The ichthyofauna associated with Taylor’s salt marsh, Kariega Estuary (Eastern Cape), South Africa

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Declaration

The work presented in this thesis was conducted in the Department of Zoology and Entomology, Rhodes University, under the supervision of Professor Pierre William Froneman. These studies represent original work by the author and have not been submitted in any form to another university.

Abstract

The spatial and temporal patterns in the ichthyofaunal community composition and structure in Taylor's salt marsh and adjacent eelgrass beds (*Zostera capensis*) in the Kariega Estuary, was investigated every two months between May 2006 and March 2007. Total ichthyofaunal abundances and biomass in the salt marsh ranged between 0.55 and 21.7 ind.10m^{-2} and between 0.03 and 1.9 g.wwt.10m^{-2}, respectively. There were no significant spatial patterns in the values evident ($P > 0.05$ in all cases) although seasonal trends were marked, with highest values consistently recorded during the warmer summer months. Investigations into the community structure showed that the ichthyofaunal community within salt marsh was composed almost exclusively of juveniles of estuarine dependant (category II) species, mainly juvenile Mugilidae (<20mm SL) that comprised up to 83% of all fish sampled. Hierarchical cluster analysis and multidimensional scaling did not identify any distinct spatial patterns in the ichthyofaunal community within the salt marsh. The absence of any spatial patterns in the community structure could be related to the absence of any significant spatial patterns in the physico-chemical (temperature, salinity and dissolved oxygen concentrations) and biological (water column and microphytobenthic algal concentrations) variables within the salt marsh ($P > 0.05$ in all cases). Temporal shifts in the ichthyofaunal community structure within the salt marsh were, however, evident largely reflecting the breeding cycles of individual species within the sub-region.

Within the adjacent eelgrass beds, total ichthyofaunal abundances and biomass ranged between 8.4 and 49.4 ind.10m^{-2} and between 2.9 and 94.5 g.wwt.10m^{-2}, respectively. Once again there were no distinct spatial patterns in the abundance and biomass values evident although seasonal patterns were marked. In contrast to the salt marsh, within the in the eelgrass community, there were a large number of adult individuals recorded. Again category II species, the estuarine dependent species, were numerically and gravimetrically dominant. The dominance of category II species reflects the marine dominance of Kariega Estuary. The remaining estuarine utilisation categories did not contribute significantly to abundance or standing stock totals.

Hierarchical cluster analysis showed that the salt marsh and eelgrass beds represented two distinct habitats within the Kariega Estuary. Within the salt marsh, the family Mugilidae were numerically dominant contributing 83% of the total catch. Within the eelgrass beds, the sparid, *Rhabdosargus holubi* and representatives of the family Gobidae contributed 36.3% and 33.9% respectively to the total catch.

Estuaries with a wide range of microhabitats have been demonstrated to support a more diverse ichthyofaunal community. Shallow water habitats in general are important areas for juvenile fish within estuaries. Taylor’s salt marsh provides an alternative shallow water habitat, occupied by a distinct ichthyofaunal community composition, with increased food availability and decreased predation pressure, for a wide range of fish species.

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Chapter 1.

Introduction

1.1. South African Estuaries

According to Day (1980), an estuary can be defined as ‘a partially enclosed body of water which is either permanently or periodically open to the sea and within which there is a measurable variation in salinity due to the mixture of sea water with fresh water derived from land drainage’ (Cooper *et. al.* 1999; Cooper 2001, 2002). The advantage of this definition in that it takes into account the smaller South African estuaries which are often closed by a sand bar at the mouth for varying periods of time. The majority of South African estuaries (approximately 70%) take the form of these temporarily open/closed systems (Whitfield 1998, Vorwerk 2000).

Throughout the world, shallow inshore marine waters, embayments and estuaries are recognised as important habitats for a variety of commercially and recreationally important marine taxa, including fish and invertebrates (Whitfield 1999; Able 2005). In South Africa, it has been proposed that estuaries are especially important ecologically, as they provide sheltered areas along the high-energy coastline and are used by a number of fish species as breeding areas (Potter *et. al.* 1990; Whitfield 1999; Strydom *et. al.* 2003). Results of numerous studies indicate that the ichthyofaunal community structure of an estuary is determined by a number of biotic and abiotic factors which act synergistically with each other (Whitfield 1999).

Of the abiotic factors determining the species composition of an estuary, geographic location, salinity, and temperature are regarded as the most important (Harrison 2005). In South Africa, sub-tropical estuaries of KwaZulu-Natal tend to have a greater number of fish species than cool-temperate estuaries of the Western Cape, or warm-temperate estuaries of the eastern and southern Cape coasts (Harrison 2004, 2005). Salinity tolerance and salinity patterns within an estuary are important in determining which species of fish are present in a given region of an estuary (Whitfield and Marais 1999). It has been found that there is a positive correlation between fish biomass and decreasing salinity (Whitfield and Marais 1999). Thus, estuaries with reduced freshwater input and hypersaline conditions tend to have lower biomass and diversity values than those estuaries that receive regular pulses of freshwater (Whitfield and Marais 1999). Floods, however, cause the biomass and diversity of the ichthyofauna to decrease significantly as a large proportion of the population is swept out to sea (Whitfield and Marais 1999).

In addition to the abiotic factors, biotic factors such as food availability, suitable habitats and predation avoidance all contribute towards shaping the ichthyofaunal community composition and distribution within estuaries (Whitfield 1999). Estuaries with a wide range of substrata, including sandy, rocky and muddy areas, as well as areas with extensive littoral plant growth, and submerged macrophytes, have higher fish biodiversity than estuaries with only a few habitat types (Whitfield and Marais 1999). Submerged macrophytes in particular, play an important role in the estuarine ecosystems by providing a habitat for juvenile fish, invertebrates and epiphytic organisms, as well as several sources of food (Sullivan and Moncreiff 1990; MacIntyre *et. al.* 1996; Adams *et. al.* 1999; Whitfield and Marais 1999; Nozais *et. al.* 2001; Perissinotto *et. al.* 2002). Macrophytes are an important source of detrital material that forms the basis of food webs within estuaries; the macrophytes themselves are also occasionally grazed directly (Whitfield 1999). Submerged macrophytes also provide a surface for epiphytic organisms which in turn are consumed by a variety of invertebrates and fish and finally the fish and invertebrates themselves which are in turn eaten by pisciverous fish and other predators (Adams *et. al.* 1999, Whitfield 1999).

There have been a large number of studies conducted on the ichthyofaunal species composition and community structures within both permanently open and temporarily open/closed (TOC) southern African estuaries (see for example; Melville-Smith and Baird 1980, Beckley 1983, Ter Morshuizen and Whitfield 1994, Whitfield *et. al.* 1994, Cowley 1998, Whitfield 1998, Vorwerk 2000). To investigate the utilisation patterns of estuaries by fish, the main channel of many estuaries have been extensively studied using various gear types, including gill and seine nets and otter trawls (Beckley 1984). In an attempt to investigate recruitment processes and factors influencing larval densities and abundance in these estuaries, research has been conducted at the mouth of permanently open estuaries (Beckley 1984; Young *at al.* 1997; Bell *et. al.* 2001; Cowley *et. al.* 2001) and during overtopping and breaching events in TOC estuaries (Kemp and Froneman 2004). Similarly, various habitats within the main channel of estuaries have also been studied including eelgrass (*Zostera capensis*) beds (Sogard and Able 1991; Connolly 1994; Rotherham and West 2002; Duffy *et. al.* 2003) and comparisons between the eelgrass beds and adjacent bare areas (Hanekom and Baird 1984; Boström *et. al.* 2006). Ichthyofaunal distribution and community composition has also been investigated in different estuarine types; for example: the littoral regions of an estuarine coastal lake (Whitfield 1993), freshwater deprived systems, TOC systems (Schumann and Pearce 1997; Strydom *et. al.* 2003; Whitfield and Harrison 2003), and permanently open systems (Strydom *et. al.* 2002, 2003; Scharler and Baird 2005). These studies have shown that the degree of freshwater flow, which is linked to salinity and turbidity gradients, as well as the state of the mouth of the estuary, appear to be the most important factors influencing the ichthyofaunal community within estuaries (Strydom *et. al.* 2002, 2003). Estuarine dependent and marine transient fish species are dominant in permanently open estuaries, while TOC estuaries are characterised by the predominance of estuarine resident species (Strydom *et. al.* 2003).

Despite the large body of research on ichthyofauna in these different habitats, relatively little work has been conducted, outside of North America, on salt marshes although they form an important part of the inter-tidal habitat (Paterson 1998). Research on North American salt marshes is extensive and has been conducted since the 1970's. Descriptive studies related to the species composition and abundance, and investigations into the factors that influence utilisation by invertebrates and ichthyofauna of tidal freshwater marshes, salt marsh creeks and flats (Cammen 1979; Crabtree and Dean 1982; Kneib 1984; de Lafontaine 1990; Chamberlain and Barnhart 1993, Peterson and Turner 1994, Desmond *et. al. 2*000, Kanouse *et. al.* 2006) have all been conducted. Only a few studies on the importance of salt marshes for ichthyofauna have been conducted in Europe (e.g. Costa *et. al.* 1994; Cattrijsse *et. al.* 1997; Laffaille *et. al.* 2000) and Australia (e.g. Edgar *et. al.* 1999; Thomas and Connolly 2001; Currie and Small 2004; Eyre and Ferguson 2006; Hollingsworth and Connolly 2006). More recently, there have been some studies on the spatial and temporal patterns in fish communities from Asia (e.g. Jin *et. al.* 2007).

1.2. General description of salt marshes

Salt marshes are defined as areas of alluvial sediments that are deposited by the sea or rivers and are subjected to tidal inundation (Cattrijsse and Hampel 2006). Salt marsh sediments range from being permanently waterlogged to at least, temporarily moist (Cattrijsse and Hampel 2006). The sediments tend to consist mainly of fine particles that are usually marine in origin, with low levels of organic carbon but high levels of peat-like detritus (Cattrijsse and Hampel 2006). The characteristics of the sediment, however, demonstrate a high degree of both spatial and temporal variability (Odum 1988). Salt marshes are usually dissected by a complex network of creeks of varying depths that create a heterogeneous habitat (Desmond *et. al.* 2000). Salt marshes are found world wide in the mid- to high latitudes (Adam 2002; Cattrijsse and Hampel 2006), and are often found in the mid- to lower reaches of estuaries although they are not always associated with rivers. They are also found on barrier islands and spits, embayments and on open shores, which are exposed to low wave energy (Odum 1988; Adam 2002).

Salt marshes are inter-tidal areas, usually located between the extreme high water mark and the neap tide level (Cattrijsse and Hampel 2006). They cover the full spectrum of tidal ranges from micro- to macrotidal, but the duration and height of the tides will vary with local hydrological conditions, current patterns and the tidal cycles (Odum 1988; Adam 2002; Cattrijsse and Hampel 2006). For example, the vegetated surface of North American salt marshes tend to flood frequently, on almost every high tide, while the vegetated surfaces of European marshes are only flooded on the highest tides (Cattrijsse and Hampel 2006). The duration of inundation has important implications for the distribution of vegetation and the use of the salt marshes by fish and invertebrates (Cattrijsse and Hampel 2006).

Salt marsh vegetation is usually dominated by halophytic plants, which have specific physiological adaptations to cope with the variations in salinity (Cattrijsse and Hampel 2006). Salinities typically range between 18 and 35 (practical salinity units - psu) although in some pools, which are present during the inter-tidal period, salinities may reach hypersaline (>35 psu) levels due to evaporation (Odum 1988). Salt marsh vegetation has distinct bands of zonation related to the duration of inundation of the habitat (Odum 1988). Frequently flooded areas have a different vegetation composition (usually a single species) to those zones which are only infrequently flooded at extremely high spring and neap tides (Odum 1988). Consequently, North American marshes tend to be composed of near monospecific stands of *Spartina alterniflora* with some subdominant species including *Spartina patens*, *Juncus roemerianus* and *Distichlis spicata* (Cattrijsse and Hampel 2006). By contrast, infrequently flooded European marshes tend to have greater diversity in vegetation. Many marshes are typified by *Halimione* species but *Salicornia* species, *Spartina anglica, Elymus athericus*, *Puccinellia maritima*, *Scirpus maritimus*, *Triglochin maritima*, *Phragmites australis*, *Atriplex hastate* and *Limonium* species are also present (Cattrijsse and Hampel 2006). It should also be noted that the extreme lower regions of salt marshes are sometimes devoid of vascular plants. Microphytobenthic and macroalgae, however, may be present on these otherwise bare areas and are an important source of food for several species of fish (Odum 1988; MacIntyre *et. al.* 1996).

The extent to which salt marshes act as a source or a sink for nutrients and detrital material has been the subject of much debate (Shenker and Dean 1979; Bosch and Turner 1984; Kneib 1984; 1987; Peterson and Turner 1994). It is generally thought that salt marshes supply the adjacent estuary or bay with nutrients and organic detritus through ‘outwelling’. The extent and direction of the nutrient flux is, however, strongly influenced by the marsh morphology, the tidal cycle, tidal height and inundation duration (Bosch and Turner 1984). North American salt marshes are flooded often and therefore much of the primary production is washed off the surface of the marsh, in the form of detritus, and into the surrounding subtidal areas where it forms the basis of the food web (Cattrijsse and Hampel 2006). Macro-consumers, including small crustaceans, annelids, meiofauna and some fish, do not consume the marsh vegetation directly, but instead gain their nutrition from the epiphytic microbes and meiofauna associated with standing vegetation and detritus (Bosch and Turner 1984; Kneib 1984). Boesch and Turner (1984) found that the detrital export is close to zero in irregularly flooded micro-tidal marshes. This is closer to the situation found in European marshes where the export of organic materials is largely absent. Much of the dead plant material decays on the marsh surface and is only flushed into the surrounding subtidal areas when the marsh is flooded by the highest spring tides (Cattrijsse and Hampel 2006).

Salt marsh fauna can be divided into resident and non-resident species (Kneib 1987; Rountree and Able 1992). Resident species usually include various species of crab, amphipods, isopods caridean and penaeid shrimps, polychaetes and some bivalve species (Odum 1988; Rountree and Able 1992; Peterson and Turner 1994). All resident species need to have a high tolerance for fluctuations in salinity levels and varying periods of inundations and exposure (Odum 1988). Non-resident species largely comprise zooplankton, which includes juvenile and larval forms of ichthyofauna and invertebrates, as well as adult fish and some water birds which can either graze directly on the vegetation or feed on the ichthyofaunal and invertebrate components of the salt marsh fauna (Rozas 1995).

Salt marshes have long been recognised to be an important habitats for fish and invertebrates within the estuarine environment (Shenker and Dean 1979; Boesch and Turner 1984; Kneib 1984a, 1984b, 1987). International research into salt marsh fauna has focused on general surveys of population structure and community composition (Rountree and Able 1992) as well as specific studies on individual species of both fish and invertebrates (Reis and Dean 1981; Rozas and Hackney 1984; Lipcius and Subrahmanyam 1986; Cattrijsse *et. al.* 1997; Madon *et. al.* 2001). Community level studies have also examined feeding by ichthyofauna (Boesch and Turner 1984; Hollingsworth and Connolly 2006) as well as ichthyofaunal habitat preferences and use (Kneib 1987; Sogard and Able 1991). Community studies have also investigated and compared natural and reconstructed salt marshes (Chamberlain and Barnhart 1993; Williams and Zedler 1999; Hampel *et. al.* 2003). Investigations have also been conducted into the spatial and temporal variations in community composition (Kneib 1984; Lipcius and Subrahmanyam 1986; Able *et. al.* 2001; 2006). Daily (Varnell *et. al.* 1995; Hampel *et. al.* 2003a), seasonal (Desmond *et. al.*2000) and semi-lunar cycles (Hampel *et. al.* 2003a) have all been shown to influence the species community composition within salt marshes for both adults and juvenile fish (Shenker and Dean 1979; Kneib 1987).

Rozas (1995) investigated the effect of the hydroperiod, in particular the irregularity of flooding along the Gulf Coast of North America, on nekton use of salt marshes. The duration for which the salt marsh is inundated and the depth to which it is flooded which had important influences over the ease of access to the salt marsh surface and the species that will be present on the marsh. A shallowly flooded marsh will only allow access to smaller fish; larger fish will be restricted to the subtidal areas of deeper water (Kneib 1987). Hydroperiod also influences the vegetation and sedimentation in a salt marsh. Areas that are frequently flooded for long periods of time tend to have lower densities of macrophytes than areas that are infrequently flooded or flooded for shorter periods of time (Rozas 1995).

Species-specific ichthyofaunal studies within salt marshes have included research into diet, habitat use and preferences, reproduction and trophic interactions (Reis and Dean 1981; Currin *et. al.*1984; Weinstein *et. al.* 1984; Madon *et. al.* 2001; Able *et. al.* 2006, 2007). Numerous studies have been conducted on the role of salt marshes as regions of increased food availability for various species of fish including the commercially important California killifish (*Fundulus parvipinnis*) (Bosch and Turner 1984, Madon *et. al.* 2001). Using a bioenergetics model, Madon *et. al.* (2001) investigated the effect of hydroperiod on the growth rate of *F. parvipinnis*. They proposed that even though southern California salt marshes are flooded for relatively short periods of time when compared to marshes along the Atlantic and Gulf coasts, the short period when the marsh is accessible, has a profound effect on the growth rate of this species. Even allowing for energetic costs related to swimming and food assimilation, individuals with access to the salt marsh were up to 20% larger than those that had no access to the marsh (Madon *et. al.* 2001). Hollingsworth and Connolly (2006) also investigated the feeding of fish visiting a flooded marsh in Australia. They found that fish captured after visiting the flooded marsh not only had fuller guts, they also had a different prey species composition. It is thought that this short duration intensive feeding has important implications for trophodynamics and energy flow in subtropical estuaries (Hollingsworth and Connolly 2001).

