Analysis

Factor Values

Factor: Net type
Fyke
Pop

Factor Groups

Sample	Net type
TSF1	Fyke
TSF2	Fyke
TSF3	Fyke
TSF4	Fyke
TSP1	Pop
TSP2	Pop
TSP3	Pop
TSP4	Pop

Global Test

Sample statistic (Global R): 0.583
Significance level of sample statistic: 2.9%
Number of permutations: 35 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 1

ANOSIM- December 01

One-way Analysis

Factor Values

Factor: Net type
Fyke
Pop

Factor Groups

Sample	Net type
TSF1	Fyke
TSF2	Fyke
TSF3	Fyke
TSF4	Fyke
TSP1	Pop
TSP2	Pop
TSP3	Pop
TSP4	Pop

Global Test

Sample statistic (Global R): 0.854
Significance level of sample statistic: 2.9%
Number of permutations: 35 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 1

ANOSIM- January 02

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet20
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Net type
Fyke
Pop

Factor Groups

Sample	Net type
TSF1	Fyke
TSF2	Fyke
TSF3	Fyke
TSF4	Fyke
TSP1	Pop
TSP2	Pop
TSP3	Pop
TSP4	Pop

Global Test

Sample statistic (Global R): 0.24
Significance level of sample statistic: 11.4%
Number of permutations: 35 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 4

ANOSIM- February 02

One-way Analysis

Factor Values

Factor: Net type

Fyke
Pop

Factor Groups

Sample	Net type
TSF1	Fyke
TSF2	Fyke
TSF3	Fyke
TSF4	Fyke
TSP1	Pop
TSP2	Pop
TSP3	Pop
TSP4	Pop

Global Test

Sample statistic (Global R): 0.562
Significance level of sample statistic: 2.9%
Number of permutations: 35 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 1

Overall ANOSIM results for fyke and pop net catch at Towra Point saltmarsh

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet1
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Net type
Fyke
Pop
Global Test

Sample statistic (Global R): 0.29
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

1.2 Appendix

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Fish catch per fyke and pop nets at TP salt-One factorANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is Net type has 2 levels is orthogonal and is fixed
Number of replicates: 48

Transform: None

Cochran's Test
C = 0.9186 (P < 0.01)
Largest variance = 5024.3387, this belongs to cell Level: 1

The model for this analysis is :
X = MEAN + Ne + RES

Source	SS	DF	MS	F	P	F versus
Ne	75712.6667	1	75712.6667	27.69	0.0000	RES
RES	257067.8333	94	2734.7642			
TOT	332780.5000	95				

Catch performance between fyke and pop nets for *Ambassis jacksonisis*

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Glassfish abundance in fyke and pop net for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is net type has 2 levels is orthogonal and is fixed
Number of replicates: 48

Transform: Ln(X+1)

Cochran's Test
C = 0.6247 (Not Significant)
Largest variance = 1.1479, this belongs to cell Level: 2

The model for this analysis is :
X = MEAN + a + RES

Source	SS	DF	MS	F	P	F versus
a	6.2711	1	6.2711	6.83	0.0105	RES
RES	86.3697	94	0.9188			
TOT	92.6408	95				

Pseudomogil signafer

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Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Blue eye abundance in fyke and pop nets for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is net type has 2 levels is orthogonal and is fixed
Number of replicates: 48

Transform: None

Cochran's Test
C = 0.9810 (P < 0.01)
Largest variance = 909.4464, this belongs to cell Level: 1

The model for this analysis is :
X = MEAN + a + RES

Source	SS	DF	MS	F	P	F versus
a	6851.2604	1	6851.2604	14.78	0.0002	RES
RES	43569.6458	94	463.5069			
TOT	50420.9062	95				

Mugilogobius stigmaticus

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Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\CMG abundance in fyke and pop nets for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is net type has 2 levels is orthogonal and is fixed
Number of replicates: 48

Transform: None

Cochran's Test

C = 0.9982 (P < 0.01)
Largest variance = 240.9322, this belongs to cell Level: 1

The model for this analysis is :
X = MEAN + a + RES

Source	SS	DF	MS	F	P	F versus
a	969.0104	1	969.0104	8.03	0.0056	RES
RES	11343.7292	94	120.6780			
TOT	12312.7396	95				

Acanthopagrus australis

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Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Bream abundance in fyke and pop for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is net type has 2 levels is orthogonal and is fixed
Number of replicates: 48

Transform: None

Cochran's Test
C = 0.9464 (P < 0.01)
Largest variance = 21.7017, this belongs to cell Level: 1

The model for this analysis is :
X = MEAN + a + RES

Source	SS	DF	MS	F	P	F versus
a	70.0417	1	70.0417	6.11	0.0153	RES
RES	1077.7917	94	11.4659			
TOT	1147.8333	95				

Macrobrachium intermedium

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Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Grass shrimp abundance in fyke and pop for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is net type has 2 levels is orthogonal and is fixed
Number of replicates: 48

Transform: None

Cochran's Test
C = 0.9933 (P < 0.01)
Largest variance = 1070.7872, this belongs to cell Level: 1

The model for this analysis is :
X = MEAN + a + RES

Source	SS	DF	MS	F	P	F versus
a	6272.6667	1	6272.6667	11.64	0.0010	RES
RES	50668.6667	94	539.0284			
TOT	56941.3333	95				

Gobiopterus semivestitus

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Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Glass goby abundance in fyke and pop nets for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is net type has 2 levels is orthogonal and is fixed
Number of replicates: 48

Transform: Ln(X+1)

Cochran's Test
C = 0.5917 (Not Significant)
Largest variance = 1.5656, this belongs to cell Level: 1

The model for this analysis is :
X = MEAN + a + RES

Source	SS	DF	MS	F	P	F versus
a	3.4835	1	3.4835	2.63	0.1080	RES
RES	124.3710	94	1.3231			
TOT	127.8544	95				

Gerres subfasciatus

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Windows implementation by S.A. Richards and M.B. Sage
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Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Silver biddy abundancein fyke and pop nets for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is net type has 2 levels is orthogonal and is fixed
Number of replicates: 48

Transform: None

Cochran's Test
C = 0.9393 (P < 0.01)
Largest variance = 68.2832, this belongs to cell Level: 1

The model for this analysis is :
X = MEAN + a + RES

Source	SS	DF	MS	F	P	F versus
a	102.0938	1	102.0938	2.81	0.0971	RES
RES	3416.5625	94	36.3464			
TOT	3518.6562	95				

1.3 Appendix

Size effect between nets *Gobiopterus semivestitus*

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Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Fish length glass goby for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is Net has 2 levels is orthogonal and is fixed
Number of replicates: 9

Transform: None

Cochran's Test
C = 0.6693 (Not Significant)
Largest variance = 16.7500, this belongs to cell Level: 2

The model for this analysis is :
X = MEAN + Ne + RES

Source	SS	DF	MS	F	P	F versus
Ne	56.8889	1	56.8889	4.55	0.0488	RES
RES	200.2222	16	12.5139			
TOT	257.1111	17				

Gerres subfasciatus

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Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Fish length silver biddy for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is Net has 2 levels is orthogonal and is fixed
Number of replicates: 9

Transform: None

Cochran's Test
C = 0.5303 (Not Significant)
Largest variance = 36.6944, this belongs to cell Level: 1

The model for this analysis is :
X = MEAN + Ne + RES

Source	SS	DF	MS	F	P	F versus
Ne	174.2222	1	174.2222	5.04	0.0393	RES
RES	553.5556	16	34.5972			
TOT	727.7778	17				

Ambassis jacksonisis

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Windows implementation by S.A. Richards and M.B. Sage
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Header File: None

Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Fish length Glassfish for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is Net has 2 levels is orthogonal and is fixed
Number of replicates: 12

Transform: None

Cochran's Test
C = 0.6172 (Not Significant)
Largest variance = 111.5379, this belongs to cell Level: 2

The model for this analysis is :
X = MEAN + Ne + RES

Source	SS	DF	MS	F	P	F versus
Ne	96.0000	1	96.0000	1.06	0.3139	RES
RES	1987.8333	22	90.3561			
TOT	2083.8333	23				

Pseudomogil signafer

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Windows implementation by S.A. Richards and M.B. Sage
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Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Fish length blue eye for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is Net has 2 levels is orthogonal and is fixed
Number of replicates: 7

Transform: None

Cochran's Test
C = 0.5195 (Not Significant)
Largest variance = 10.8095, this belongs to cell Level: 2

The model for this analysis is :
X = MEAN + Ne + RES

Source	SS	DF	MS	F	P	F versus
Ne	28.5714	1	28.5714	2.75	0.1234	RES
RES	124.8571	12	10.4048			
TOT	153.4286	13				