It is a commonly held belief that salt marshes provide an important nursery area function within estuaries for both fish and some invertebrates (Kneib 1984; Peterson and Turner 1994; Cattrijsse *et. al.* 1997). To support this theory, the use of salt marshes, in North America, by larval and juvenile individuals of a number of species has been investigated including the common mummichog (*Fundulus heteroclitus*) and the spotfin killifish (*Fundulus luciae*) (Kneib 1984a). Costa *et. al.* (1994) found that salt marsh areas are utilised as a nursery or spawning area by up to 53% of the species found in the Mira Estuary, Portugal. The importance of salt marshes as a refuge area for killifish was investigated by Kneib (1987). Juvenile killifish suffered higher mortality rates when they occupied the same subtidal habitat as adult killifish but mortality was reduced when juveniles had access to the inter-tidal salt marshes (Kneib 1987). The structural complexity of salt marshes is thought to provide protection from predation as larger individuals, generally prefer more open habitats (Bosch and Turner 1984; Kneib 1987; Cattrijsse *et. al.* 1997). Rozas and Odum (1987) and Minello *et. al.* (1993) showed lower predation rates in unvegetated areas than in vegetated areas.

1.3. South African salt marshes

Salt marshes in South Africa occur in estuaries and protected embayments along the southern, eastern and western coasts and cover an area of approximately 17 000 ha (O’Callaghan 1994). Approximately 75% of salt marshes occur in the Langebaan, Knysna, Swartkops, Berg and Olifants estuaries (O’Callaghan 1994; Paterson 1998; Adams *et. al.* 1999). Unfortunately there is no information on inundation trends or heights of salt marshes in South Africa estuaries; however, due to the higher vegetation species diversity, South African salt marshes are more like to be infrequently flooded, similar to European salt marshes. The most common plant species found in South African salt marshes include *Spartina maritima, Sarcocornia* species, various *Salicornia* species, *Chenolea diffusa, Triglochin bulbosa, Sporobolus virginicus, Atriplex vestita, Limonium scabrum* and *Juncus krausii* (Paterson 1998, Adams 2002). Various species of microphytobenthic and macroalgae are also present on the bare areas of mud within salt marshes (Paterson 1998).

Research on salt marshes in South Africa has largely been limited to studies on the exchange of energy and nutrients between salt marshes and the surrounding habitats and vegetation composition and distribution (Taylor and Allanson 1995; Adams *et. al.* 1999). Evidence for ‘outwelling’ of nutrients and energy from South African salt marshes is limited and there is a large amount of variability in this area (Emmerson 1989; Taylor and Allanson 1995). Taylor and Allanson (1995) found that there was a net export of total, dissolved and particulate organic carbon from a salt marsh into the adjacent Kariega Estuary, Eastern Cape, although the magnitude of the fluxes were lower than recorded elsewhere. Taylor (1992) in laboratory mesocosm experiments found that there was a net export of nitrates from salt marshes although nitrites, ammonium and soluble reactive phosphate had variable results. In light of these studies, Taylor and Allanson (1995) suggested that the 'Outwelling Hypothesis' proposed by Odum (1980) and Dame *et. al.* (1986) is not as applicable to the high marshes in South Africa.

In South Africa there has been almost no work carried out investigating the faunal composition, structure and distribution with in salt marshes. Prior to this study, only one investigation to date has examined the ichthyofaunal community composition of salt marshes in South Africa. Paterson (1998) examined three intertidal salt marshes in the permanently open Kariega Estuary in the Eastern Cape province of South Africa. It was found that the ichthyofaunal community within the salt marsh was composed mainly of juvenile individuals with the Mugilidae being the dominant family (Paterson 1998). Ichthyofaunal community composition within the salt marsh was different to the community found in the adjacent eelgrass beds, although diversity indices were similar. Specifically, the absence of piscivorous fish from the salt marshes was thought to be an important structuring factor for the ichthyofaunal community structure and composition (Paterson, 1998).

Studies conducted in both the northern and southern hemispheres have demonstrated the importance of salt marshes as a habitat for fish within estuaries (see above). The general lack of studies on the importance of salt marshes as a habitat for estuarine fish in South Africa is therefore, surprising. This study aims to improve our understanding of the importance of salt marshes as a habitat for estuarine ichthyofauna. The study was conducted in the Taylor's salt marsh located in the lower reaches of the permanently open, Kariega Estuary in the Eastern Cape province of South Africa, The objectives of this study are as follows:

1. To investigate the spatial and temporal patterns in the ichthyofaunal community composition within the Taylor's salt marsh. Specifically;
    - to assess any patterns in ichthyofaunal community composition and structures,
    - to relate the ichthyofaunal distributional patterns to variations in physico-chemical or biological parameters.
2. To compare the fish community within the Taylor's salt marsh with that of an adjacent eelgrass (*Zostera capensis)* bed. Specifically to determine;
    - whether or not the salt marsh habitat is distinct from that of the adjacent eelgrass bed,
    - the extent to which the salt marsh and eelgrass habitats act as nursery areas for juvenile fish.
3. To compare the main findings of this study with the results of the previous investigation conducted within the same salt marsh by Paterson (1998).

Even though there was only one study site (Chapter 2), the method of data collection employed (Chapter 3) allowed for two broad comparisons to be made. Firstly, comparisons between different reaches within the salt marsh are reported and discussed (Chapter 4) in terms of physico-chemical and biological parameters and the ichthyofaunal community structure and composition. These parameters are then used to compare the salt marsh habitat to the eelgrass habitat which is reported and discussed in Chapter 5. Finally, a general discussion and conclusion comparing the results obtained in this study to the previous study by Paterson (1998) are presented in Chapter 6.

Chapter 2.

Study Site

2.1. Kariega Estuary

The Kariega Estuary is a permanently open system situated on the east coast of South Africa (mouth coordinates 33°41’S, 26° 42’E) adjacent to the town of Kenton-on-Sea (Fig 2.1). It is approximately 18km long, the upper reaches are approximately 40 – 60m wide and are flanked by steep slopes covered with valley-bushveld vegetation (Paterson 1998; Froneman 2001). The lower reaches are approximately 100m wide and are bordered by sand flats and salt marshes. The channel depth varies between 2.5 and 3.5m along the whole length of the estuary. The estuary was formed by the drowning of a river valley following a sea level rise and thus can be called a mature Ria-type estuary (Reddering and Rust 1990).

The Kariega Estuary is a freshwater deprived system and often experiences extended periods of reduced or no freshwater input (Paterson 1998). The low freshwater input into the estuary is exacerbated by the small catchment area (686km^2) and a poor rainfall to run-off conversion (Whitfield and Bruton 1989). The Kariega River is also highly regulated by three major dams and numerous small farm weirs. The mean annual rainfall in the region is approximately 540mm with an autumn-spring bimodal pattern, with a spring peak. The mean tidal range in the estuary is approximately 1.6m, placing it into the micro-tidal category. The mouth of the estuary is maintained in an open state due to scoring by tidal currents and the large tidal prism (Paterson 1998). The strong marine influence and minimal freshwater input into the estuary results the virtual absence of any longitudinal gradients in salinity within the system (Paterson 1998; Froneman 2001) although during drought periods, the upper reaches can experience hypersaline (>35 psu) conditions (Paterson 1998). The system generally has low turbidity (<10 NTU) with almost no thermal or salinity stratification at any point during the tidal cycle (Paterson 1998).

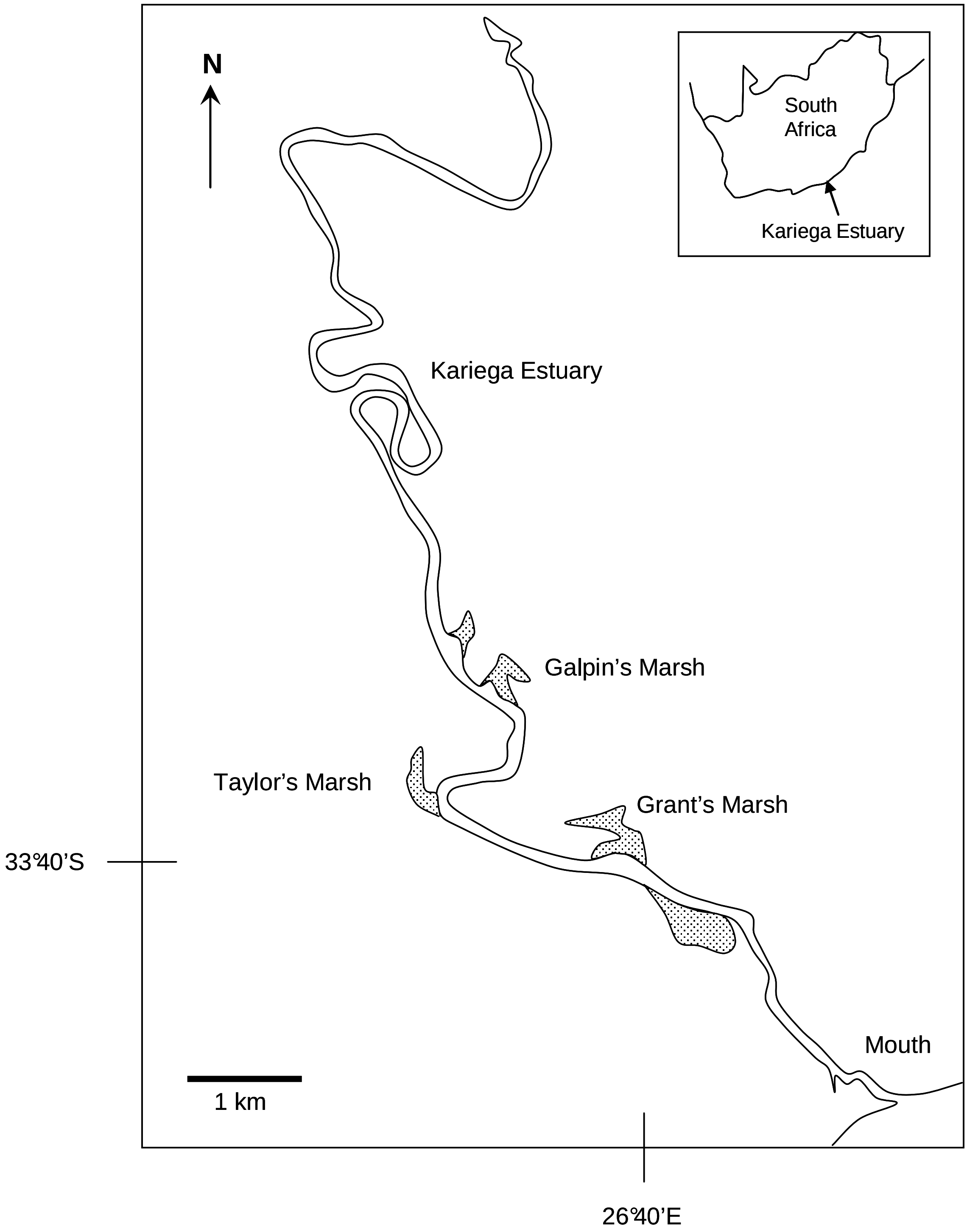


Figure 2.1: Map of Kariega Estuary indicating the position of Taylor's salt marsh (after Paterson and Whitfield 2000).

2.2. Taylor’s Salt Marsh

The small inter-tidal Taylor’s salt marsh is located ≈5km from the mouth of the estuary (Fig 2.1) and is between 0.5m and 1.8m above mean sea level (Taylor 1987). The marsh is well differentiated into single branching, unvegetated tidal creek surrounding by vegetated salt marsh flats. The creek is approximately 20m wide at the junction with the main estuarine channel and ≈1.2m deep at high tide. A single unbranched, unvegetated creek dominates the lower reaches of the salt marsh with a surface area (estimated from an aerial photograph), of 1884m^2 (Paterson 1998). During neap tides, only the lower extremities of the creek are flooded. The middle and upper reaches of the creek are flooded on most high tides, the degree on inundation varies with the lunar cycle and changes in daily mean sea level, but the vegetated salt marsh flats are only flooded on spring tides (Paterson 1998). Consequently, a large area of the marsh remains exposed between high tides. The middle reaches (970m^2) and upper (742m^2) reaches of the creek consist of numerous branching shallow channels (<0.5m deep) and pools. There several shallow (<0.5m deep) pools which are loosely connected to the creek, but there is no obvious channel. These upper pools are only flood in exceptionally high tides and do not drain completely in the inter-tidal period (Fig 2.2).

The most common plant species within Taylor’s salt marsh include the high marsh plants *Sarcocornia perennis* and *Chenolea diffusa.* The common marsh grass *Spartima maritima* is found only at the mouth. Within the main channel of the estuary adjacent to the mouth of the marsh there are eelgrass (*Zostra capensis)* beds (Paterson 1998).

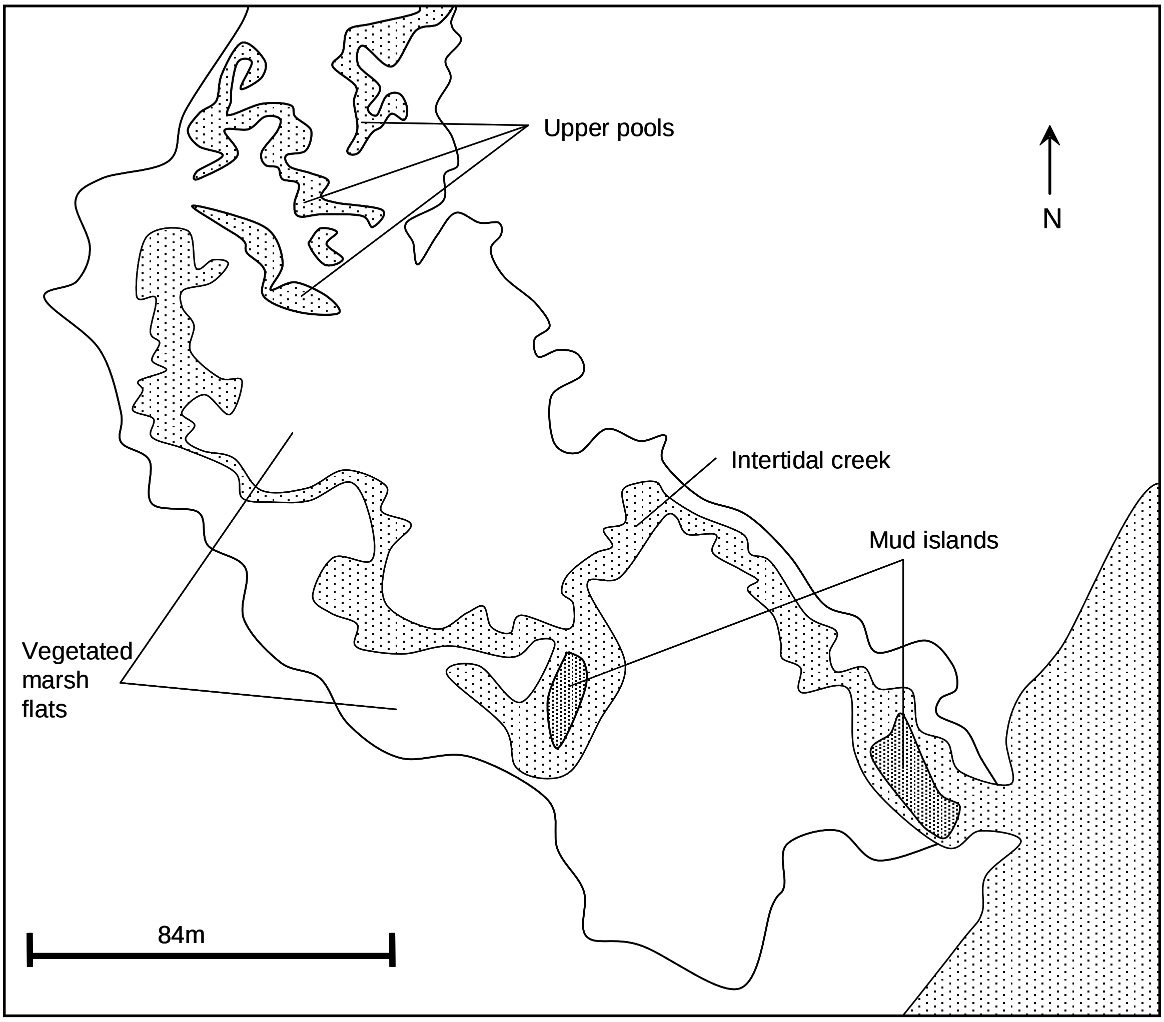


Figure 2.2: Map of Taylor's salt marsh, created by author from aerial photograph, Google Earth, Digital Globe (2007).

Chapter 3.

Materials and Methods

Different studies within salt marshes have used a wide range of sampling techniques; from the traditional active seine netting methods (Madon *et al*. 2001) to more passive techniques such as fyke nets (Varnell *et. al.* 1995) flume nets (Hollingsworth and Connolly 2006) and channel or block nets (Williams and Zedler 1999, Desmond *et. al.* 2000). Several studies have combined active and passive techniques. Kneib (1984) for example, constructed a series of artificial pools on the marsh surface that trapped invertebrates and fish at low tide. These pools were then sampled exhaustively using a dip net. A similar approach was used by Kanouse *et. al.* (2006) where metal-sided throw traps were used and the nekton collected using a sweep net.

Due to the lack of previous work conducted on the fauna of salt marshes within South Africa, very little information exists with regards the best method of sampling these systems. Paterson (1998) deemed Taylor's salt marsh unsuitable for sub-sampling techniques such as seine netting, lift traps or drop samplers due to the narrow width of the channel and the densely vegetated marsh surface. As a consequence, for both this study and the previous study of Paterson (1998) the block netting method was employed to sample the fish within the salt marsh. The block net method avoids the necessity for sub-sampling as all the fish present within a section are sampled. It also avoids other problems associated with other techniques such as net avoidance, variation in towing speeds and size and species selectivity (Paterson 1998). In addition the creek within Taylor's salt marsh is ideally suited to block netting as there is only one opening into the main estuarine channel and the creek is well defined and un-vegetated. The salt marsh drains completely at low tide meaning that the fish are forced into the creek where they could easily be collected. In addition, by employing the same methods as the only existing previous study, results obtained here are directly comparable to previous work.

At slack high tide two nets, each 10m x 2.5m deep with a mesh size of ≈ 0.5mm were deployed and secured across the opening of the inter-tidal creek (Fig 3.1). These two nets were joined carefully using cable ties and rope to ensure that there were no gaps between them that fish could escape through. The nets were supported with wooden stakes driven into the mud and the top rope was suspended a minimum of 50cm above the surface of the water to prevent fish from escaping by jumping over the net. The bottom rope was weighted down to prevent the net lifting off the bottom as the creek drained. Once net across the mouth was secure, a further two nets were deployed to divide the salt marsh into the upper, middle and lower reaches according to Paterson (1998) The nets remained in place as the tide ebbed and the salt marsh creek drained. (see Fig. 3.1).

As large extractive samples have been shown to have significant effects on local fish communities within small systems, especially resident species, which may have limited exchanges with surrounding areas (Cain and Dean 1976), sampling was carried out every two months between May 2006 and March 2007. This was judged to be a sufficient interval to ameliorate any changes in community structure and to preserve the integrity of future samples. The periodicity of the sampling also minimised damage to the vegetation on the salt marsh flats from trampling. Samples were collected early in the morning, between 07:00 and 11:00, during the same period of the tidal phase to standardise as many of the physical and chemical parameters as possible.

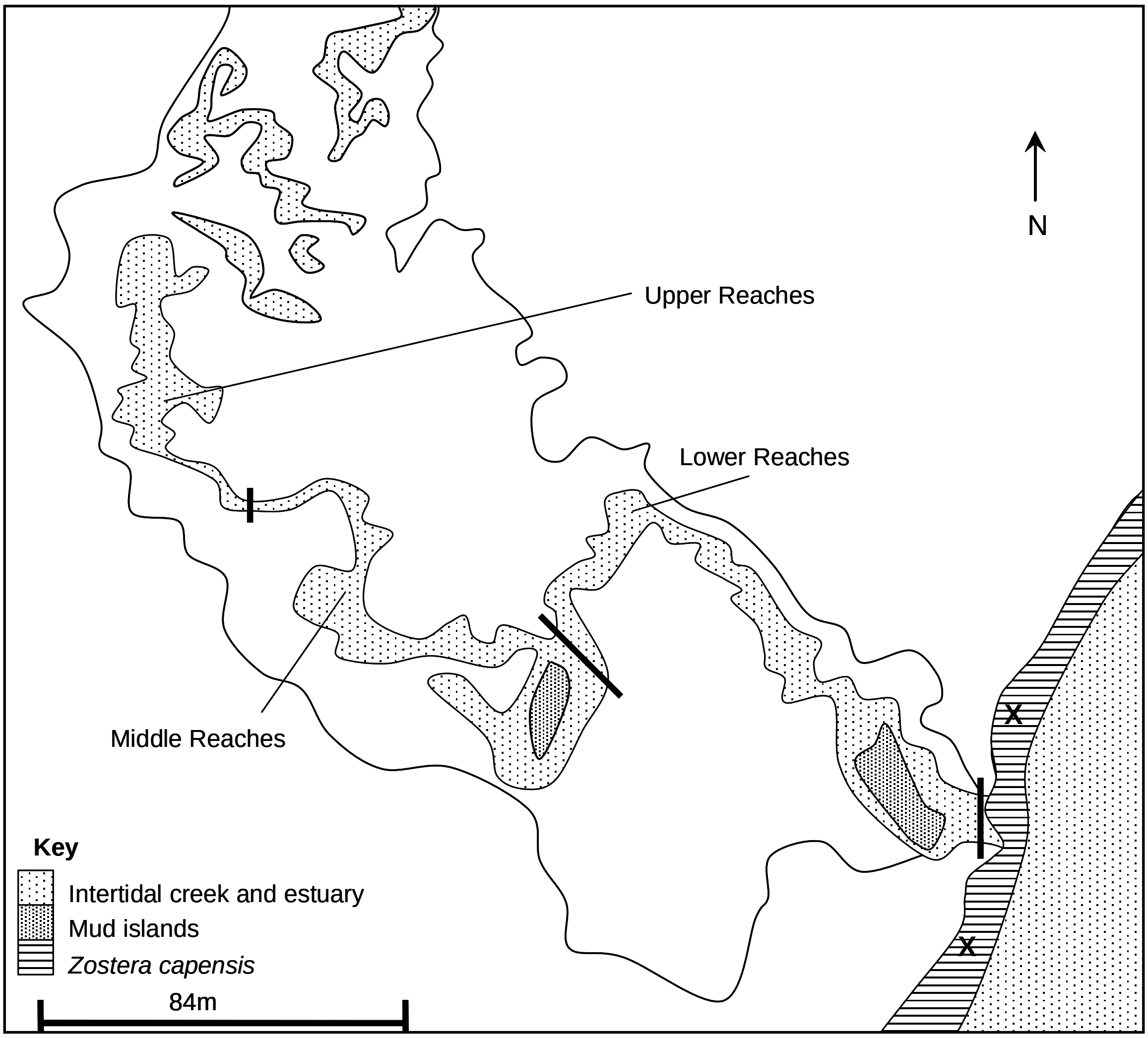


Figure 3.1: Map of Taylor's salt marsh indicating the regions sampled. Bold lines show position of block nets. **X** marks the seine net sampling stations. (Line drawing created by author from aerial photograph, Google Earth Digital Globe (2007))

3.1. Field Sampling Protocols

3.1.1. Physico-chemical and biological variables

Prior to the collection of the fish, temperature (°C) and dissolved oxygen concentrations ($mg.O_2.L^{-1}$) within the three reaches of the salt marsh were recorded adjacent to each net, using an YSI 550 water quality probe. Salinity (practical salinity units – psu) was determined in the field using an Atago handheld refractometer. Water samples were collected for analysis of biological parameters in the laboratory. Due to the shallow nature of this system (<50cm), it was assumed that light penetration was not limited and therefore turbidity was not measured.

The physico-chemical and biological parameters of the habitats were recorded in order to identify spatial and temporal patterns in the environment which may have had an influence on the ichthyofaunal community composition and structure.

3.1.2. Ichthyofaunal sampling

At low tide, fish within the salt marsh were restricted to shallow (10 – 20cm deep) pools in the immediate vicinity of the block nets. Fish concentrated within the pools were sampled using 1 x 1m drag net (500 µm mesh). Sampling was continued until five net tows revealed no further fish. All fish collected were placed into clearly labelled Ziploc packets and preserved in the field with 10% buffered formalin for later identification and analysis in the laboratory. Rarer species such as the endangered estuarine pipefish, *Sygnathus acus*, were measured in the field and then released.

In addition to the salt marsh creek, two sites within the main estuarine channel were also sampled. Two stations; approximately 10m upstream and downstream of the mouth of the salt marsh creek were occupied. These sites were dominated by *Zostera capensis* beds with >90% cover. Sampling at these sites was undertaken with a 5m seine net (mesh ≈0.5mm) with a weighted bottom line and net spreaders. The seine was dragged so that an area of ≈$25m^2$ was sampled each time. The seine net was then carefully lifted onto the bank and all fish collected. Specimens were transported back to the laboratory, or measured and released as described above.

The division of the salt marsh creek into three reaches enables the detection of spatial and temporal patterns in ichthyofaunal community structure and composition within the salt marsh itself. The patterns can them be related to any variation in the physico-chemical and biological parameters. In additoin combining the data from all reaches of the salt marsh gives a clearer picture of the salt marsh habitat as a whole. The physical and biological parameter as well as the ichthyofaunal community composition and structure of the salt marsh was then compared to the eelgrass beds in order to determine whether or not the two habitats were utilised by different suites of species.

3.2. Laboratory Protocols

3.2.1. Particulate organic matter

Total seston concentration was determined by gently filtering (vacuum < 5 cm Hg) a 300ml water sample collected from each reach of the salt marsh through a pre-weighed G/F Whatmann filter. The filters were then dried at 60°C for 24 hours and weighed on a Sartoruis microbalance before being combusted at 500°C for a further 24 hours. They were then re-weighed again and the difference was expressed as particulate organic matter in mg.L^{-1}. Three replicates for each reach, for each sampling trip were processed.

3.2.2. Biological Variables

Chlorophyll-*a*

Total chlorophyll-*a* concentration within the water column was determined flurometrically (Holm-Hansen and Riemann 1978). From each region, a 300ml water sample was gently filtered (vacuum < 5cm Hg) through a 0.2µm Whatmann G/F filter. The filter was then placed into a test tube and extracted with 8ml of 90% acetone and placed in a -20°C deep freeze in the dark for 24hours. The test tubes were then centrifuged for 5 minutes at 5000 rpm and the supernatant poured off into clean glass tubes. These were then placed into the fluorometer and an initial and post acidification reading was taken. If dilutions were necessary, the supernatant was added to 8ml of 90% acetone and the resulting mixture re-measured. The chlorophyll-*a* concentration was then calculated (taking into account any dilutions) according to the formula adapted from Holm-Hansen *et. al.* (1965) and expressed as µg.chl-*a*.L^{-1}.

Microphytobenthic algae

Microphytobenthic algae concentrations within the salt marsh and in the littoral zone of the estuary (n = 5 for each reach) were determined flurometrically from a 1.0cm^2 area of surface sediment. Sediment samples were collected using a corer. Samples collected were extracted in 8ml of 90% acetone in the dark for 24 hours in a -20°C deep freeze. Samples were then centrifuged for five minutes at 5000 rpm and the supernatant poured off into clean glass tubes. The chlorophyll-*a* concentration was there determined as described above and expressed as chlorophyll-*a* equivalents per unit area (mg.chl-*a*.cm^{-2}). No attempt was made to identify the various species of microphytobenthic algae as this was outside the scope of this study.

3.2.3. Ichthyofauna

For each reach of the salt marsh creek, as well as for the eelgrass habitat, the ichthyofauna was collected were identified to species level. The standard length (in mm) and preserved wet weight (g.wwt) for each individual was recorded after removing excess water with blotting paper. Only the small Mugilidae (those with a standard length of less than 20mm) were not identified to species level. The identifying characteristics for this family are not developed under this size and therefore these individuals were grouped together

3.3. Statistical analyses

3.3.1. Physico-chemical and biological parameters

As only one reading was taken for the physico-chemical variables (temperature, salinity and dissolved oxygen concentration) per reach per trip, it was not possible to perform statistical analysis for these variables for each reach of the salt marsh. However, data for each habitat was able to be analysed as the readings from each reach of the salt marsh (n = 3) and each for the seine net stations (n = 2) was pooled to give readings for each habitat for each sampling trip. Spatial patterns in each physico-chemical parameter between different habitats were then analysed using univariate ANOVAs in STATISTICA (2004, version 7).

For temporal analysis, sampling trips were separated into two seasons; summer (November, January and March) and winter (May, July and September). Temporal patterns for each habitat and each region of the salt marsh were analysed on a seasonal (salt marsh: n = 9 per season) and a trip by trip (where possible) basis using univariate and factorial ANOVAs in STATISTICA (2004, version 7). Any significant results were further investigated using Newman-Keuls *post hoc* multiple range test for homogenous groups as well as significant differences. The presence of any correlations between any of the physico-chemical and biological parameters and the abundance and biomass values between different reaches of the salt marsh were investigated.

3.3.2. Ichthyofauna

After each sampling trip, the species present, and the region of the salt marsh in which they occurred, was recorded. The total ichthyofaunal abundances (individuals per 10m^{-2}) and standing stock values (g.wwt.10m^{-2}) were calculated for each region of the salt marsh and then the data was pooled to calculate abundances and standing stock for the salt marsh habitat. Abundance and standing stock values for the eelgrass habitat was also calculated by pooling the data from both stations (n = 2). Spatial patterns in the ichthyofaunal species composition and distribution as well as the abundance and standing stock values within the salt marsh could then be identified. In addition, pooled data from the salt marsh habitat allowed differences in community composition, abundance and standing stock to be identified between the two habitats. Temporal patterns were identified by comparing the ichthyofaunal species composition, abundance and standing stocks between sampling trips for the various reaches of the salt marsh and the two habitats investigated.

Each species identified during the study was then assigned to an estuarine utilisation category according to Whitfield (1998). The percentage contribution of each category to the total number of fish caught within each reach of the salt marsh and in the two different habitats (the salt marsh and the eelgrass beds) was then calculated. This allow an investigation into the types of fish utilising the salt marsh and the eelgrass beds and helped to determine whether or not the ichthyofaunal communities supported by the two habitats belonged to different categories. The relative importance of each species of fish within the different regions of the salt marsh, and within the eelgrass beds, was then calculated using the following formula (after Paterson 1998):

$$\text{Abundance (ind.10m}^{-2}\text{)} + \text{Biomass (g.10m}^{-2}\text{)} + \text{Percentage Contribution to habitat/reach Total} + \text{Frequency of Occurrence} = \text{Rank}$$

The stage of sexual maturity of individuals of all species for each habitat and reach was also determined by comparing the means sizes of individuals captured each month with the published literature on the size of sexual maturity (Whitfield 1998; FISHBASE). Size (mm SL) frequency graphs were also created for each species for each habitat and each region as well as for each sampling trip. This contributed to an understanding of the ichthyofaunal community structures and provided information on the extent to which the salt marsh and the eelgrass beds act as nursery areas within the Kariega Estuary.

Spatial patterns in ichthyofaunal abundance and biomass between different habitats and different reaches of the salt marsh were analysed using univariate and factorial ANOVAs in the computer package STATISTICA (2004, version 7). For temporal analysis, sampling trips were separated into two seasons; the predominantly summer/autumn trips (November, January and March trips) and winter/spring trips (May, July and September). Temporal patterns for each habitat and each region of the salt marsh were analysed on a seasonal and a trip-by-trip basis. Any significant results in either the temporal or spatial analyses were further investigated using Newman-Keuls *post hoc* multiple range test for homogenous groups as well as significant differences.

Table 3.1: Description of estuarine utilisation categories of southern African fish (after Whitfield 1998).

Category	Description
I	True estuarine species that breed in the estuary and complete their lifecycle within the estuary. Divided into: • Ia – Resident species that have not been recorded spawning in marine or freshwater environments. • Ib – Resident species that also have marine or freshwater breeding populations.
II	Euryhaline marine species, which breed at sea, but which show varying degrees of dependence estuaries as juveniles. Further divided into: • IIa – Juveniles dependent on estuaries as nursery areas. • IIb – Juveniles occurring mainly in estuaries but also found at sea. • IIc – Juveniles occur in estuaries but are usually more abundant at sea.
III	Marine species, infrequently found in estuaries, they are not dependent on estuaries for any stage of their lifecycle.
IV	Freshwater species, which can breed either in the freshwater, or the estuarine environment. The penetration of these species into the estuary depends on the salinity tolerance of a particular species.
V	Species that use the estuary purely in transit between the marine and freshwater environments. This can be further divided into: • Va – Obligative catadromous species that require a freshwater phase for their development. • Vb – Facultative catadromous species, which do not require a freshwater, phase in their development.

3.3.3. Ichthyofaunal community analyses

To assess the spatial and temporal patterns in the ichthyofaunal community composition numerical analyses were conducted on the ichthyofaunal abundance data. For each habitat as well as for the different reaches of the salt marsh, ichthyofaunal abundance data was log(x+1) transformed and a Bray-Curtis similarity matrix was produced using the computer package; Plymouth Routines In Multivariate Ecological Research (PRIMER, version 5.2.4). The Bray-Curtis similarity matrix was then used to perform ordination (using multidimensional scaling – MDS), and classification (hierarchical agglomerative clustering with group averages and complete linkages) procedures (Paterson 1998).