Macrobrachium intermedium

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Windows implementation by S.A. Richards and M.B. Sage
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Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Fish length grass shrimp for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is Net has 2 levels is orthogonal and is fixed
Number of replicates: 8

Transform: None

Cochran's Test
C = 0.8013 (Not Significant)
Largest variance = 15.8393, this belongs to cell Level: 2

The model for this analysis is :
X = MEAN + Ne + RES

Source	SS	DF	MS	F	P	F versus
Ne	10.5625	1	10.5625	1.07	0.3188	RES
RES	138.3750	14	9.8839			
TOT	148.9375	15				

Mugilogobius stigmaticus

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Windows implementation by S.A. Richards and M.B. Sage
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Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Fish length CMG for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is Net has 2 levels is orthogonal and is fixed
Number of replicates: 2

Transform: None

Cochran's Test
C = 0.9412 (Not Significant)
Largest variance = 72.0000, this belongs to cell Level: 2

The model for this analysis is :
X = MEAN + Ne + RES

Source	SS	DF	MS	F	P	F versus
Ne	72.2500	1	72.2500	1.89	0.3031	RES
RES	76.5000	2	38.2500			
TOT	148.7500	3				

Acanthopagrus australis

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Windows implementation by S.A. Richards and M.B. Sage
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Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Net comparison\Fish length yellow-fin bream for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is Net has 2 levels is orthogonal and is fixed
Number of replicates: 6

Transform: None

Cochran's Test
C = 0.6565 (Not Significant)
Largest variance = 450.5667, this belongs to cell Level: 2

The model for this analysis is :
X = MEAN + Ne + RES

Source	SS	DF	MS	F	P	F versus
Ne	3.0000	1	3.0000	0.01	0.9274	RES
RES	3431.6667	10	343.1667			
TOT	3434.6667	11				

Deleted: 1

Formatted

2 Appendix

2.1 Appendix

ANOSIM

Analysis of Similarities

Similarity Matrix

File: Sheet7
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Habitat
Saltmarsh
Mangrove

Factor Groups

Sample Habitat

Global Test

Sample statistic (Global R): 0.078
Significance level of sample statistic: 1.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 10

Deleted: 1

2.2 Appendix

Species richness between seasons at TP saltmarsh

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
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Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Pop net paper\Fish sp. richness in different seasons at TP saltmarsh using GMAV.txt

Experimental Details
Number of factors: 1
Factor 1 is Season has 4 levels is orthogonal and is fixed
Number of replicates: 12

Transform: None

Cochran's Test
C = 0.3687 (Not Significant)
Largest variance = 0.4601, this belongs to cell Level: 2

The model for this analysis is:
X = MEAN + Se + RES

Source	SS	DF	MS	F	P	F versus
Se	2.1933	3	0.7311	2.34	0.0860	RES
RES	13.7255	44	0.3119			
TOT	15.9188	47				

2.3 Appendix

Species richness between seasons at TP mangrove

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File: C:\Documents and Settings\Owner\My Documents\Pop net paper\Fish sp. richness in different seasons at TP mangrove using Pop for GMAV.txt

Experimental Details
Number of factors: 1
Factor 1 is Season has 4 levels is orthogonal and is fixed
Number of replicates: 12

Transform: None

Cochran's Test
C = 0.3815 (Not Significant)
Largest variance = 0.6004, this belongs to cell Level: 2

The model for this analysis is :
X = MEAN + Se + RES

Source	SS	DF	MS	F	P	F versus
Se	3.0755	3	1.0252	2.61	0.0636	RES
RES	17.3106	44	0.3934			
TOT	20.3861	47				

2.4 Appendix

ANOSIM results comparing fish assemblages in saltmarsh and mangrove season wise- TP,

Autumn 01
ANOSIM
Parameters

Analyse between: Samples
Similarity measure: Bray Curtis
Standardise: No
Transform: Square root

ANOSIM
Analysis of Similarities

One-way Analysis

Factor Values

Factor: Habitat

Deleted: 1

Saltmarsh
Mangrove

Factor Groups

Sample	Habitat
TSP1	Saltmarsh
TSP2	Saltmarsh
TSP3	Saltmarsh
TSP4	Saltmarsh
TSP1	Saltmarsh
TSP2	Saltmarsh
TSP4	Saltmarsh
TSP2	Saltmarsh
TSP3	Saltmarsh
TMP1	Mangrove
TMP2	Mangrove
TMP3	Mangrove
TMP1	Mangrove
TMP2	Mangrove
TMP3	Mangrove
TMP4	Mangrove
TMP1	Mangrove
TMP2	Mangrove
TMP3	Mangrove

Global Test

Sample statistic (Global R): 0.592
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 92378)
Number of permuted statistics greater than or equal to Global R: 0

Winter_01

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet3
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Habitat
Saltmarsh
Mangrove

Factor Groups

Sample	Habitat
TSP2	Saltmarsh
TSP3	Saltmarsh
TSP4	Saltmarsh
TSP2	Saltmarsh
TSP3	Saltmarsh
TSP4	Saltmarsh
TSP2	Saltmarsh
TSP3	Saltmarsh
TSP4	Saltmarsh
TMP1	Mangrove
TMP2	Mangrove
TMP3	Mangrove
TMP1	Mangrove
TMP3	Mangrove
TMP4	Mangrove
TMP1	Mangrove
TMP2	Mangrove
TMP3	Mangrove
TMP4	Mangrove

Global Test

Sample statistic (Global R): 0.443
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 92378)
Number of permuted statistics greater than or equal to Global R: 0

Spring 01
ANOSIM

One-way Analysis

Factor Values

Factor: Habitat

Saltmarsh
Mangrove

Factor Groups

Sample	Habitat
TSP1	Saltmarsh
TSP2	Saltmarsh
TSP3	Saltmarsh
TSP4	Saltmarsh
TSP1	Saltmarsh
TSP2	Saltmarsh
TSP3	Saltmarsh
TSP4	Saltmarsh
TSP1	Saltmarsh
TSP2	Saltmarsh
TSP3	Saltmarsh
TSP4	Saltmarsh
TMP1	Mangrove
TMP2	Mangrove
TMP3	Mangrove
TMP4	Mangrove
TMP1	Mangrove
TMP2	Mangrove
TMP3	Mangrove
TMP4	Mangrove
TMP1	Mangrove
TMP2	Mangrove
TMP3	Mangrove
TMP4	Mangrove

Global Test

Sample statistic (Global R): 0.24
Significance level of sample statistic: 0.4%
Number of permutations: 999 (Random sample from 1352078)
Number of permuted statistics greater than or equal to Global R: 3

Summer 01

ANOSIM

One-way Analysis

Factor Values

Factor: Habitat
Saltmarsh
Mangrove

Factor Groups

Sample	Habitat
TSP1	Saltmarsh
TSP2	Saltmarsh
TSP3	Saltmarsh
TSP4	Saltmarsh
TSP1	Saltmarsh
TSP2	Saltmarsh
TSP3	Saltmarsh
TSP4	Saltmarsh
TSP1	Saltmarsh
TSP2	Saltmarsh
TSP3	Saltmarsh
TSP4	Saltmarsh
TMP1	Mangrove
TMP2	Mangrove
TMP3	Mangrove
TMP4	Mangrove
TMP1	Mangrove
TMP2	Mangrove
TMP3	Mangrove
TMP4	Mangrove
TMP1	Mangrove
TMP2	Mangrove
TMP3	Mangrove
TMP4	Mangrove

Global Test

Sample statistic (Global R): 0.263
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 1352078)
Number of permuted statistics greater than or equal to Global R: 0

2.5 Appendix

All seasons for saltmarsh

One-way Analysis

Deleted: 1

Factor Values

Factor: Season
Autumn
Winter
Spring
Summer

Global Test

Sample statistic (Global R): 0.105
Significance level of sample statistic: 0.9%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 8

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
Autumn, Winter	0.141	4.9	24310	999	48
Autumn, Spring	0.213	1.7	293930	999	16
Autumn, Summer	0.039	25.6	293930	999	255
Winter, Spring	0.025	31.9	293930	999	318
Winter, Summer	0.132	3.8	293930	999	37
Spring, Summer	0.115	2.9	1352078	999	28

All seasons for mangrove

One-way Analysis

Factor Values

Factor: Season
Autumn
Winter
Spring
Summer

Global Test

Sample statistic (Global R): 0.247
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Deleted: 1

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
Autumn, Winter	0.188	2.5	92378	999	24
Autumn, Spring	0.43	0.1	646646	999	0
Autumn, Summer	0.14	5.9	646646	999	58
Winter, Spring	0.177	2.1	293930	999	20
Winter, Summer	0.177	2.7	293930	999	26
Spring, Summer	0.328	0.2	1352078	999	1

2.6 Appendix

BIOENV
Biota and/or Environment matching

Worksheet

File: A:\Fish catch by pop nets at TP and env. data-BIOENV.xls
Sample selection: All
Variable selection: 3

Similarity Matrix

File: A:\Pop catch for BIOENV.sid
Data type: Similarities
Sample selection: All

Parameters

Rank correlation method: Spearman
Maximum number of variables: 5

Similarity Matrix Parameters for sample data worksheet:
Analyse between: Samples
Similarity measure: Bray Curtis
Standardise: No
Transform: Square root

Variables

1 Time (Hours)

Best results

No. Vars Corr. Selections
1 0.100 All

Deleted: 1

BIOENV
Biota and/or Environment matching

Worksheet

File: A:\Fish catch by pop nets at TP and env. data-BIOENV.xls
Sample selection: All
Variable selection: 1

Similarity Matrix

File: A:\Pop catch for BIOENV.sid
Data type: Similarities
Sample selection: All

Parameters

Rank correlation method: Spearman
Maximum number of variables: 5

Similarity Matrix Parameters for sample data worksheet:
Analyse between: Samples
Similarity measure: Bray Curtis
Standardise: No
Transform: Square root

Variables

1 Tide(m)

Best results

No. Vars	Corr.	Selections
1	0.096	All

BIOENV
Biota and/or Environment matching

Worksheet

File: A:\Fish catch by pop nets at TP and env. data-BIOENV.xls
Sample selection: All
Variable selection: 2

Similarity Matrix

File: A:\Pop catch for BIOENV.sid
Data type: Similarities
Sample selection: All

Parameters

Rank correlation method: Spearman
Maximum number of variables: 5

Similarity Matrix Parameters for sample data worksheet:
Analyse between: Samples
Similarity measure: Bray Curtis
Standardise: No
Transform: Square root

Variables

1 Temp.

Best results

No. Vars	Corr.	Selections
1	-0.112	All

BIOENV
Biota and/or Environment matching

Worksheet

File: A:\Fish catch by pop nets at TP and env. data-BIOENV.xls
Sample selection: All
Variable selection: All

Deleted: 1

Similarity Matrix

File: A:\Pop catch for BIOENV.sid
Data type: Similarities
Sample selection: All

Parameters

Rank correlation method: Spearman
Maximum number of variables: 5

Similarity Matrix Parameters for sample data worksheet:
Analyse between: Samples
Similarity measure: Bray Curtis
Standardise: No
Transform: Square root

Variables

1 Tide(m)
2 Temp.
3 Time (Hours)

Best results

No. Vars	Corr.	Selections
2	0.102	1,3
1	0.100	3
1	0.096	1
2	0.082	2,3
3	0.078	All
2	-0.100	1,2
1	-0.112	2

Deleted: 1

Formatted

3 Appendix

3.1 Appendix

Fish assemblages between saltmarsh and mangrove at Towra Point

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet1
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Habitat
Saltmarsh
Mangrove

Factor Groups

Sample Habitat
Global Test

Sample statistic (Global R): 0.343
Significance level of sample statistic: 0.7%
Number of permutations: 999 (Random sample from 18564)
Number of permuted statistics greater than or equal to Global R: 6

SIMPER
Similarity Percentages - species contributions

Worksheet

File: C:\Documents and Settings\Owner\My Documents\Fish\Fish abundance in TP,BP & Allens salt.&Mang.in same months-L.xls
Sample selection: 1-18
Variable selection: All

Parameters

Deleted: 1

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Habitat

Factor groups
Saltmarsh
Mangrove

Groups Saltmarsh & Mangrove

Average dissimilarity = 66.01

	Group Saltmarsh	Group Mangrove				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Glassfish	9.00	66.33	8.75	0.77	13.26	13.26
Grass shrimp	18.17	22.17	7.97	1.42	12.08	25.34
Blue eye	29.75	5.33	7.93	1.28	12.01	37.35
Silver biddy	9.08	20.67	7.06	1.21	10.70	48.05
Glass goby	4.08	9.50	4.50	1.17	6.82	54.87
Blue spot goby	6.50	4.00	4.02	1.24	6.08	60.95
Sand mullet	3.08	4.67	3.75	1.36	5.69	66.64
Yellow-fined bream	5.00	4.17	3.65	1.21	5.52	72.17
Checkered mangrove goby	6.50	1.50	3.43	0.86	5.19	77.36
Dusky falthead	2.92	0.00	3.02	1.37	4.58	81.93
Common toad	1.42	0.00	2.26	1.07	3.42	85.35
Mangrove goby	1.00	1.17	2.21	0.89	3.35	88.71
School prawn	1.50	0.00	2.08	0.85	3.15	91.85

Deleted: 1

3.2 Appendix

Fish assemblages in Bicentennial Park

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet2
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Habitat
Saltmarsh
Mangrove

Global Test

Sample statistic (Global R): 0.306
Significance level of sample statistic: 1.1%
Number of permutations: 999 (Random sample from 8008)
Number of permuted statistics greater than or equal to Global R: 10

SIMPER
Similarity Percentages - species contributions

Worksheet

File: C:\Documents and Settings\Owner\My Documents\Fish abundance Homebush bay wetlands.xls
Sample selection: 1-7,9,11-18
Variable selection: All

Parameters

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Habitat

Factor groups
Saltmarsh
Mangrove

Groups Saltmarsh & Mangrove

Average dissimilarity = 78.79

	Group Saltmarsh	Group Mangrove				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Blue spot goby	1.70	31.83	16.62	2.12	21.10	21.10
Blue eye	4.60	5.33	7.30	1.14	9.26	30.36
Mosq.fish	0.00	9.33	6.81	1.14	8.64	39.00
Mangrove goby	2.00	5.00	6.47	1.30	8.21	47.21
Grass shrimp	0.30	3.33	6.39	1.48	8.12	55.33
Flat tail mullet	0.00	1.83	5.89	1.11	7.47	62.80
Glass goby	0.90	2.17	4.61	1.00	5.86	68.66
Unidentified	0.50	2.83	4.25	1.19	5.40	74.06
Port jackson glassfish	0.00	1.67	3.80	0.70	4.82	78.87
Flat head gudgeon	0.00	1.00	3.41	1.20	4.33	83.21
Yellow-fined bream	0.00	0.83	3.26	0.85	4.13	87.34
Checked mangrove goby	0.00	2.33	2.42	0.69	3.07	90.41

3.3 Appendix

Fish assemblages in Allens Creek

ANOSIM
One-way Analysis

Deleted: 1

Factor Values

Factor: Habitat
Saltmarsh
Mangrove

Global Test

Sample statistic (Global R): 0.228
Significance level of sample statistic: 3.2%
Number of permutations: 999 (Random sample from 5005)
Number of permuted statistics greater than or equal to Global R: 31

SIMPER
Similarity Percentages - species contributions

File: C:\Documents and Settings\Owner\My Documents\Fish abundance
Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Habitat

Factor groups
Saltmarsh
Mangrove

Groups Saltmarsh & Mangrove

Average dissimilarity = 68.56

	Group Saltmarsh	Group Mangrove				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Glass goby	50.33	2.83	16.76	1.05	24.45	24.45
Blue eye	5.89	0.33	8.78	1.14	12.80	37.24
Grass shrimp	7.56	4.00	7.84	0.96	11.44	48.68
Checked mangrove goby	2.44	1.17	5.20	1.11	7.59	56.27
Striped gudgeon	0.00	1.83	4.99	0.85	7.28	63.54
Dusky falthead	1.67	0.17	4.66	1.19	6.79	70.34
Glassfish	1.56	0.67	4.47	0.71	6.52	76.86
Flat tail mullet	2.11	0.33	4.31	1.01	6.29	83.15
Mangrove goby	0.22	1.33	4.26	0.70	6.21	89.36
School prawn	1.11	0.00	2.32	0.66	3.39	92.75

3.4 Appendix

Comparison of Fish assemblages between saltmarshes

ANOSIM
Analysis of Similarities

One-way Analysis

Factor: Site
TP salt.
BP salt.
AC salt.