To test if the different habitats, and the different regions of the salt marsh had distinct fish communities, an analysis of similarities (ANOSIM) test was performed on the ichthyofaunal abundance data using PRIMER, The ANOSIM test used the same similarity matrix as the cluster and ordination procedure and tests for differences between and within *a priori* groupings (Clark and Gorley 2001). The ANOSIM gives a test statistic (R), which reflects the observed differences between groupings, contrasted with differences within groupings (Clark and Gorley 2001). If $R \approx 1$ then all sites within a group are more similar to each other than any sites from different groups; if R is approximately zero then the similarities between and within groups are the same on average (Clarke and Gorley 2001).

PRIMER statistical package (version 5.2.4) was also employed to calculate Margalef’s species richness index (D), the Shannon-Weiner species diversity index (H’) and Pielou’s evenness index (J’). These were calculated for each habitat and reach, on a trip-by-trip basis as well as overall.

Chapter 4.

Salt Marsh

This chapter presents the physico-chemical and biological results for the different reaches of Taylor's salt marsh.

4.1. Physico-chemical Results

Temperature

Water temperatures in the salt marsh showed a seasonal trend with the highest temperatures recorded in summer (25°C) and the lowest (14.1°C) in winter (Fig 4.1 A). Intermediate temperatures were recorded in spring and autumn. The mean water temperature was 18.8 ± 3.6°C (SD). A factorial ANOVA showed that there were no significant differences in water temperature between the different reaches of the salt marsh ($F_{(2, 12)} = 0.22$, $p>0.05$) but there was a significant difference between the different seasons ($F_{(1, 12)} = 48.29$, $p<0.001$). There was no interaction between the reach of the salt marsh and the month sampled ($F_{(2, 12)} = 0.02$, $p>0.05$).

Salinity

Salinity values in the salt marsh ranged between 33 and 46 (mean = 36.9 ± 3.3). Slightly lower salinities were recorded in November and January, particularly in the middle and upper reaches of the salt marsh (34 and 33, respectively) which may have been be due seepage into the system from the large amounts rain received prior to the sampling trip (pers. obs. Fig 4.1 B). A factorial ANOVA showed that there was a significant difference between summer and winter salinities ($F_{(1, 12)} = 6.07$, $p<0.05$) but that there were no significant differences in salinity between the different reaches of the salt marsh ($F_{(2, 12)} = 0.07$, $p>0.05$). In addition there was no interaction between season and reach ($F_{(2, 12)} = 0.36$, $p>0.05$).

Dissolved oxygen concentration

Dissolved oxygen (dO_2) concentrations in the salt marsh also demonstrated a seasonal trend with the lowest concentrations (3.88 to 4.85 $mg.O_2.L^{-1}$) recorded in summer and the highest (3.94 – 6.0 $mg.O_2.L^{-1}$) in winter (Fig 4.1 C). The mean dO_2 concentration for the salt marsh as a whole was 4.7 ± 0.35 $mg.O_2.L^{-1}$. A factorial ANOVA showed that there was a significant difference between summer and winter values ($F_{(1, 12)} = 5.90$, $p<0.05$). There was also a significant difference between the different reaches of the salt marsh ($F_{(1, 12)} = 5.22$, $p<0.05$) with the lower reaches having higher values and belonging to a separate group (Newman-Keuls *post hoc* test). There was no interaction between season and reach ($F_{(2, 12)} = 2.19$, $p>0.05$).

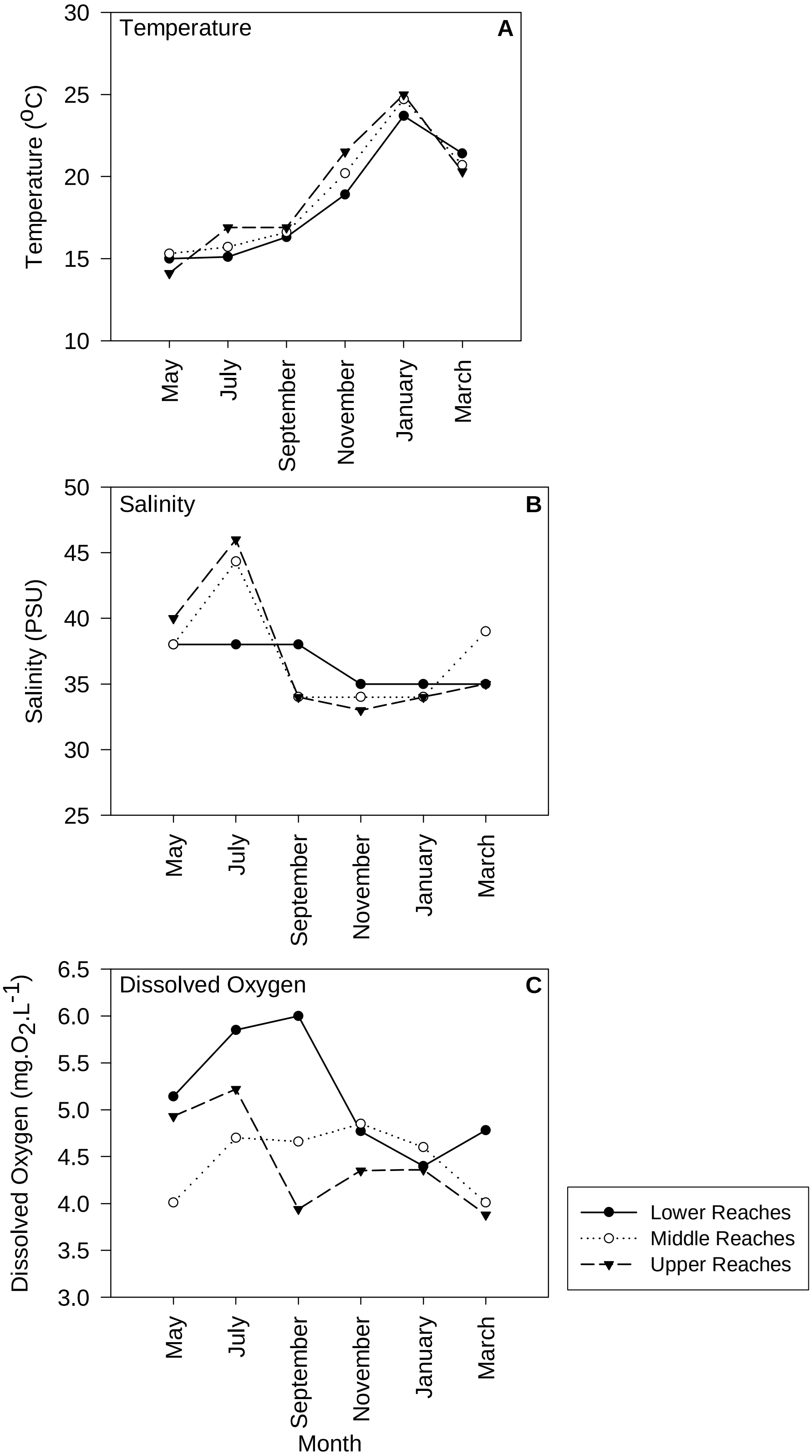


Figure 4.1: Monthly recorded physico-chemical variables for each reach of Taylor's salt marsh. Temperature (°C), Salinity (psu) and Dissolved oxygen (mg.O_2.L^{-1}).

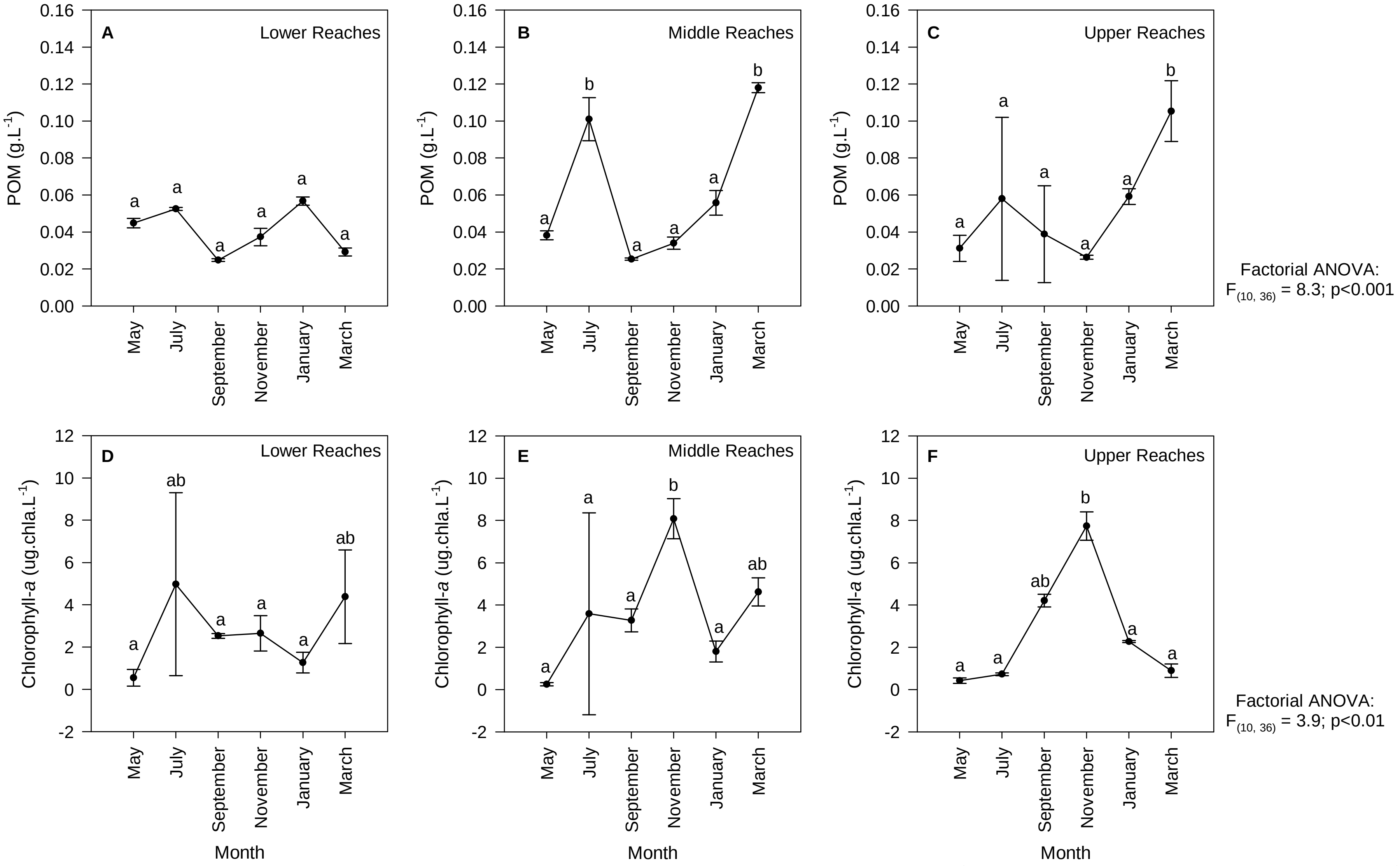
Particulate Organic Matter (POM)

Particulate organic matter (POM) concentrations in the salt marsh varied between 0.01 g. L^{-1} and 0.1 g.L^{-1} (mean = 0.05 ± 0.03 g.L^{-1}). The data for the POM concentrations was not normally distributed and therefore the permutational statistical analysis program PERMANOVA (Anderson 2001, 2005) was employed to analyse the data. PERMANOVA analyses multivariate data on the basis of any distance measure according to any linear ANOVA model, using permutations (Anderson 2005). Within the salt marsh, there was a significant difference between the different sampling dates ($F_{5, 36} = 24.99$; $p = 0.0002$) and between date and reach ($F_{10, 36} = 8.34$; $p = 0.0002$, Fig 4.2 A, B and C). The analysis was run with no transformations or standardisations of the data, and was calculated using Euclidian distances based on 5000 permutations of unrestricted raw data. The pair-wise *a posteriori* comparisons (500 permutations) showed that POM concentrations in January and March were significantly different to all other dates for all reaches, and that the lower reaches in March was also different to all other dates and reaches.

4.2. Biological Results

Chlorophyll-*a*

Water column chlorophyll-*a* concentrations in the salt marsh creek ranged between 0.2 µg.*chl*-*a*.L^{-1} and 9.2 µg.chl-*a*.L^{-1} (mean = 3.0±2.7 µg.chl-*a*.L^{-1}). A factorial ANOVA showed that there were no significant spatial differences in total chlorophyll-*a* concentration in the salt marsh ($F_{(2, 51)} = 0.64$, $p<0.05$). There was however, a significant difference between summer and winter values ($F_{(1, 48)} = 4.22$, $p<0.05$) but there was no interaction between season and reach ($F_{(2, 48)} = 1.0$, $p>0.05$). A further factorial ANOVA showed that there were significant differences between the sampling months ($F_{(5, 36)} = 11.9$, $p<0.001$) with November, May and January separating from the other months. There was also an interaction between month and reach ($F_{(10, 36)} = 3.8$, $p<0.01$), which is illustrated in Figure 4.2 D, E and F.



Factorial ANOVA:
$F_{(10, 36)} = 8.3; p<0.001$

Factorial ANOVA:
$F_{(10, 36)} = 3.9; p<0.01$

Figure 4.2: Monthly recorded biological parameters for each reach of Taylor's salt marsh. POM (g.L^{-1}) – A, B and C; Chlorophyll-*a* (µg.chl-*a*.L^{-1}) - D, E and F. Error bars indicate ±1 SD.

Microphytobenthic algae

In the salt marsh, the total microphytobenthic chlorophyll-*a* concentration ranged between 183.04 µg.chl-*a*.cm^{-2} and 6957.6 µg.chl-*a*.cm^{-2} (mean: 2695.9 ±1825.5 µg.chl-*a*.cm^{-2}). A factorial ANOVA showed that there was no interaction between season and reach ($F_{(2, 84)} = 0.46$, $p>0.05$) and between month and reach ($F_{(10, 72)} = 0.72$, $p>0.05$). There were however, significant differences between the months sampled ($F_{(5, 72)} = 10.5$, $p<0.001$) and a *post hoc* test showed that the total microphytobenthic chlorophyll-*a* concentration during May and November (Newman-Keuls) sampling trips were significantly higher than the remaining months. The monthly microphytobenthic algae concentrations for each reach are illustrated in Fig 4.3. Values are summarised in Appendix 1, Tables 4.1 and 4.2.

4.3. Ichthyofauna

4.3.1. Ichthyofaunal abundance and standing Stock

A total of 9011 individuals were caught in the salt marsh; 3300 in the lower reaches, 3823 in the middle reaches and 1888 in the upper reaches, throughout the study. Abundances ranged between 0.55 and 21.68 ind.10m^{-2} (Fig 4.4). Abundances for each reach of the salt marsh during the six sampling trips are summarised in Appendix 1, Table 4.3 and Figure 4.4.

When the data from each reach was pooled, (n = 6), the highest abundances were recorded in the middle reaches (6.57 ± 7.78 ind.10m^{-2}) followed by the upper reaches (4.24 ± 2.61 ind.10m^{-2}) and finally, the lower reaches (2.92 ± 3.89 ind.10m^{-2}). There were no significant differences in abundances between the sampling months ($F_{5, 12} = 2.48$; $p>0.05$) or between the different reaches of the salt marsh ($F_{2, 15} = 0.75$; $p>0.05$, Fig. 5.3). Regression analyses were carried out between abundance and temperature, salinity and dO_2 concentration, which showed that; although there were relationships ($R^2 = 0.087$, 0.18, and 0.04 respectively) none were significant (p = 0.23, 0.08, and 0.43 respectively). In addition, the relationships between abundance and water column chlorophyll-*a* concentration ($R^2 = 0.18$) and POM ($R^2 = 0.03$) were not significant (p = .0.08 and 0.51 respectively). There was also no significant relationship between total ichthyofaunal abundance and microphytobenthic algae chlorophyll-*a* concentration ($R^2 = 0.10$, p = 0.20).

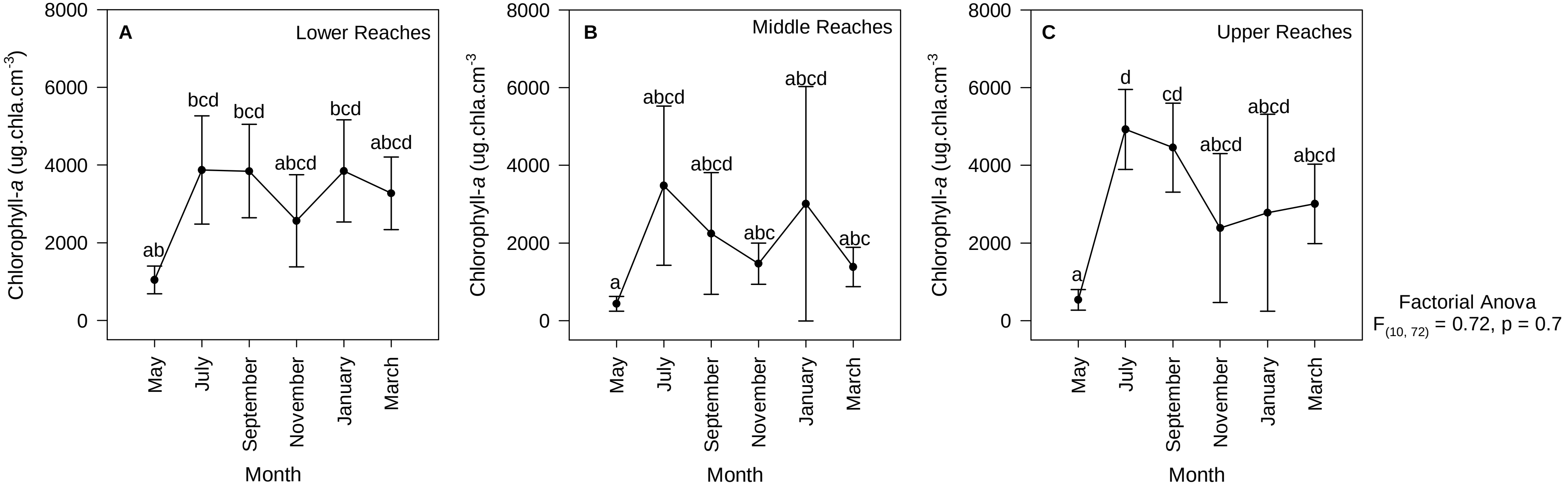


Figure 4.3: Monthly recorded microphytobenthic algae concentration (µg.chl-*a*.cm^{-3}) for each reach of Taylor's salt marsh. A – Lower Reaches, B – Middle Reaches, C- Upper Reaches. Error bars indicate ±1 SD.

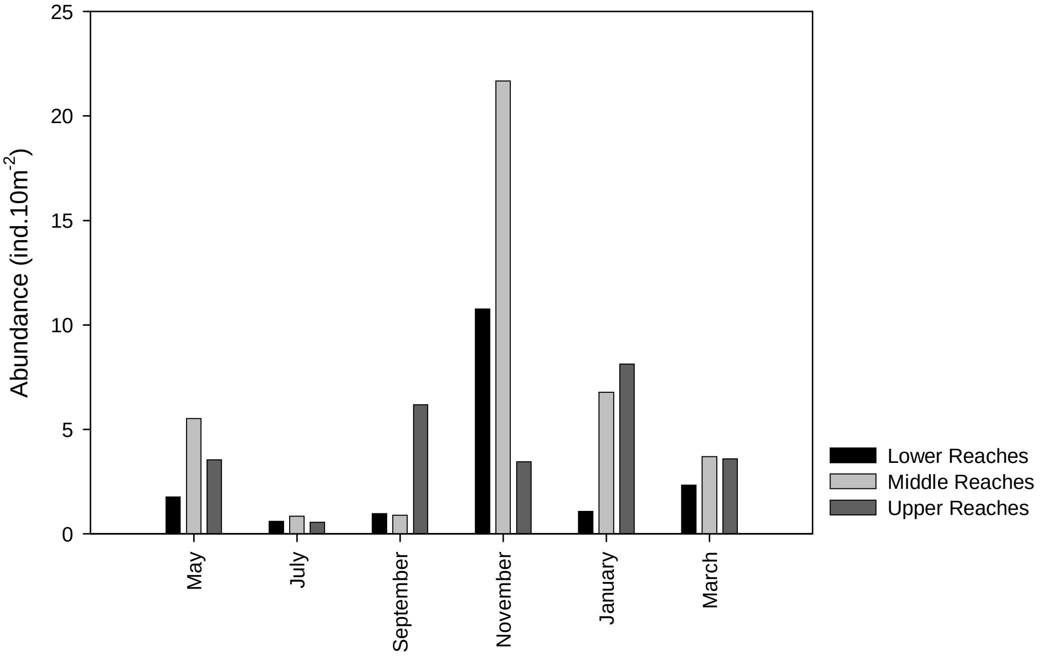


Figure 4.4: Monthly recorded abundance (ind.10m^{-2}) for each reach of Taylor's salt marsh.

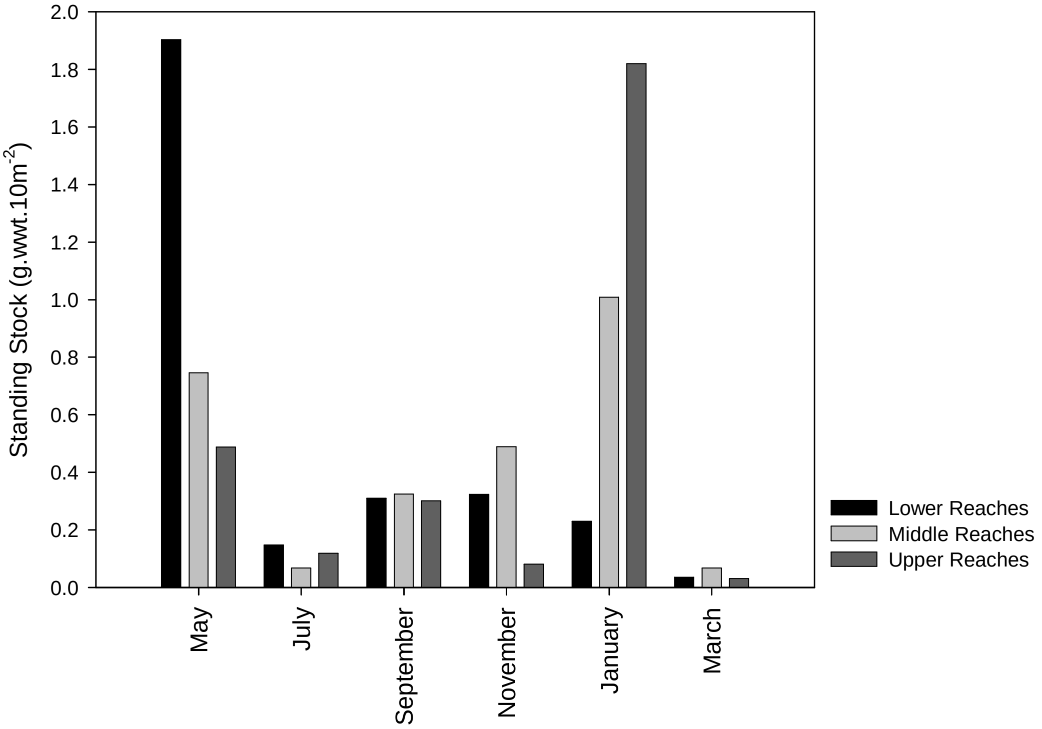


Figure 4.5: Monthly recorded standing stock (g.wwt.10m^{-2}) for each reach of Taylor's salt marsh.

The total biomass of fish caught in the salt marsh over the whole study period, was 0.96 kg.wwt (wet weight) with a range of 15.50 g.wwt to 467.2 g.wwt and a mean of 159.6 ± 164.7 g.wwt. The mean standing stock for the salt marsh as a whole was 0.44 ± 0.46 g.wwt.10m^{-2}. The monthly-recorded standing stock for each region of Taylor's salt marsh is summarised in Table 4.4 and Figure 5.4. The lower reaches had the greatest standing stock (0.49 ± 0.70 g.wwt.10m^{-2}) followed by the middle reaches (0.45 ± 0.38 g.wwt.10m^{-2}) while the upper reaches had the lowest standing stock overall (0.32 ± 0.33 g.wwt.10m^{-2}). There were no significant differences in standing stock between the different sampling months ($F_{5, 12} = 1.31$; $p>0.05$) or between the different reaches of the salt marsh ($F_{5, 12} = 2.48$; $p>0.05$, Fig 4.5). Regression analyses between standing stock and the physico-chemical variables revealed no significant relationships (temperature: $R^2 = 1.78$, $p = 0.08$; salinity: $R^2 = 0.05$, $p = 0.39$; dissolved oxygen: $R^2 = 0.001$, $p = 0.90$). There were also no significant relationships between standing stock and the total water column chlorophyll-*a*, ($R^2 = 0.12$ $p = 0.16$) POM, ($R^2 = 0.03$, $p = 0.53$) and microphytobenthic algal concentrations ($R^2 = 0.14$, $p = 0.13$).

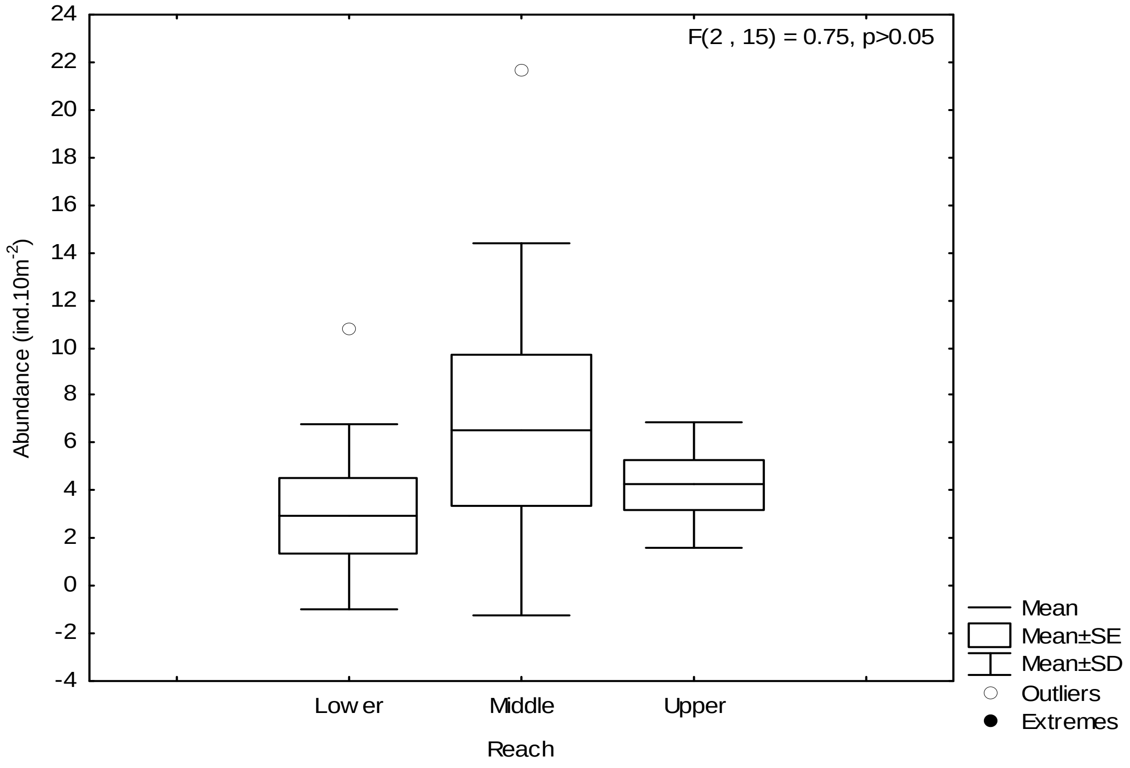


Figure 4.6: Total ichthyofaunal abundance (ind.$10m^{-2}$) for each reach of Taylor's salt marsh (n = 6).

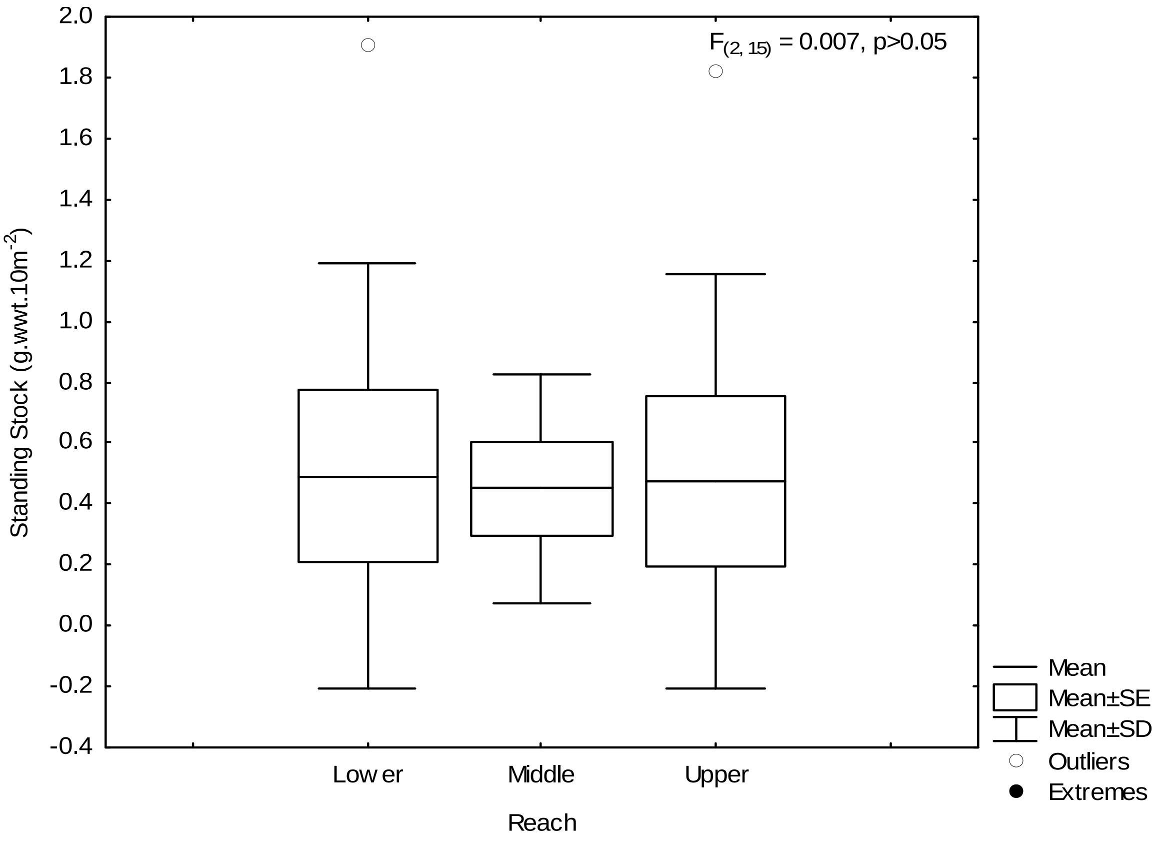


Figure 4.7: Total standing stock (g.wwt.$10m^{-2}$) for each reach of Taylor's salt marsh (n = 6).

4.3.2. Community Composition

Three diversity indices; Margalef's, Pielou's and Shannon-Weiner's index; were calculated. Margalef's index (d) is an indicator of species richness, Pielou's evenness index (J') gives an indication of how even the contribution of different species is to the population while the Shannon-Weiner index (H') gives an overall indication of diversity (Peet 1974). These indices were calculated for each reach of the salt marsh for every sampling trip, as well as for the entire study period (based on pooled data, n = 6) and the results were used to compare the species richness and diversity between each reach of the salt marsh.

A total of 19 fish species were caught in the salt marsh throughout the study. Seventeen species were recorded in the lower reaches and 14 species in the middle and upper reaches. Of the total number of fish species recorded, 12 species were common to all three reaches of the salt marsh (Table 4.5). Three species; *Caffrogobius nudiceps, Arothron hispidus* and *Heteromycteris capensis* were only recorded in the lower reaches, while two species; *Monodactylus falsiformis* and *Liza tricuspidens* were restricted to the upper reaches of the salt marsh. No species were restricted to the middle reaches of the salt marsh during the study.

The Shannon-Weiner and Pielou's indexes both showed that the ichthyofaunal community within the upper reaches was more diverse (H' = 1.27) with a higher degree of evenness (J' = 0.48) than middle and lower reaches of the salt marsh (H' = 0.85 and 1.23 respectively; J' = 0.32 and 0.43 respectively) (Fig 4.8). Margalef's index showed that the lower reaches had higher species richness (d = 1.98) than either the middle (d = 1.57) or upper (d = 1.72) reaches.

In the lower reaches, all three indices broadly follow demonstrated the same trend (Fig 4.9). Margalef's index was relatively high at the start of the study in May 2006, and then decreased initially in July before rising to its maximum value in September 2006 (d = 2.11). The Shannon-Weiner index also decreases initially before reaching its maximum value, also in September (H' = 2.24). Pielou's index rises gradually to a maximum of 0.90 in September. There is then a dramatic decrease for all three indices in November to their lowest values (d = 1.18. J' = 0.07, H' = 0.17). Pielou's and Shannon-Weiner indices both show recovery to similar values to the beginning of the study, but Margalef's index does not show the same extent of recovery (Fig 4.9).

Table 4.5: Fish species and estuarine utilisation category (after Whitfield 1998) recorded in the different reaches of Taylor's salt marsh throughout the study.