Factor Groups

Global Test

Sample statistic (Global R): 0.505
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
TP salt., BP salt.	0.625	0.1	646646	999	0
TP salt., AC salt.	0.439	0.1	293930	999	0
BP salt., AC salt.	0.437	0.1	92378	999	0

3.5 Appendix

Comparison of Fish assemblages between mangroves

ANOSIM
File: C:\Documents and Settings\Owner\My Documents\Fish abundance in TP,BP & Allens salt.&Mang.in same months.xls

Similarity measure: Bray Curtis
Standardise: No
Transform: Square root

ANOSIM
Analysis of Similarities

One-way Analysis
Factor Values

Deleted: 1

Factor: Site
TP Mang.
BP Mang.
AC Mang.

Global Test

Sample statistic (Global R): 0.477
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 2858856)
Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
TP, BP	0.487	0.4	462	462	2
TP, AC	0.357	1.3	462	462	6
BP, AC	0.583	0.2	462	462	1

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4 Appendix

4.1 Appendix

ANOSIM results for crab abundance within vegetation communities

File: E:\Crab abundance by Trap for all months (adding factor level).pri
Sample selection: 1-72,74-168
Variable selection: All

Parameters

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Vegetations type

Factor groups
SARCO
SPRO
JUNC
MANG

Global Test

Sample statistic (Global R): 0.483
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
SARCO, SPRO	0.145	0.1	Too Many	999	0
SARCO, JUNC	0.205	0.1	Too Many	999	0
SARCO, MANG	0.578	0.1	Too Many	999	0
SPRO, JUNC	0.024	9.1	Too Many	999	90
SPRO, MANG	0.827	0.1	Too Many	999	0
JUNC, MANG	0.933	0.1	Too Many	999	0

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SIMPER results crab abundance within vegetation communities

File: E:\Crab abundance by Trap for all months (adding factor level).pri
Sample selection: 1-72,74-168
Variable selection: All

Parameters

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Vegetations type

Factor groups
SARCO
SPRO
JUNC
MANG

Groups SARCO & SPRO

Average dissimilarity = 44.39

	Group SARCO	Group SPRO				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Helograpsus haswellianus	2.60	6.05	18.82	1.41	42.40	42.40
Sesarma erythrodactyla	1.74	1.07	13.83	1.15	31.16	73.56
Paragrapsus laevis	1.24	0.62	11.00	0.90	24.78	98.34

Groups SARCO & JUNC

Average dissimilarity = 46.83

	Group SARCO	Group JUNC				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Helograpsus haswellianus	2.60	6.80	20.30	1.50	43.35	43.35
Sesarma erythrodactyla	1.74	1.95	16.58	1.27	35.40	78.75
Paragrapsus laevis	1.24	0.00	9.19	0.74	19.63	98.38

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Groups SPRO & JUNC

Average dissimilarity = 34.83

	Group SPRO	Group JUNC				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Helograpsus haswellianus	6.05	6.80	15.50	1.21	44.50	44.50
Sesarma erythrodactyla	1.07	1.95	14.04	1.19	40.32	84.82
Paragrapsus laevis	0.62	0.00	5.29	0.57	15.18	100.00

Groups SARCO & MANG

Average dissimilarity = 59.99

	Group SARCO	Group MANG				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Helograpsus haswellianus	2.60	0.00	24.06	1.90	40.11	40.11
Paragrapsus laevis	1.24	2.12	19.83	1.56	33.06	73.17
Sesarma erythrodactyla	1.74	2.31	15.28	1.16	25.47	98.64

Groups SPRO & MANG

Average dissimilarity = 74.83

	Group SPRO	Group MANG				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Helograpsus haswellianus	6.05	0.00	38.54	3.01	51.51	51.51
Paragrapsus laevis	0.62	2.12	19.93	1.64	26.63	78.14
Sesarma erythrodactyla	1.07	2.31	16.36	1.21	21.86	100.00

Groups JUNC & MANG

Average dissimilarity = 83.47

	Group JUNC	Group MANG				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Helograpsus haswellianus	6.80	0.00	40.06	3.24	47.99	47.99
Paragrapsus laevis	0.00	2.12	24.47	2.47	29.32	77.31
Sesarma erythrodactyla	1.95	2.31	18.94	1.30	22.69	100.00

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4.2 Appendix

ANOSIM for crab abundance between saltmarsh and mangrove by visual census

ANOSIM for all months

Analysis of Similarities

Similarity Matrix

File: Sheet1
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Habitat
Saltmarsh
Mangrove

Global Test

Sample statistic (Global R): 0.261
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

ANOSIM for April 02
Worksheet

File: C:\Documents and Settings\Owner\My Documents\Visual census month wise.xls
Sample selection: All
Variable selection: All

Parameters

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Habitat

Factor groups
Saltmarsh
Mangrove

Global Test

Sample statistic (Global R): 0.452
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 1352078)
Number of permuted statistics greater than or equal to Global R: 0

ANOSIM for August 02
Worksheet

File: C:\Documents and Settings\Owner\My Documents\Visual census month wise.xls
Sample selection: All
Variable selection: All

Parameters

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Habitat

Factor groups
Saltmarsh
Mangrove

Global Test

Sample statistic (Global R): 0.347
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 1352078)
Number of permuted statistics greater than or equal to Global R: 0

ANOSIM results for December 02

Worksheet

File: C:\Documents and Settings\Owner\My Documents\Visual census month wise.xls
Sample selection: All
Variable selection: All

Parameters

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Habitat

Factor groups
Saltmarsh
Mangrove

Global Test

Sample statistic (Global R): 0.527
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 1352078)
Number of permuted statistics greater than or equal to Global R: 0

SIMPER for crab abundance between saltmarsh and mangrove by visual census

April 02

SIMPER
Similarity Percentages - species contributions

Worksheet

File: C:\Documents and Settings\Owner\My Documents\Visual census month wise.xls
Sample selection: All
Variable selection: All

Parameters

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Habitat

Factor groups
Saltmarsh
Mangrove

Groups Saltmarsh & Mangrove

Average dissimilarity = 22.84

	Group Saltmarsh	Group Mangrove				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Sesarma erythrodactyla	1.08	2.58	13.19	1.17	57.75	57.75
Helocius cordiformis	2.92	1.42	9.65	1.76	42.25	100.00

SIMPER results for Visual Census- Month wise
August 02

SIMPER
Similarity Percentages - species contributions

Worksheet

File: C:\Documents and Settings\Owner\My Documents\Visual census month wise.xls
Sample selection: All
Variable selection: All

Parameters

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Habitat

Factor groups
Saltmarsh
Mangrove

Groups Saltmarsh & Mangrove

Average dissimilarity = 39.44

	Group Saltmarsh	Group Mangrove				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Helocius cordiformis	3.42	1.08	25.20	1.51	63.89	63.89
Sesarma erythrodactyla	0.42	0.58	14.24	0.98	36.11	100.00

ANOSIM & SIMPER results for Visual Census- Month wise

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SIMPER results for Visual Census- Month wise
December 02

SIMPER
Similarity Percentages - species contributions

Worksheet

File: C:\Documents and Settings\Owner\My Documents\Visual census month wise.xls
Sample selection: All
Variable selection: All

Parameters

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Habitat

Factor groups
Saltmarsh
Mangrove

Groups Saltmarsh & Mangrove

Average dissimilarity = 12.45

	Group Saltmarsh	Group Mangrove				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Sesarma erythrodactyla	1.50	2.92	7.85	1.58	63.06	63.06
Helocius cordiformis	3.25	2.42	4.60	1.36	36.94	100.00

4.3 Appendix

ANOSIM results between vegetation communities by artificial structure

Global Test

Sample statistic (Global R): 0.025
Significance level of sample statistic: 3.7%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 36

Pairwise Tests

Deleted: 1

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
Sarcocornia, Sporobolus	0.004	33.	Too Many	999	329
Sarcocornia, Mangrove	0.051	1.7	Too Many	999	16
Sporobolus, Mangrove	0.021	9.9	Too Many	999	98

SIMPER results between vegetation communities by artificial structure

SIMPER
Similarity Percentages - species contributions

Worksheet

File: C:\Documents and Settings\Owner\My Documents\Crab abundance by Block samp. all months.xls
Sample selection: 2-21,23-26,28-33,35-37,39-48,50-59,61-105
Variable selection: All

Parameters

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Vegetation type

Factor groups
Sarcocornia
Sporobolus
Mangrove

Groups Sarcocornia & Sporobolus

Average dissimilarity = 23.85

Species	Group Sarcocornia Av.Abund	Group Sporobolus Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Sesarma erythrodactyla	2.39	1.97	14.30	1.23	59.96	59.96
Helograpsus haswellianus	0.26	0.12	6.06	0.45	25.41	85.37
Helocius cordiformis	0.00	0.12	2.56	0.31	10.73	96.09