Scientific name	**Common Name**	**Estuarine Utilisation Category**	**Lower Reaches**	**Middle Reaches**	**Upper Reaches**
Psammagobius knysnaesis	Knysna Sand Goby	Ib	X	X	X
Glossogobius callidus	River Goby	Ib	X	X	X
Caffrogobius gillchristii	Prison Goby	Ib	X	X	
Caffrogobius nudiceps	Barehead Goby	Ib	X		
Terapon jarbua	Thornfish	IIa	X	X	X
Oreochromis mossambicus	Mozambique Tilapia	IV	X	X	X
Liza richardsonii	Southern Mullet	IIc	X	X	X
Liza dumerilii	Groovy Mullet	IIb	X	X	X
Myxus capensis	Freshwater Mullet	Vb	X	X	X
Mugil cephalus	Flat-head Mullet	IIa	X	X	X
Liza tricuspidens	Striped Mullet	IIb			X
Gilchristella aestuaria	Estuarine Round-herring	Ia	X	X	
Atherina breviceps	Cape Silverside	Ib	X	X	X
Arothron hispidus	Whitespotted Blaasop	III	X		
Heteromycteris capensis	Cape Sole	IIb	X		
Mugilidae <20mm SL	Juvenile Mullet	Multiple	X	X	X
Clinus superciliosus	Super Klipfish	IIb	Not recorded in salt marsh		
Synganathus temenkii	Long-nosed pipefish	Ib	Not recorded in salt marsh		
Rhabdosargus holubi	Cape Stumpnose	IIa	X	X	X
Caffrogobius saldanah	Commafin goby	Unknown	Not recorded in salt marsh		
Diplo sargus capensis	Blacktail	IIc	Not recorded in salt marsh		
Elops machnata	Ladyfish/ Springer	IIa	X	X	X
Monodactylus falsiformis	Mooney	IIa			X
Fistularia commersonii	Flute nose	III	Not recorded in salt marsh		
Argyrosomus japonicus	Dusky Kob	IIa	Not recorded in salt marsh		
Diplodus cervinus hottentotus	Zebra	III	Not recorded in salt marsh		
Caragoides ferdau	Blue Kingfish	Unknown	Not recorded in salt marsh		
Lutjanus argentimaculatus	River snapper	IIc	Not recorded in salt marsh		

The indices in the middle reaches show a different pattern. All three indices were low at the beginning of the study before rising sharply in September; where Shannon-Weiner’s and Pielou’s reach their maximum values (J’ = 0.85, H’ = 1.76). Similar to the lower reaches, all indices experience their minimum values in November (d = 0.65, J’ = 0.06, H’ = 0.11). Margalef’s values then increased and reaches its maximum value in January 2007 (d = 1.85), however, the value drops dramatically again in March. Neither Shannon-Weiner’s index nor Pielou’s index show the same degree of recovery as Margalef’s index and both these indices remain at levels similar to the start of the study for the remainder of the survey (Fig 4.10).

The upper reaches have very different trends to the middle and lower reaches of the salt marsh (Fig 4.11). Maximum values for the diversity indices in the upper reaches were recorded in January 2007 as opposed to November 2006 for the middle and lower reaches. Margalef’s index decreases steadily from the start of the study until September before rising to its maximum value (d = 1.72). Pielou’s and Shannon-Weiner indices both rise between May and July 2006 but then decrease until November 2006 before rising again in January to the maximum values (J’ = 0.59, H’ = 1.47). All three indices drop dramatically in March 2007, but this may be an artefact of the conditions experienced in this particular region of the salt marsh in March 2007. The salt marsh did not flood as completely as on previous trips with the result that the upper reaches were very shallow and very few individuals from only three species were caught. Actual values for diversity indices calculated are presented in Appendix 1, Table 4.6 to Table 4.9.

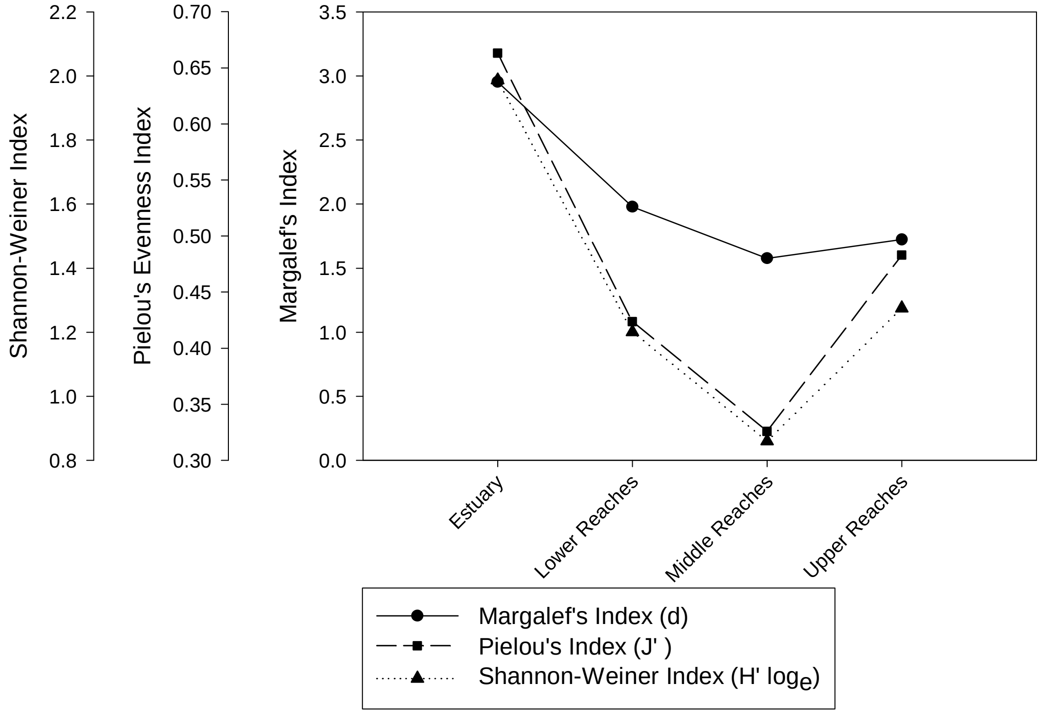


Figure 4.8: Diversity indices for each reach of Taylor's salt marsh and the adjacent estuarine eelgrass beds. Data pooled, n = 6.

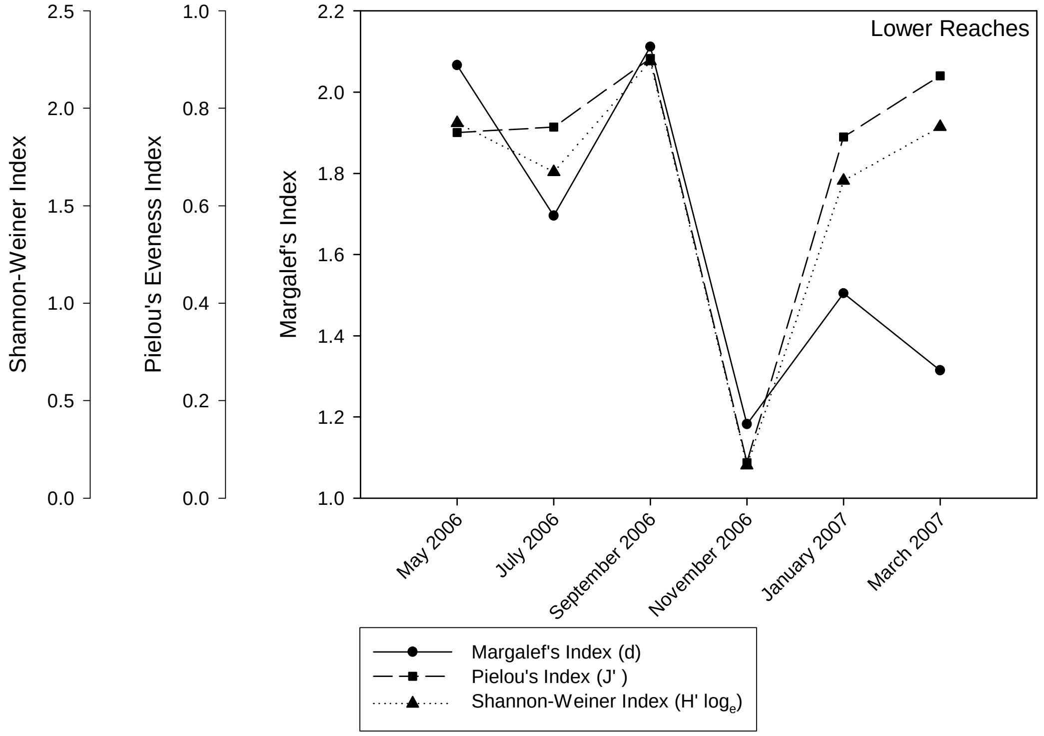


Figure 4.9: Monthly diversity indices for the lower reach of Taylor's salt marsh.

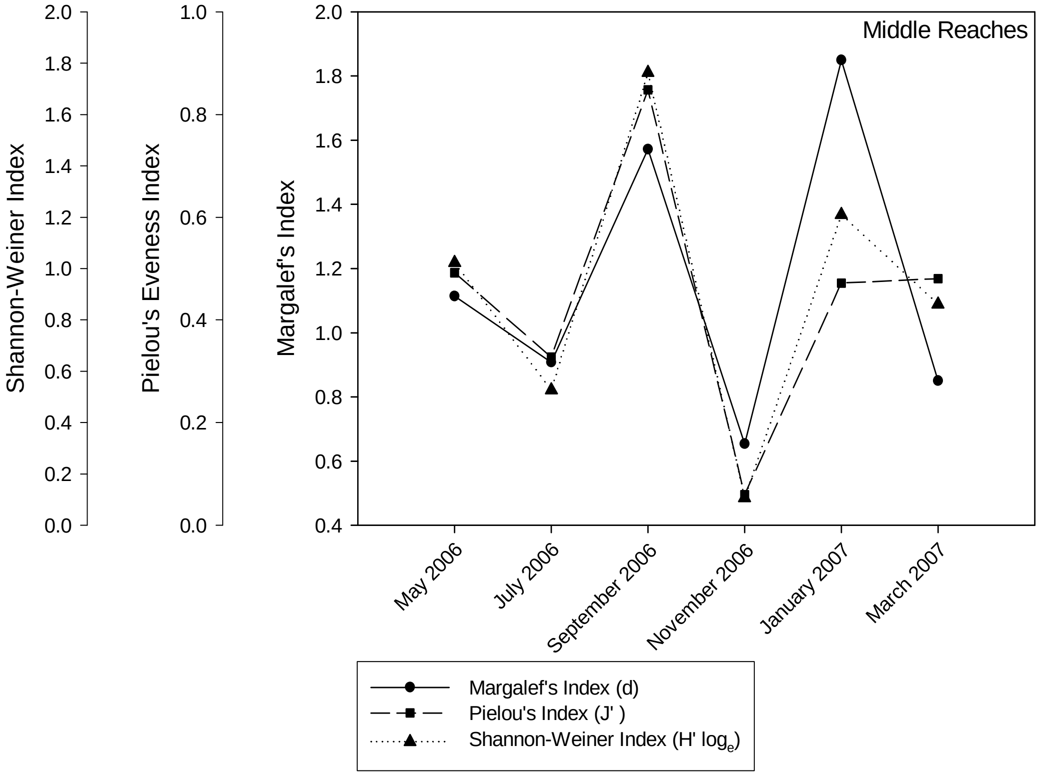


Figure 4.10: Monthly diversity indices for the middle reach of Taylor's salt marsh

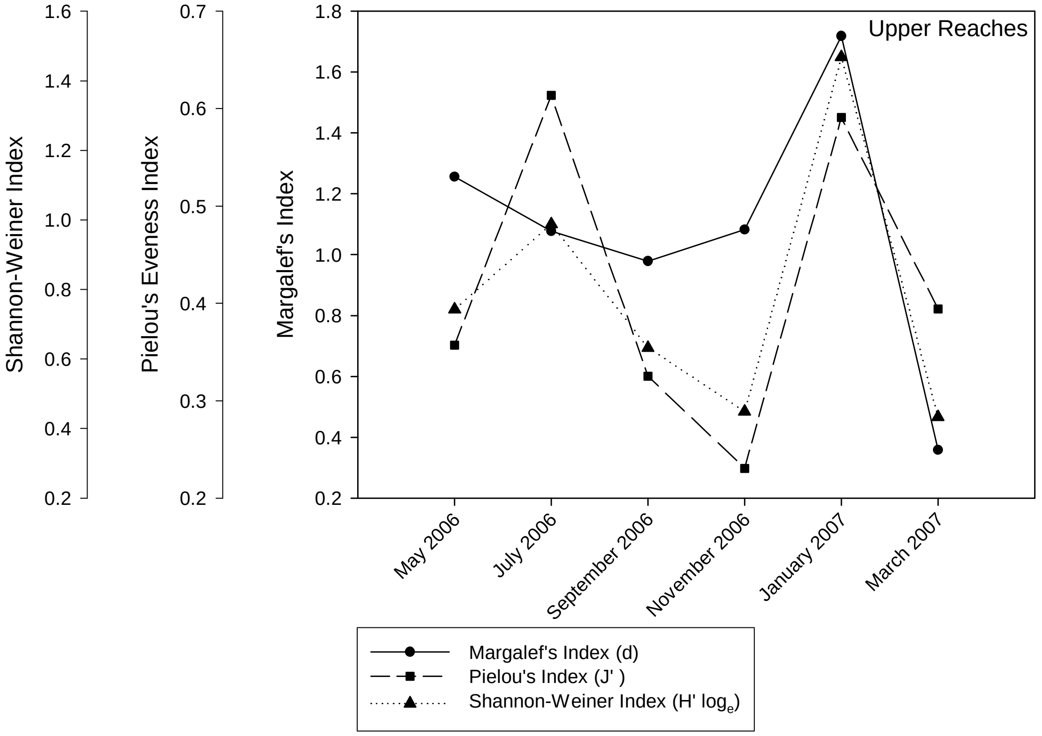


Figure 4.11: Monthly diversity indices for the upper reach of Taylor's salt marsh.

In all months except November, more species were recorded in the lower reaches of the salt marsh than in the middle and upper reaches. The middle and upper reaches of the salt marsh had similar numbers of species except for November when the middle reaches recorded the most species and March when the upper reaches only recorded three species (Fig 4.12).

January 2007 recorded the most species caught in the salt marsh as a whole (15). This is reflected in the large number of species caught in the middle and upper reaches of the salt marsh (13 and 12 respectively). The large number of species caught in January may indicate a greater number of species recruiting into the estuary as a whole and the salt marsh in particular.

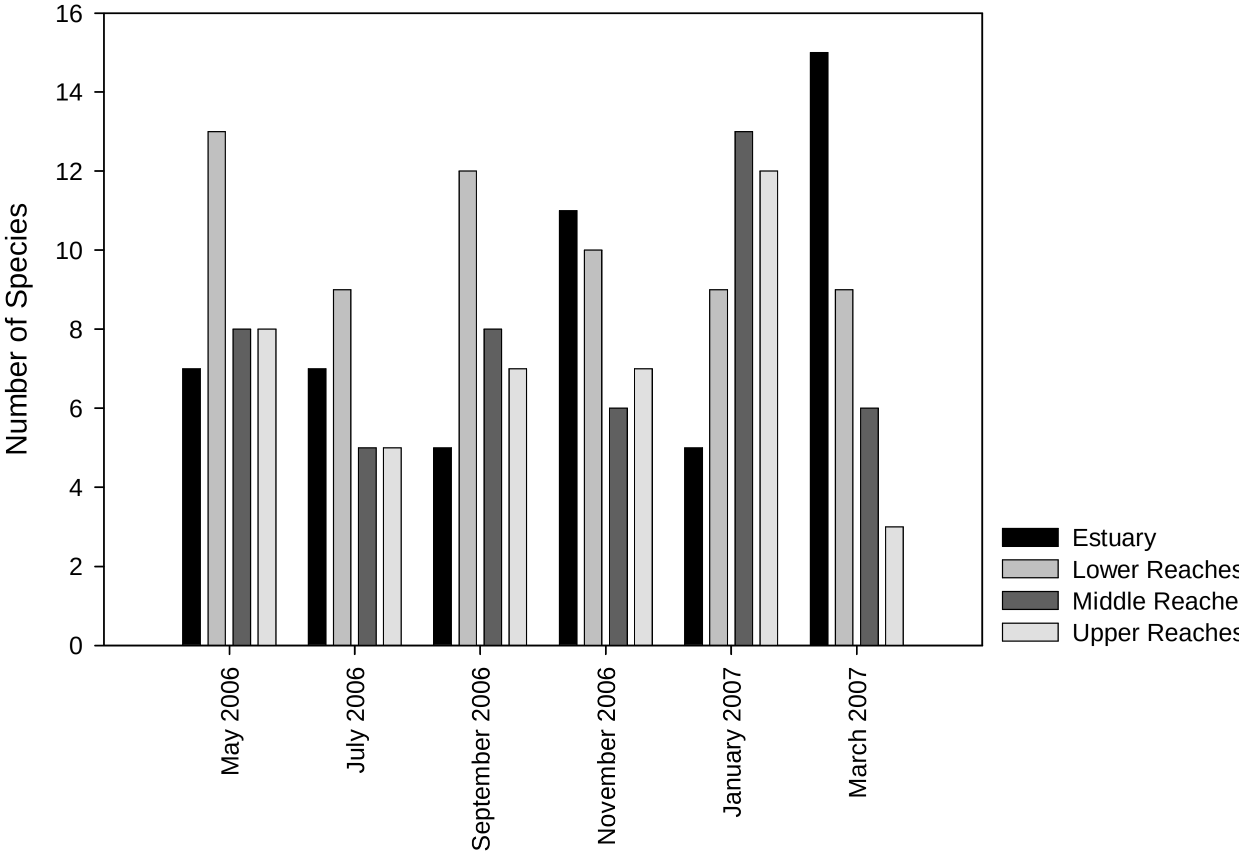


Figure 4.12: Number of species recorded monthly in each reach of Taylor's salt marsh and the adjacent estuarine eelgrass beds.

4.3.3. Estuarine dependence

The estuarine utilisation categories for all species of fish collected in the salt marsh during the study were obtained from Whitfield (1998). The percentage contribution of each category, in terms of abundance and standing stock, to the total catch in each reach was calculated. Juvenile Mugilidae (those individuals <20mm SL) were not included in this data as the different species may belong to different categories (Whitfield 1998). The relative proportions contributed by each category are summarised in Table 4.10 (Appendix) and illustrated in Figure 4.13 A, B and C.

In all reaches of the salt marsh, category II species; those species which have juveniles that rely on estuaries to varying degrees, contributed most in terms of abundance. The greatest percentage of category II species were caught in the middle reaches of the salt marsh (22%), followed by the upper reaches (21%) and finally the lower reaches (19%). Within category II, individuals belonging to category IIa (which are those species that have juveniles which are dependant on estuaries as a nursery area) contributed between 12% and 20% of all individuals caught within the different reaches of the salt marsh.

Category II species also contribute most to the overall standing stock with the greatest contribution (44%) from the lower reaches, followed by the middle reaches (11%) and finally the upper reaches (5%). Category IIb species where juveniles have also been recorded in the marine environment, contributed most to the total standing stock (29% and 3%) in the lower and upper reaches respectively. In the middle reaches, the majority of the standing stock (7%) was composed of category IIa species.

The true estuarine species, category I, were the second most abundant group in the lower and middle reaches of the salt marsh, contributing 13% and 6% to the total abundance, and 12% and 8% of standing stock, respectively. In the upper reaches, this category contributes less than 2% towards both abundance and standing stock totals. Individuals belonging to category Vb (the facultative catadromous species) were the most abundant category (4%) in the upper reaches, while category IV species (freshwater stragglers) contributed most to total standing stock (4%) in the upper reaches of the salt marsh. Category Vb was represented exclusively by *Myxus capensis* and category IV by *Oreochromis mossambicus*. Nevertheless, when categories I and II were combined, they were the most dominant in terms of both abundance and standing stock in all reaches of the salt marsh (lower – 31% and 58%, middle – 29% and 19% and upper – 22% and 7% respectively).

Of the remaining categories in the lower and middle reaches, category Vb contributed most to the total abundances (7% for both) and standing stock (3% for both). Category IV is also a contributor though it only contributed between 0.2% and 2% of the total abundance and 0.05% and 4% of the total standing stock. Only one specimen of *Arothron hispidus* (category III) was caught throughout the study and no species belonging to category Va were recorded.

4.3.4. Reproductive status

The reproductive status of individuals of different species caught within each reach of the salt marsh was determined by comparing the mean size (mm SL) of each species captured during each sampling trip with the size of sexual maturity obtained from the literature (Whitfield 1998, FISHBASE). All specimens of Springer (*Elops machnata*) and the small Mugilidae (<20mm SL) were juveniles. The remaining species showed various patterns of maturity, which were related to seasonality of breeding and recruitment as well as the degree to which a particular species relied on estuaries.

The majority of individuals caught within the salt marsh could be considered to be juveniles (Figs 4.14 and 4.15). Exceptions were presented by the Knysna sand goby (*Psammogobius knysnaensis*) and the River goby (*Glossogobius callidus*). Adults were present in the winter and spring months (between May and September) but were restricted to the middle and upper reaches of the salt marsh. The Thornfish, (*Terapon jarbua*) was found in summer and autumn in all reaches of the salt marsh, but was absent in winter. The Prison goby (*Caffrogobius callidus*) was restricted to the lower reaches of the salt marsh where, with one exception, all individuals caught were juveniles. All specimens of the Mozambique tilapia (*Oreochromis mossambicus*) recorded were juveniles with the exception of September and November. This species was initially only recorded in the middle and upper reaches of the salt marsh in May and July, before occurring in all reaches. *O. mossambicus* was present in the upper reaches only of the salt marsh in midwinter (July, Fig.4.14).

Adult *Gilchristella aestuaria* were recorded in the lower reaches in May, July, September and January and in the middle reaches in January. Juvenile *Atherina breviceps* were also present between July and November in both the lower and middle reaches. Juvenile *Rhabdosargus holubi* were present between September and March although they were present predominantly in the middle and upper reaches in January and March (Fig 4.15).

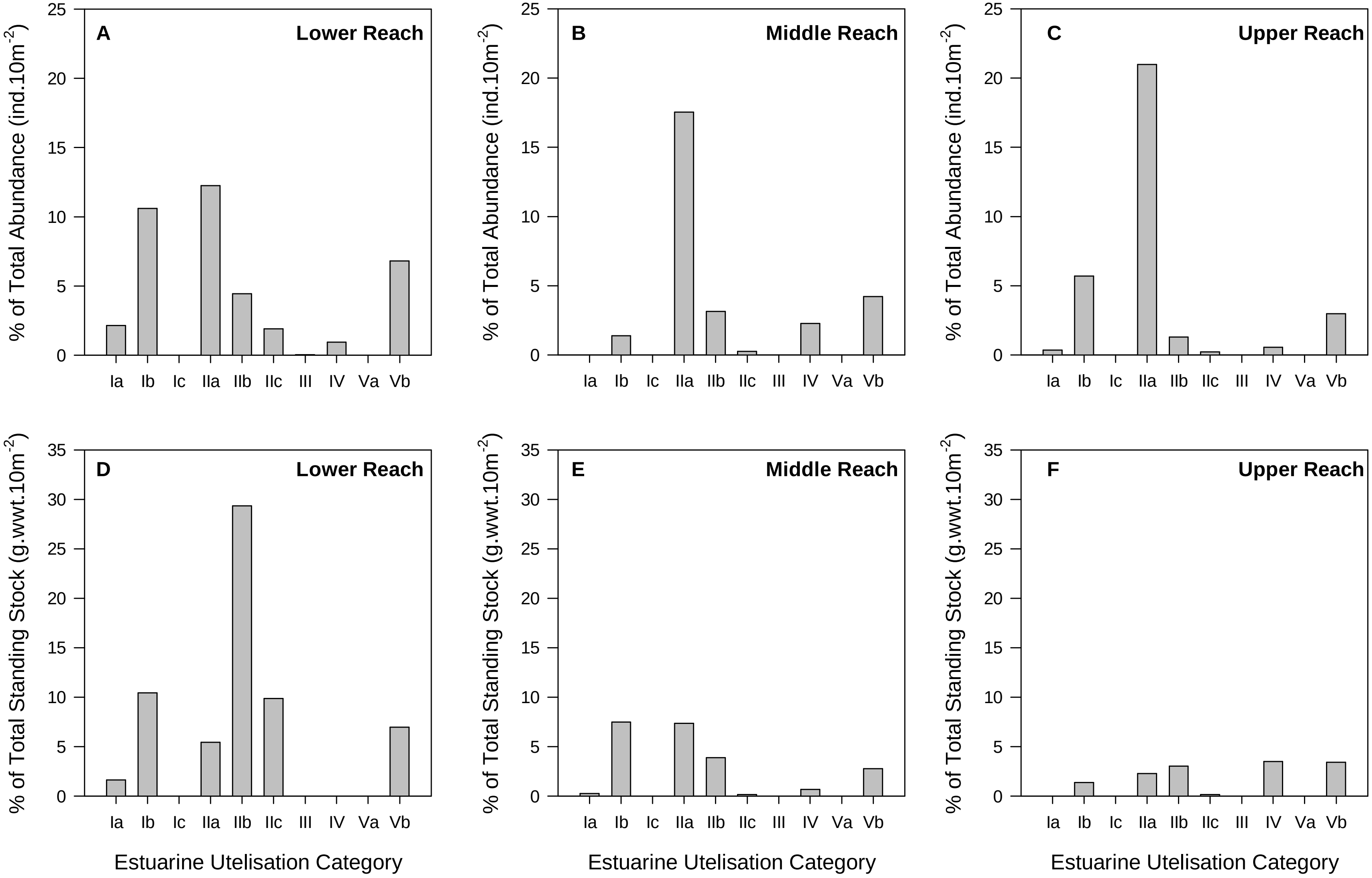


Figure 4.13: Percentage contribution to total abundance (ind.10m^{-2}) and standing stock (g.wwt.10m^{-2}) for ichthyofaunal utilisation categories in each reach of Taylor's salt marsh.

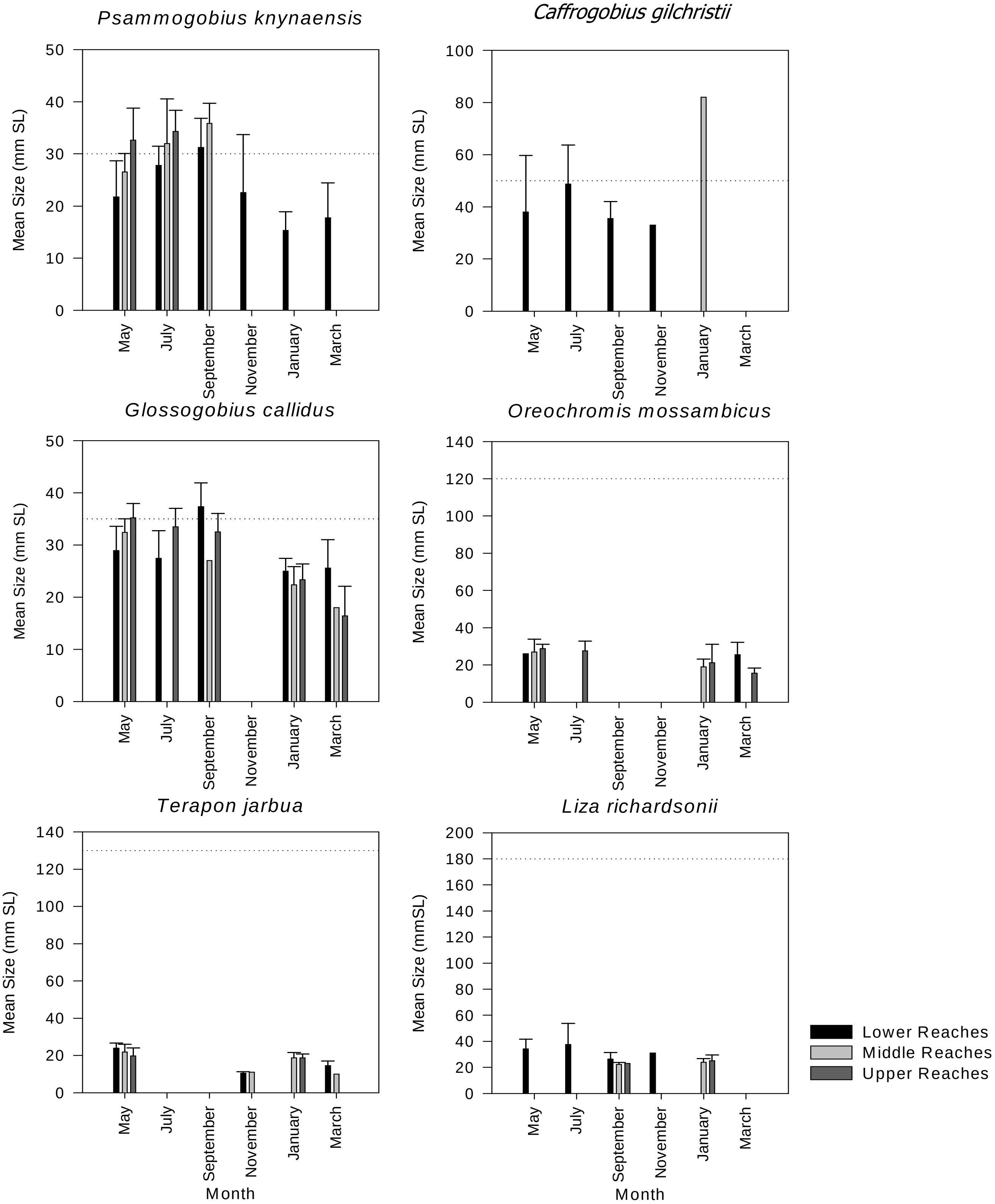


Figure 4.14: Mean monthly size (mm SL ± 1 SD) for various species of fish in different reaches of Taylor's salt marsh. (Data pooled n = 6). Dotted line indicates size at which sexual maturity (mm SL) is obtained. (Size at which sexual maturity is attained was obtained from the literature).

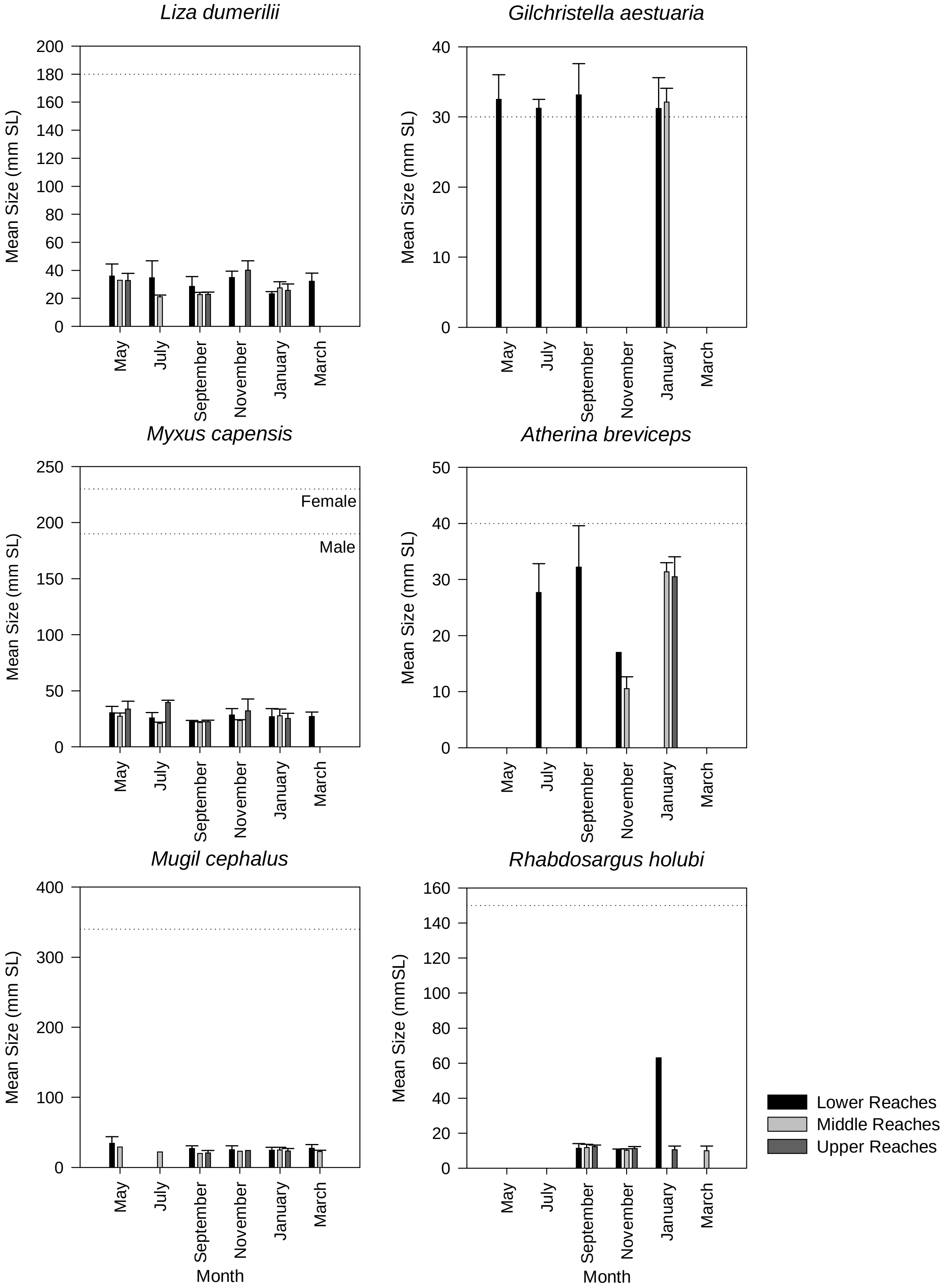


Figure 4.15: Mean monthly size (mm SL ± 1 SD) for various species of fish in different reaches of Taylor's salt marsh (Data pooled n = 6). Dotted line indicates size at which sexual maturity (mm SL) is obtained. (Size at which sexual maturity is attained was obtained from the literature)

4.3.5. Dominance

To determine the relative importance or dominance of each species within each habitat, each species was ranked. The juvenile Mugilidae (<20mm SL) are comprised of a number of different species but for the purposes of this analysis, the group was treated as a 'species'. The ranking formula is set out in Chapter Three.