Groups Sarcocornia & Mangrove

Average dissimilarity = 23.76

	Group Sarcocornia	Group Mangrove				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Sesarma erythrodactyla	2.39	1.70	13.58	1.22	57.13	57.13
Paragrapsus laevis	0.03	0.18	5.68	0.50	23.90	81.03
Helograpsus haswellianus	0.26	0.00	4.51	0.38	18.97	100.00

Groups Sporobolus & Mangrove

Average dissimilarity = 22.12

	Group Sporobolus	Group Mangrove				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Sesarma erythrodactyla	1.97	1.70	12.08	1.14	54.59	54.59
Paragrapsus laevis	0.00	0.18	5.25	0.47	23.74	78.33
Helocius cordiformis	0.12	0.00	2.70	0.31	12.23	90.55

4.4 Appendix

ANOSIM results for a month basis between vegetation communities by artificial structure

June 02

Global Test

Sample statistic (Global R): 0.355
Significance level of sample statistic: 0.2%
Number of permutations: 999 (Random sample from 19953648)
Number of permuted statistics greater than or equal to Global R: 1

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
Sarcocornia, Sporobolus	0.119	16.4	792	792	130
Sarcocornia, Mangrove	0.43	1.9	792	792	15
Sporobolus, Mangrove	0.493	0.5	1716	999	4

SIMPER results for a month basis between vegetation communities by artificial structure

June 02

SIMPER
Similarity Percentages - species contributions

Worksheet

File: C:\Documents and Settings\Owner\My Documents\Crab abundance by Block samplingm month wise.xls
Sample selection: 2,3,5-21
Variable selection: All

Parameters

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Vegetation type

Factor groups
Sarcocornia
Sporobolus
Mangrove

Groups Sarcocornia & Sporobolus

Average dissimilarity = 12.45

	Group Sarcocornia	Group Sporobolus				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Sesarma erythrodactyla	4.00	3.14	12.45	1.65	100.00	100.00

Groups Sarcocornia & Mangrove

Average dissimilarity = 36.03

	Group Sarcocornia	Group Mangrove				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Sesarma erythrodactyla	4.00	1.43	21.37	1.95	59.32	59.32
Paragrapsus laevis	0.00	0.57	14.66	1.12	40.68	100.00

Groups Sporobolus & Mangrove

Average dissimilarity = 32.73

	Group Sporobolus	Group Mangrove				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Sesarma erythrodactyla	3.14	1.43	17.46	2.01	53.32	53.32
Paragrapsus laevis	0.00	0.57	15.28	1.14	46.68	100.00

ANOSIM results for a month basis between vegetation communities by artificial structure

JULY 02
Global Test

Sample statistic (Global R): 0.094
Significance level of sample statistic: 10.6%
Number of permutations: 999 (Random sample from 2858856)
Number of permuted statistics greater than or equal to Global R: 105

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
Sarcocornia, Sporobolus	-0.064	74.	462	462	342
Sarcocornia, Mangrove	0.104	18.2	462	462	84
Sporobolus, Mangrove	0.233	6.1	462	462	28

August 02

Global Test

Sample statistic (Global R): 0.048
Significance level of sample statistic: 24.%
Number of permutations: 999 (Random sample from 23279256)
Number of permuted statistics greater than or equal to Global R: 239

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
Sarcocornia, Sporobolus	0.044	23.8	1716	999	237
Sarcocornia, Mangrove	0.129	20.8	462	462	96
Sporobolus, Mangrove	-0.022	42.5	1716	999	424

September 02

Global Test

Sample statistic (Global R): 0.103
Significance level of sample statistic: 11.6%
Number of permutations: 999 (Random sample from 66512160)
Number of permuted statistics greater than or equal to Global R: 115

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
Sarcocornia, Sporobolus	0.079	16.5	1716	999	164
Sarcocornia, Mangrove	0.169	10.2	1716	999	101
Sporobolus, Mangrove	0.055	24.8	1716	999	247

October 02

Global Test

Sample statistic (Global R): 0.038
Significance level of sample statistic: 24.6%
Number of permutations: 999 (Random sample from 66512160)
Number of permuted statistics greater than or equal to Global R: 245

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
Sarcocornia, Sporobolus	0.084	20.7	1716	999	206
Sarcocornia, Mangrove	-0.086	100.	1716	999	999
Sporobolus, Mangrove	0.114	12.2	1716	999	121

4.5 Appendix

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Pearson correlations results

Correlation between different methods in saltmarsh

Correlations

		TRAP	BLOCK	VISUAL	BURROW
TRAP	Pearson Correlation	1	-.240	-.016	-.022
	Sig. (2-tailed)	.	.295	.945	.925
	N	21	21	21	21
BLOCK	Pearson Correlation	-.240	1	-.177	.201
	Sig. (2-tailed)	.295	.	.444	.382
	N	21	21	21	21
VISUAL	Pearson Correlation	-.016	-.177	1	-.024
	Sig. (2-tailed)	.945	.444	.	.917
	N	21	21	21	21
BURROW	Pearson Correlation	-.022	.201	-.024	1
	Sig. (2-tailed)	.925	.382	.917	.
	N	21	21	21	21

Correlations between methods in mangrove

Correlations

		TRAP	BLOCK	VISUAL	BURROW
TRAP	Pearson Correlation	1	.268	.173	.628**
	Sig. (2-tailed)	.	.239	.454	.002
	N	21	21	21	21
BLOCK	Pearson Correlation	.268	1	-.079	.469*
	Sig. (2-tailed)	.239	.	.733	.032
	N	21	21	21	21
VISUAL	Pearson Correlation	.173	-.079	1	.271
	Sig. (2-tailed)	.454	.733	.	.236
	N	21	21	21	21
BURROW	Pearson Correlation	.628**	.469*	.271	1
	Sig. (2-tailed)	.002	.032	.236	.
	N	21	21	21	21

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

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5 Appendix

5.1 Appendix

ANOVA results for pilot study

All months

January 01
GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File: C:\Documents and Settings\Owner\My Documents\Zooplankton\Crab larval release in 3 conseqiutive days in Janu..txt

Experimental Details
Number of factors: 1
Factor 1 is Tide has 3 levels is orthogonal and is fixed
Number of replicates: 8

Transform: None

Cochran's Test
C = 0.6417 (Not Significant)
Largest variance = 2824.5714, this belongs to cell Level: 1

The model for this analysis is:
X = MEAN + Ti + RES

Source	SS	DF	MS	F	P	F versus
Ti	36945657.5833	2	18472828.7917	12589.49	0.0000	RES
RES	30813.7500	21	1467.3214			
TOT	36976471.3333	23				

November 01
GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None

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Data File : C:\Documents and Settings\Owner\My Documents\Zooplankton\Crab larval release in 3 conseqiutive days in Nov..txt

Experimental Details
Number of factors: 1
Factor 1 is Tide has 3 levels is orthogonal and is fixed
Number of replicates: 8

Transform: Sqrt(X+1)

Cochran's Test
C = 0.6361 (Not Significant)
Largest variance = 3.2715, this belongs to cell Level: 2

The model for this analysis is:
X = MEAN + Ti + RES

Source	SS	DF	MS	F	P	F versus
Ti	170.5141	2	85.2571	49.73	0.0000	RES
RES	36.0037	21	1.7145			
TOT	206.5178	23				

March 01
GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Zooplankton\Crab larval release in 3 conseqiutive days in Mar..txt
Experimental Details
Number of factors: 1
Factor 1 is Tide has 3 levels is orthogonal and is fixed
Number of replicates: 8

Transform: None
Cochran's Test
C = 0.9603 (P < 0.01)
Largest variance = 2677.4107, this belongs to cell Level: 2

The model for this analysis is:
X = MEAN + Ti + RES

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Source	SS	DF	MS	F	P	F versus
Ti	512209.3333	2	256104.6667	275.56	0.0000	RES
RES	19517.6250	21	929.4107			
TOT	531726.9583	23				

5.2 Appendix

ANOSIM results for zooplankton assemblages between incoming and outgoing tides in different months at Towra Point saltmarsh

March 01

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet1
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

April 01

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet2
Data type: Similarities

Deleted: 1

Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

May 01

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet3
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

June 01

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ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet4
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.2%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 1

July 01

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet5
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

August 01

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet6
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

September 01

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet7
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

October 01

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet8
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

November 01

ANOSIM
Analysis of Similarities

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Similarity Matrix

File: Sheet9
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

December 01

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet10
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%

Deleted: 1

Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

January 02

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet1
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

February 02

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet2
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

March 02

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet1
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

April 02

ANOSIM
Analysis of Similarities

Deleted: 1

Similarity Matrix

File: Sheet2
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

May 02

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet3
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Deleted: 1

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

June 02

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet4
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.2%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 1

July 02

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet5
Data type: Similarities
Sample selection: All

One-way Analysis

Deleted: 1

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

August 02

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet6
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming
Outgoing

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

Deleted: 1

5.3 Appendix

SIMPER results for zooplankton assemblages between incoming and outgoing tides from saltmarsh at Towra Point saltmarsh

All months

SIMPER
Similarity Percentages - species contributions
Worksheet
File: C:\Documents and Settings\Owner\My Documents\Zooplankton\Zooplankton abundance in TP all months.xls
Sample selection: All
Variable selection: All

Parameters
Standardise data: No
Transform: None
Cut off for low contributions: 100.00%
Factor name: Tide

Factor groups
Incoming
Outgoing

Groups Incoming & Outgoing

Average dissimilarity = 78.21

	Group Incoming	Group Outgoing				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Gastropod larvae	56.94	3764.94	33.95	1.05	43.41	43.41
Crab larvae	4.00	2124.62	29.11	0.98	37.21	80.62
Copepods	695.90	514.74	11.47	0.83	14.66	95.28
Amphipod	151.05	101.76	2.78	0.73	3.55	98.83
Others	57.51	31.89	0.91	0.75	1.17	100.00

Deleted: 1

5.4 Appendix

Pearson correlation test results between crab and gastropod larval release from saltmarsh

Correlations

		CL	GL
CL	Pearson Correlation	1	-.043
	Sig. (2-tailed)	.	.468
	N	289	289
GL	Pearson Correlation	-.043	1
	Sig. (2-tailed)	.468	.
	N	289	289

5.5 Appendix

ANOSIM for zooplankton assemblages across sites

Incoming tide

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet2
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
In TP
In BP
In AC

Global Test

Sample statistic (Global R): 0.009
Significance level of sample statistic: 38.9%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 388

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
In TP, In BP	-0.026	64.3	Too Many	999	642
In TP, In AC	-0.081	95.6	Too Many	999	955
In BP, In AC	0.223	1.1	1352078	999	10

SIMPER for zooplankton assemblages across sites

Incoming tide

SIMPER
Similarity Percentages - species contributions

Worksheet
File: C:\Documents and Settings\Owner\My Documents\Zooplankton\TP, BP & AC zooplankton abundance same months.xls
Sample selection: 1-24,49-60,73-84
Variable selection: All

Parameters
Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Tide

Factor groups
In TP
In BP
In AC

Groups In TP & In BP

Average dissimilarity = 32.86

Species	Group In TP Av.Abund	Group In BP Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%

Deleted: 1

Copepods	1101.08	970.25	17.93	1.50	54.57	54.57
Gastropod larvae	66.75	0.00	6.61	1.10	20.12	74.69
Amphipod	177.92	68.25	4.90	1.24	14.92	89.61
Others	72.79	49.92	2.63	1.07	8.02	97.63

Groups In TP & In AC

Average dissimilarity = 30.70

	Group In TP	Group In AC				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Copepods	1101.08	796.25	16.17	1.77	52.67	52.67
Gastropod larvae	66.75	0.00	6.21	1.11	20.21	72.88
Amphipod	177.92	133.33	4.34	1.91	14.15	87.03
Others	72.79	92.50	3.25	1.41	10.58	97.60

Groups In BP & In AC

Average dissimilarity = 18.40

	Group In BP	Group In AC				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Copepods	970.25	796.25	10.82	1.58	58.82	58.82
Amphipod	68.25	133.33	4.24	1.61	23.06	81.89
Others	49.92	92.50	3.33	1.17	18.11	100.00

ANOSIM for zooplankton assemblages across sites

Outgoing tide

ANOSIM

Analysis of Similarities

One-way Analysis

Factor Values

Factor: Tide
Out TP
Out BP
Out AC

Global Test

Sample statistic (Global R): 0.203
Significance level of sample statistic: 0.3%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 2

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
Out TP, Out BP	0.315	0.2	Too Many	999	1
Out TP, Out AC	0.059	12.9	Too Many	999	128
Out BP, Out AC	0.232	1.1	1352078	999	10

5.6 Appendix

ANOVA results for crab larval abundance across sites

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Zooplankton\Crab larva In & Out in TP, BP & AC (same months) ANOVA.txt

Experimental Details
Number of factors: 3
Factor 1 is Tide has 2 levels is orthogonal and is fixed
Factor 2 is Site has 3 levels is orthogonal and is fixed
Factor 3 is Month has 3 levels is orthogonal and is fixed
Number of replicates: 4

Transform: None
Cochran's Test
C = 0.3802 (P < 0.01)
Largest variance = 6390.2500, this belongs to cell Level: 2 2 3
The model for this analysis is :
X = MEAN + Ti + Si + Mo + TiXSi + TiXMo + SiXMo + TiXSiXMo + RES

Source	SS	DF	MS	F	P	F versus
Ti	21491660.6806	1	21491660.6806	23017.07	0.0000	RES
Si	20701780.1111	2	10350890.0556	11085.57	0.0000	RES
Mo	5844717.8611	2	2922358.9306	3129.78	0.0000	RES

Deleted: 1

TiXSi	20701780.1111	2	10350890.0556	11085.57	0.0000	RES
TiXMo	5844717.8611	2	2922358.9306	3129.78	0.0000	RES
SiXMo	19756920.2222	4	4939230.0556	5289.80	0.0000	RES
TiXSiXMo	19756920.2222	4	4939230.0556	5289.80	0.0000	RES
RES	50421.2500	54	933.7269			
TOT	114148918.3194	71				

5.7 Appendix

ANOVA results for gastropod larval abundance across sites

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Zooplankton\Gastropod larva In & Out in TP, BP and AC (same months)- ANOVA.txt

Experimental Details
Number of factors: 3
Factor 1 is Tide has 2 levels is orthogonal and is fixed
Factor 2 is Site has 3 levels is orthogonal and is fixed
Factor 3 is Month has 3 levels is orthogonal and is fixed
Number of replicates: 4

Transform: None

Cochran's Test
C = 0.3398 (P < 0.01)
Largest variance = 3021.5833, this belongs to cell Level: 2 1 1

The model for this analysis is :
X = MEAN + Ti + Si + Mo + TiXSi + TiXMo + SiXMo + TiXSiXMo + RES

Source	SS	DF	MS	F	P	F versus
Ti	40383084.5000	1	40383084.5000	81737.94	0.0000	RES
Si	34743661.0833	2	17371830.5417	35161.69	0.0000	RES
Mo	26459694.0833	2	13229847.0417	26778.06	0.0000	RES
TiXSi	32143871.5833	2	16071935.7917	32530.62	0.0000	RES
TiXMo	24362940.5833	2	12181470.2917	24656.07	0.0000	RES
SiXMo	75757781.0833	4	18939445.2708	38334.65	0.0000	RES
TiXSiXMo	70856132.0833	4	17714033.0208	35854.33	0.0000	RES
RES	26679.0000	54	494.0556			
TOT	304733844.0000	71				

5.8 Appendix

ANOVA results for copepod abundance across sites

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File: C:\Documents and Settings\Owner\My Documents\Zooplankton\Copepod in & out in TP, BP & AC for ANOVA.txt

Experimental Details
Number of factors: 3
Factor 1 is Tide has 2 levels is orthogonal and is fixed
Factor 2 is Site has 3 levels is orthogonal and is fixed
Factor 3 is Month has 3 levels is orthogonal and is fixed
Number of replicates: 4

Transform: None

Cochran's Test
C = 0.5706 (P < 0.01)
Largest variance = 395619.6667, this belongs to cell Level: 1 2 3

The model for this analysis is:
X = MEAN + Ti + Si + Mo + TiXSi + TiXMo + SiXMo + TiXSiXMo + RES

Source	SS	DF	MS	F	P	F versus
Ti	1672010.8889	1	1672010.8889	43.41	0.0000	RES
Si	847116.8611	2	423558.4306	11.00	0.0001	RES
Mo	8781875.5278	2	4390937.7639	113.99	0.0000	RES
TiXSi	76276.3611	2	38138.1806	0.99	0.3782	RES
TiXMo	397150.3611	2	198575.1806	5.16	0.0089	RES
SiXMo	25018010.2222	4	6254502.5556	162.37	0.0000	RES
TiXSiXMo	1657519.8889	4	414379.9722	10.76	0.0000	RES
RES	2080053.0000	54	38519.5000			
TOT	40530013.1111	71				

5.9 Appendix

ANOVA results for amphipod abundance across sites

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Deleted: 1

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Zooplankton\Amphipod in & Out for TP, BP & AC for ANOVA.txt

Experimental Details
Number of factors: 3
Factor 1 is Tide has 2 levels is orthogonal and is fixed
Factor 2 is Site has 3 levels is orthogonal and is fixed
Factor 3 is Month has 3 levels is orthogonal and is fixed
Number of replicates: 4

Transform: Sqrt(X+1)

Cochran's Test
C = 0.1897 (Not Significant)
Largest variance = 2.8093, this belongs to cell Level: 1 3 2

The model for this analysis is :
X = MEAN + Ti + Si + Mo + TiXSi + TiXMo + SiXMo + TiXSiXMo + RES

Source	SS	DF	MS	F	P	F versus
Ti	119.1766	1	119.1766	144.88	0.0000	RES
Si	239.4412	2	119.7206	145.54	0.0000	RES
Mo	180.6350	2	90.3175	109.80	0.0000	RES
TiXSi	1.3380	2	0.6690	0.81	0.4487	RES
TiXMo	0.8413	2	0.4207	0.51	0.6025	RES
SiXMo	618.6880	4	154.6720	188.03	0.0000	RES
TiXSiXMo	6.8936	4	1.7234	2.10	0.0941	RES
RES	44.4195	54	0.8226			
TOT	1211.4334	71				

5.10 Appendix

ANOSIM results for zooplankton assemblages in saltmarsh and mangrove

December (01)

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet2
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming TP saltm.
Outgoing TP saltm.
Incoming Kurnell mang.
Outgoing Kurnell mang.

Factor Groups

Global Test

Sample statistic (Global R): 0.995
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
In TP saltm., Out TP saltm.	1.	0.1	6435	999	0
In TP saltm., In Kur mang.	1.	0.2	495	495	1
In TP saltm., Out Kurl mang.	1.	0.2	495	495	1
OutTP saltm., In Kur mang.	1.	0.2	495	495	1
Outg TP saltm., Out Kur mang.	1.	0.2	495	495	1
In Kur mang., Out Kur mang.	1.	2.9	35	35	1

January (02)

NOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet3
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Factor: Tide
Incoming TP saltm.
Outgoing TP saltm.
Incoming Kurnell mang.
Outgoing Kurnell mang.

Factor Groups

Global Test

Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
In TP saltm., OutTP saltm.	1.	0.1	6435	999	0
In TP saltm., In Kur mang.	1.	0.2	495	495	1
In TP saltm., Out Kur mang.	1.	0.2	495	495	1
Out TP saltm., In Kurl mang.	1.	0.2	495	495	1
Out TP saltm., Out Kur mang.	1.	0.2	495	495	1
In Kur mang., Out Kurl mang.	1.	2.9	35	35	1

June (02)

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet1
Data type: Similarities
Sample selection: All

One-way Analysis

Factor Values

Deleted: 1

Factor: Tide
Incoming TP saltm.
Outgoing TP saltm.
Incoming Kurnell mang.
Outgoing Kurnell mang.

Factor Groups

Global Test

Sample statistic (Global R): 0.952
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
In.TP saltm. Out. TP saltm.	1.	0.1	6435	999	0
In.TP saltm., In. Kur.mang.	1.	0.2	495	495	1
In.TP saltm., Out.Kur.mang.	1.	0.2	495	495	1
Out.TP saltm., In. Kur.mang.	1.	0.2	495	495	1
Out.TP saltm., Out. Kur. mang.	1.	0.2	495	495	1
In. Kur. mang., Out. Kur.mang.	0.208	17.1	35	35	6

SIMPER results for zooplankton assemblages in the incoming tide between saltmarsh and mangrove

SIMPER
Similarity Percentages - species contributions

Worksheet

File: C:\Documents and Settings\Owner\My Documents\Zooplankton\Zooplankton abundance in TP and Kurnell month by month.xls
Sample selection: All
Variable selection: All

Parameters

Deleted: 1

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Tide

Factor groups
Incoming TP saltm.
Outgoing TP saltm.
Incoming Kurnell mang.
Outgoing Kurnell mang.

Groups Incoming TP saltm. & Incoming Kurnell mang.

Average dissimilarity = 25.99

	Group Incoming TP saltm.	Group Incoming Kurnell mang.				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Copepods	1249.75	2537.75	10.73	7.86	41.27	41.27
Others	24.88	308.50	9.01	7.90	34.67	75.94
Amphipod	130.12	328.00	4.76	3.56	18.31	94.25

5.11 Appendix

ANOVA results for crab larval abundance in saltmarsh and mangrove

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Zooplankton\Crab larva in and out from TP and Kurnell for ANOVA.txt

Experimental Details
Number of factors: 3
Factor 1 is Tide has 2 levels is orthogonal and is fixed
Factor 2 is Site has 2 levels is orthogonal and is fixed
Factor 3 is Month has 3 levels is orthogonal and is fixed
Number of replicates: 4

Transform: None

Cochran's Test

C = 0.4668 (P < 0.01)
Largest variance = 2748.2500, this belongs to cell Level: 2 1 3

The model for this analysis is :
X = MEAN + Ti + Si + Mo + TiXSi + TiXMo + SiXMo + TiXSiXMo + RES

Source	SS	DF	MS	F	P	F versus
Ti	61067664.1875	1	61067664.1875	124467.36	0.0000	RES
Si	58390614.1875	1	58390614.1875	119011.03	0.0000	RES
Mo	57796763.3750	2	28898381.6875	58900.33	0.0000	RES
TiXSi	58390614.1875	1	58390614.1875	119011.03	0.0000	RES
TiXMo	57796763.3750	2	28898381.6875	58900.33	0.0000	RES
SiXMo	59311713.3750	2	29655856.6875	60444.20	0.0000	RES
TiXSiXMo	59311713.3750	2	29655856.6875	60444.20	0.0000	RES
RES	17662.7500	36	490.6319			
TOT	412083508.8125	47				

5.12 Appendix

ANOVA results for gastropod larval abundance in saltmarsh and mangrove
GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney
Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Zooplankton\Gastropod larva in and out from TP & Kurnell for ANOVA.txt

Experimental Details
Number of factors: 3
Factor 1 is Tide has 2 levels is orthogonal and is fixed
Factor 2 is Site has 2 levels is orthogonal and is fixed
Factor 3 is Month has 3 levels is orthogonal and is fixed
Number of replicates: 4

Transform: None
Cochran's Test
C = 0.5286 (P < 0.01)
Largest variance = 5806.6667, this belongs to cell Level: 2 2 2

The model for this analysis is :
X = MEAN + Ti + Si + Mo + TiXSi + TiXMo + SiXMo + TiXSiXMo + RES

Source	SS	DF	MS	F	P	F versus
Ti	37083252.0833	1	37083252.0833	40507.85	0.0000	RES
Si	32373675.0000	1	32373675.0000	35363.35	0.0000	RES
Mo	49504327.1667	2	24752163.5833	27038.00	0.0000	RES
TiXSi	30194268.7500	1	30194268.7500	32982.68	0.0000	RES
TiXMo	45942011.1667	2	22971005.5833	25092.36	0.0000	RES

SiXMo	48882810.5000	2	24441405.2500	26698.54	0.0000	RES
TiXSiXMo	45367660.5000	2	22683830.2500	24778.66	0.0000	RES
RES	32956.5000	36	915.4583			
TOT	289380961.6667		47			

5.13 Appendix

ANOVA results for larval abundance across four shallow water habitats

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File: C:\Documents and Settings\Owner\My Documents\Zooplankton\Crab larval abundance between 4 locations for ANOVA.txt
Experimental Details
Number of factors: 1
Factor 1 is Location has 4 levels is orthogonal and is fixed
Number of replicates: 4

Transform: None
Cochran's Test
C = 0.9044 (P < 0.01)
Largest variance = 5732.2500, this belongs to cell Level: 1

The model for this analysis is:
X = MEAN + Lo + RES

Source	SS	DF	MS	F	P	F versus
Lo	117774788.6875	3	39258262.8958	24776.11	0.0000	RES
RES	19014.2500	12	1584.5208			
TOT	117793802.9375	15				

5.14 Appendix

ANOSIM and SIMPER results for other zooplankton (except crab larvae) assemblages within near shore habitats

ANOSIM
Analysis of Similarities

Similarity Matrix

File: Sheet1
Data type: Similarities
Sample selection: All

One-way Analysis
Factor Values

Factor: Locations
Saltmarsh
Mangrove
Seagrass
Bay

Factor Groups

Global Test
Sample statistic (Global R): 1.
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 2627625)
Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
Saltmarsh, Mangrove	1.	2.9	35	35	1
Saltmarsh, Seagrass	1.	2.9	35	35	1
Saltmarsh, Bay	1.	2.9	35	35	1
Mangrove, Seagrass	1.	2.9	35	35	1
Mangrove, Bay	1.	2.9	35	35	1
Seagrass, Bay	1.	2.9	35	35	1

SIMPER
Similarity Percentages - species contributions

Worksheet

File: C:\Documents and Settings\Owner\My Documents\Zooplankton\Zooplankton abundance in 4 location towards estuary, TP.xls

Deleted: 1

Sample selection: All
Variable selection: All

Parameters

Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Locations

Factor groups
Saltmarsh
Mangrove
Seagrass
Bay

Groups Saltmarsh & Mangrove

Average dissimilarity = 22.17

	Group Saltmarsh	Group Mangrove				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Gastropod larvae	1485.25	589.25	9.37	9.90	42.27	42.27
Copepods	932.00	1862.00	8.28	9.46	37.36	79.63
Amphipods	21.25	131.75	4.52	11.57	20.37	100.00

Groups Saltmarsh & Seagrass

Average dissimilarity = 28.19

	Group Saltmarsh	Group Seagrass				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Gastropod larvae	1485.25	250.50	16.06	14.26	56.98	56.98
Copepods	932.00	2090.25	10.73	13.51	38.06	95.04

Groups Saltmarsh & Bay

Average dissimilarity = 33.75

	Group Saltmarsh	Group Bay				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Gastropod larvae	1485.25	140.00	18.93	15.68	56.09	56.09

Deleted: 1

Copepods	932.00	1914.50	9.35	10.48	27.70	83.79
Amphipods	21.25	152.00	5.47	14.38	16.21	100.00

Deleted: 1

6 Appendix

6.1 Appendix

ANOVA results for the proportion of crab larvae in the stomach of fish

Mangrove goby (*M. paludis*)

GMAV (1997) - Licensed to Debashish Mazumder
Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Trophic relation\Stomach content for MG-all months for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is Food has 3 levels is orthogonal and is fixed
Number of replicates: 42

Transform: Sqrt(X+1)

Cochran's Test
C = 0.3764 (Not Significant)
Largest variance = 1.3280, this belongs to cell Level: 3

The model for this analysis is:
X = MEAN + Fo + RES

Source	SS	DF	MS	F	P	F versus
Fo	462.9245	2	231.4623	196.80	0.0000	RES
RES	144.6650	123	1.1761			
TOT	607.5895	125				

Blue eye (*P.signafer*)
GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Trophic relation\Stomach content of Blue eye-all months- ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is Food has 3 levels is orthogonal and is fixed
Number of replicates: 42

Transform: None

Cochran's Test
C = 0.5000 (P < 0.05)
Largest variance = 684.0883, this belongs to cell Level: 1

The model for this analysis is:
X = MEAN + Fo + RES

Source	SS	DF	MS	F	P	F versus
Fo	104404.7619	2	52202.3810	114.46	0.0000	RES
RES	56095.2381	123	456.0588			
TOT	160500.0000	125				

Glassfish (*A. jacksoniensis*)

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Trophic relation\Stomach content for glassfish-all months for ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is Food has 3 levels is orthogonal and is fixed
Number of replicates: 42

Transform: None

Cochran's Test
C = 0.5000 (P < 0.05)
Largest variance = 88.6179, this belongs to cell Level: 1

Deleted: 1

The model for this analysis is :
X = MEAN + Fo + RES

Source	SS	DF	MS	F	P	F versus
Fo	227733.3333	2	113866.6667	1927.38	0.0000	RES
RES	7266.6667	123	59.0786			
TOT	235000.0000	125				

Flat tail mullet (*L. argenta*)

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Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Trophic relation\Stomach content of FTmullet-all months-ANOVA.txt

Experimental Details
Number of factors: 1
Factor 1 is Food has 3 levels is orthogonal and is fixed
Number of replicates: 42

Transform: None

Cochran's Test
C = 0.5000 (P < 0.05)
Largest variance = 413.7195, this belongs to cell Level: 1

The model for this analysis is:
X = MEAN + Fo + RES

Source	SS	DF	MS	F	P	F versus
Fo	74725.0000	2	37362.5000	135.46	0.0000	RES
RES	33925.0000	123	275.8130			
TOT	108650.0000	125				

6.2 Appendix

Larval consumption between months

Mangrove goby (*M. paludis*)

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File: C:\Documents and Settings\Owner\My Documents\Trophic relation\Crab larval consumption by MG in different months.txt

Experimental Details
Number of factors: 1
Factor 1 is Months has 6 levels is orthogonal and is fixed
Number of replicates: 7

Transform: None

Cochran's Test
C = 0.2560 (Not Significant)
Largest variance = 20.2381, this belongs to cell Level: 4

The model for this analysis is:
X = MEAN + Mo + RES

Source	SS	DF	MS	F	P	F versus
Mo	585.3571	5	117.0714	8.89	0.0000	RES
RES	474.2857	36	13.1746			
TOT	1059.6429	41				

Blue eye (*P.signafer*)

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Trophic relation\Crab larval consumption by Blye eye in different months.txt

Experimental Details
Number of factors: 1

Factor 1 is Months has 6 levels is orthogonal and is fixed
Number of replicates: 7

Transform: None

Cochran's Test
C = 0.5889 (P < 0.01)
Largest variance = 930.9524, this belongs to cell Level: 2

The model for this analysis is :
X = MEAN + Mo + RES

Source	SS	DF	MS	F	P	F versus
Mo	18561.9048	5	3712.3810	14.09	0.0000	RES
RES	9485.7143	36	263.4921			
TOT	28047.6190	41				

Glassfish (*A. jacksoniensis*)

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney
Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Trophic relation\Crab larval consumption by glassfish in different months.txt

Experimental Details
Number of factors: 1
Factor 1 is Months has 6 levels is orthogonal and is fixed
Number of replicates: 7

Transform: None

Cochran's Test
C = 0.5870 (P < 0.01)
Largest variance = 128.5714, this belongs to cell Level: 5

The model for this analysis is:
X = MEAN + Mo + RES

Source	SS	DF	MS	F	P	F versus
Mo	2319.0476	5	463.8095	12.70	0.0000	RES
RES	1314.2857	36	36.5079			
TOT	3633.3333	41				

Deleted: 1

Flat tail mullet (*L. argenta*)

GMAV (1997) - Licensed to Debashish Mazumder Designed and coded by A.J. Underwood and M.G. Chapman
Windows implementation by S.A. Richards and M.B. Sage
Institute of Marine Ecology, University of Sydney

Header File: None
Data File : C:\Documents and Settings\Owner\My Documents\Trophic relation\Crab larval consumption by mullet in different months.txt

Experimental Details
Number of factors: 1
Factor 1 is Months has 6 levels is orthogonal and is fixed
Number of replicates: 7

Transform: None

Cochran's Test
C = 0.5009 (P < 0.01)
Largest variance = 665.4762, this belongs to cell Level: 4

The model for this analysis is:
X = MEAN + Mo + RES

Source	SS	DF	MS	F	P	F versus
Mo	8991.0714	5	1798.2143	8.12	0.0000	RES
RES	7971.4286	36	221.4286			
TOT	16962.5000	41				

6.3 Appendix

Correlations results for larval abundance in water and consumption by fish

Mangrove goby (*M. paludis*)

		CRABLARV	CLINMG
CRABLARV	Pearson Correlation	1	-.494
	Sig. (2-tailed)	.	.319
	N	6	6
CLINMG	Pearson Correlation	-.494	1
	Sig. (2-tailed)	.319	.
	N	6	6

Deleted: 1

Blue eye (*P.signafer*)

		CRABLARV	CLINBEYE
CRABLARV	Pearson Correlation	1	.552
	Sig. (2-tailed)	.	.256
	N	6	6
CLINBEYE	Pearson Correlation	.552	1
	Sig. (2-tailed)	.256	.
	N	6	6

Glassfish (*A. jacksoniensis*)

Correlations

		CRABLARV	CLINGF
CRABLARV	Pearson Correlation	1	.034
	Sig. (2-tailed)	.	.950
	N	6	6
CLINGF	Pearson Correlation	.034	1
	Sig. (2-tailed)	.950	.
	N	6	6

Flat tail mullet (*L. argenta*)

Correlations

		CRABLARV	CLINMULL
CRABLARV	Pearson Correlation	1	.450
	Sig. (2-tailed)	.	.370
	N	6	6
CLINMULL	Pearson Correlation	.450	1
	Sig. (2-tailed)	.370	.
	N	6	6