The top ten species in each reach are listed in Tables 4.11 to 4.13 below. All three reaches of the salt marsh had several ranked species in common including the juvenile Mugilidae (<20mm SL), *Liza dumerilii, Myxus capensis, Psammogobius knysnaensis, Mugil cephalus, Glossogobius callidus* and *Elops machnata.* The rank of each of these species varied in each reach; except for the juvenile Mugilidae (<20mm SL), which topped the list in all reaches of the salt marsh and was the most clearly dominant 'species' by at least one order of magnitude. Three species occurred in the top ten positions for the lower reaches, (*Liza richardsonii* – sixth, *Gilchristella aestuaria* – ninth and *Caffrogobius gilchristii* - tenth) which did not occur in the top ten positions in the middle or lower reaches. *Terapon jarbua, Rhabdosargus holubi* and *Oreochromis mossambicus* ranked within the top ten species for the middle and upper reaches, but did not appear on the list for the lower reaches.

Table 4.11: Top ten species by rank for the lower reaches of Taylor's salt marsh (Data pooled for all dates, n = 6)

Rank	Species	Estuarine Utilisation Category	Abundance (ind.10m^{-2})	Standing stock (g.wwt.10m^{-2})	% of reach total	Frequency of occurrence	Total
1	*Mugilidae <20mm SL*	-	12.63	0.30	72.1%	100%	**14.66**
2	*Liza dumerilii*	IIb	0.60	1.21	3.4%	100%	**2.85**
3	*Myxis capensis*	Vb	0.84	0.29	4.8%	100%	**2.17**
4	*Psammagobius knysnaesis*	Ib	0.88	0.22	5.0%	100%	**2.15**
5	*Mugil cephalus*	IIa	0.48	0.11	2.8%	83%	**1.45**
6	*Liza richardsonii*	IIc	0.23	0.41	1.3%	67%	**1.32**
7	*Glossogobius callidus*	Ib	0.25	0.05	1.4%	83%	**1.15**
8	*Elops machnata*	IIa	0.70	0.01	4.0%	33%	**1.08**
9	*Gilchristella aestuaria*	Ia	0.27	0.07	1.5%	67%	**1.01**
10	*Caffrogobius gillchristii*	Ib	0.07	0.11	0.4%	67%	**0.85**

Table 4.12: Top ten species by rank for the middle reaches of Taylor's salt marsh (Data pooled for all dates, n = 6).

Rank	Species	Estuarine Utilisation Category	Abundance (ind.10m^{-2})	Standing stock (g.wwt.10m^{-2})	% of reach total	Frequency of occurrence	Total
1	*Mugilidae <20mm SL*	-	32.78	0.92	80.6%	100%	**35.51**
2	*Elops machnata*	IIa	3.09	0.14	7.6%	33%	**3.64**
3	*Psammagobius knysnaesis*	Ib	1.18	0.42	2.9%	67%	**2.29**
4	*Terapon jarbua*	IIa	1.21	0.35	3.0%	67%	**2.26**
5	*Myxis capensis*	Vb	0.73	0.23	1.8%	83%	**1.81**
6	*Mugil cephalus*	IIa	0.40	0.08	1.0%	100%	**1.50**
7	*Liza dumerilii*	IIb	0.30	0.32	0.7%	67%	**1.29**
8	*Rhabdosargus holubi*	IIa	0.48	0.03	1.2%	67%	**1.19**
9	*Glossogobius callidus*	Ib	0.11	0.03	0.3%	67%	**0.80**
10	*Oreochromis mossambicus*	IV	0.14	0.06	0.3%	33%	**0.53**

Table 4.13: Top ten species by rank for the upper reaches of Taylor's salt marsh (Data pooled for all dates, n = 6).

Rank	Species	Estuarine Utilisation Category	Abundance (ind.10m^{-2})	Standing stock (g.wwt.10m^{-2})	% of reach total	Frequency of occurrence	Total
1	*Mugilidae <20mm SL*	-	25.89	0.46	64.7%	83%	**27.83**
2	*Elops machnata*	IIa	6.61	0.003	16.5%	50%	**7.28**
3	*Myxus capensis*	Vb	2.08	0.36	5.2%	83%	**3.32**
4	*Liza dumerilii*	IIb	1.36	0.24	3.4%	67%	**2.29**
5	*Oreochromis mossambicus*	Ib	1.12	0.37	2.8%	67%	**2.19**
6	*Mugil cephalus*	IIa	0.97	0.14	2.4%	50%	**1.64**
7	*Glossogobius callidus*	Ib	0.47	0.07	1.2%	83%	**1.38**
8	*Terapon jarbua*	IIa	0.59	0.08	1.5%	33%	**1.02**
9	*Rhabdosargus holubi*	IIa	0.42	0.02	1.1%	50%	**0.96**
10	*Psammagobius knysnaesis*	Ib	0.17	0.07	0.4%	33%	**0.58**

4.3.6. Numerical analysis

An analysis of similarity (ANOSIM) was used to investigate the abundances of different species in each reach of the salt marsh. ANOSIM showed that there were no significant differences (R = 0.012, p = 0.387) in community composition between the different reaches of the salt marsh.

The hierarchical cluster analysis did however, identify three distinct groups of ichthyofauna at the 40% similarity level (Fig 4.18). These were designated as Groups 1 to 3. Group 1 was composed of the middle and upper reaches of the salt marsh in March, which may be due to the lower than expected tide on that sampling trip. Group 1 was broadly composed of the lower and middle reaches winter sampling trips; with the exception of the lower reaches in January and March. Group Two was broadly composed of middle and upper reaches summer sampling trips, with the exception of the middle and upper reaches in May and the upper reaches in September.

The groups observed in the cluster analysis were confirmed using multidimensional scaling. Again, the middle and upper reaches in March formed a group, and Groups 1 and 2 are composed of the same reaches and trips as the cluster analysis (Fig 4.17). A SIMPER analysis showed that dissimilarities between the reaches were due to the relative abundances of different species, and not to the presence or absence of specific species. The most numerically dominant species within each grouping identified by the hierarchical cluster analysis are presented in Table: 4.14 below.

Table 4.14: SIMPER determined contribution of each species (average abundance) to the groups identified in the hierarchical cluster analysis (Primer, Fig 4.16).

Group	**Species**	**Average Abundance (ind 10 m^{-2})**
Group 1	Mugilidae (<20mm SL)	2.11
	Psammogobius knysnaensis	0.15
	Myxus capensis	0.14
	Liza dumerilii	0.10
	Mugil cephalus	0.08
	Glossogobius callidus	0.04
Group 2	Mugilidae (<20mm SL)	5.29
	Myxis capensis	0.12
	Elops machnata	0.50
	Psammogobius knysnaensis	0.19
Group 3	Mugilidae (<20mm SL)	2.74
	Oreochromis mossambicus	0.12
	Myxus capensis	0.22
	Elops machnata	0.70

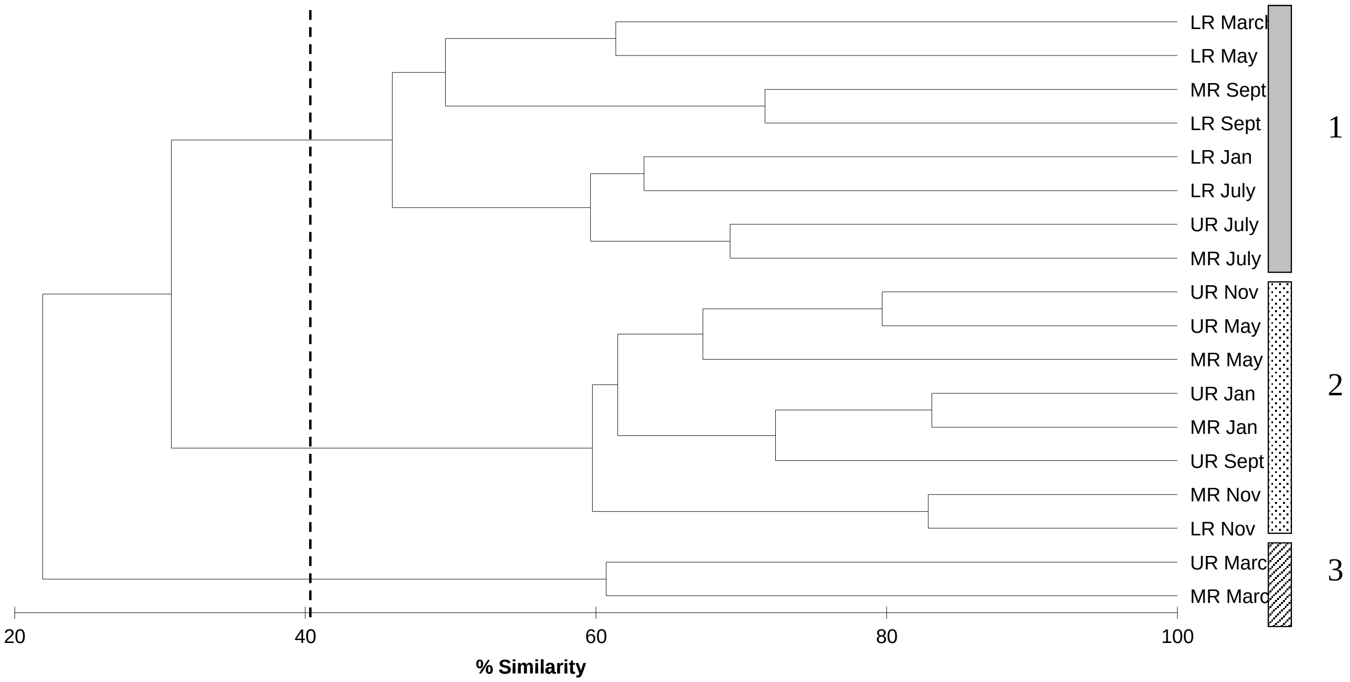


Figure 4.16: Cluster analysis (group linkage) for abundances (ind.10m-2) in each reach of Taylor’s salt marsh. Data was log (x+1) transformed 40% similarity level is indicated. LR – Lower Reaches, MR – Middle Reaches, UR – Upper Reaches.

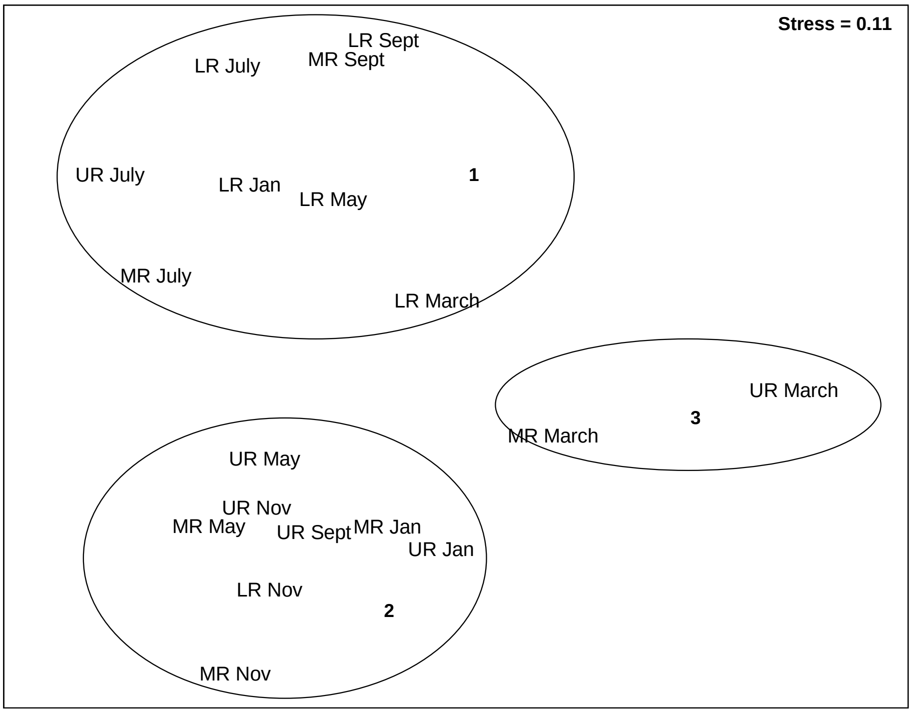


Figure 4.17: Multidimensional scaled (MDS) plot of abundance (ind.10m^{-2}) data for each reach of Taylor's salt marsh. LR – Lower Reaches, MR – Middle Reaches, UR – Upper Reaches. 1,2 and 3 refers to the groups formed in the hierarchical cluster analysis (Fig 4.16).

4.4. Discussion

4.4.1. Physico-chemical and biological variables

Temperature, salinity and dissolved oxygen concentrations

The absence of any significant ($P > 0.05$ in all cases) spatial patterns in selected physico-chemical variables between the different reaches of the salt marsh during this study, suggests that it can be regarded as a single homogenous habitat. Not surprisingly, there were strong seasonal patterns in the selected physico-chemical variables (Figs 4.1 and 4.2). Results obtained during this study are in agreement with the findings of Paterson (1998) and are within the expected range for the geographical region (Harrison 2004). The highest water temperatures were recorded in summer and the lowest in winter. Mean salinities recorded in Taylor's salt marsh during this study (36.5 ± 3.5 psu), were slightly higher than those observed by Paterson (1998; 34.7±0.8 psu). There was also a greater range in salinities in this study, between 33 psu and 46 psu compared to 32 psu and 35 psu recorded by Paterson (1998).

Particulate Organic Matter

Particulate organic matter (POM) is composed of a range of organic matter including suspended detritus, phytoplankton and zooplankton (Froneman 2001; Murphy and Voulgaris, 2006). The estimates of POM concentration recorded during this study are substantially higher than those reported in the channel of the estuary (Grange et al. 2000; Froneman 2001). For example, Grange et al. (2000) recorded concentrations of between 11 $mg.L^{-1}$ and 23 $mg.L^{-1}$, which are substantially lower than the 12.4 $mg.L^{-1}$ to 124 $mg.L^{-1}$ recorded in the current study. The elevated POM concentrations within the salt marsh may be due to the re-suspension of detritus rich sediments as the floodwaters enter the salt marsh.

Chlorophyll-*a* concentration

Few studies have presented data on water column chlorophyll-*a* (chl-*a*) concentrations within salt marsh habitats. The water column chlorophyll-*a* values recorded in the salt marsh during this investigation are comparable to those obtained from the main channel of a variety of estuaries within the same coastal region (Adams and Bate 1999; Grange *et. al.* 2000; Snow *et. al.* 2000Froneman 2004, 2004a). For example, Grange *et. al.* (2000) reported maximum values of 1.0 $\mu g.chl\text{-}a.L^{-1}$ from the Kariega River while Froneman (2004) reported a range of between 0.91 and 5.93 $mg.chl\text{-}a.m^{-3}$ for the Kariega and 0.2 and 3.43 $mg.chl\text{-}a.m^{-3}$ for the temporarily open/closed Kasouga Estuary (Froneman 2004a). It is worth noting however, that the estimates of total chl-*a* concentration during this study are substantially lower than those reported for permanently open estuaries with continuous freshwater inflow. Adams and Bate (1999) recorded values of up to 100 mg.chl-*a*.L^{-1} in the Sunday's River Estuary and up to 210 mg.chl-*a*.L^{-1} in the Great Fish Estuary. The reduced chl-*a* concentrations recorded in the Kariega Estuary are typical of freshwater deprived estuaries and reflects the low macronutrient availability within these systems (Whitfield 2005). The strong temporal pattern observed in chl-*a* concentration within the salt marsh during this study is similar to those observed by Froneman (2004) and Thomas et al. (2005) and can be related to the effect of water temperature of the growth rates of the phytoplankton (Froneman 2001).

Microphytobenthic algae

Microphytobenthic algae, have long been acknowledged to be an important source of primary productivity in coastal food webs (Sullivan and Moncreiff 1990; MacIntyre *et. al.* 1996; Adams *et. al.* 1999; Nozais *et. al.* 2001; Perissinotto *et. al.* 2002). Additionally, microphytobethic algae represent an important carbon source for numerous small grazers including amphipods, isopods, shrimp and fish, especially the mugilids (Bishop and Miglarses 1978, Whitfield and Marais 1999). Typically, microphytobenthic chlorophyll-*a* concentrations are one to two orders of magnitude greater than the water column chlorophyll-*a* concentrations (Perissinotto *et al*. 2002). Lukey (2006) found that microphytobenthic values were lowest in summer after the onset of summer rains, possibly due to the increased turbidity of the system and re-suspension of sediments. At this time there was also an increase in water column chlorophyll-*a* concentrations due to the increased availability of nutrients from the freshwater inflow (Lukey 2006). Perissinotto *et. al.* (2002) and Nozias *et. al.* (2001) found similar patterns in the temporarily open/closed (TOC) Mpenjati and Mdloti Estuaries (south coast) where microphytobenthic algae concentrations increased when the estuary breached due to increased rainfall.

Microphytobenthic algae concentrations tend to be higher in temporarily open/closed (TOC) systems than in permanently open estuaries (Nozais *et. al.* 2001). It is thought that the reduced amount of mixing in TOC estuaries results in increased light penetration, and allows phytoplankton to settle out of the water column resulting in high benthic readings (Nozais *et. al.* 2001). Perissinotto *et. al.* (2002) recorded values of between 10.9 µg.cm^{-2} and 27 µg.cm^{-2} in the temporarily open/closed (TOC) Mpenjati Estuary in KwaZulu Natal while Lukey (2006) recorded values of between 0.38 µg.cm^{-2} and 14.6 µg.cm^{-2} in the TOC Grant's Valley Estuary.

The high microphytobenthic algal concentrations observed in the current study may be due to several factors. Perissinotto *et. al.* (2002) suggested that the microphytobenthic algal concentrations may be increased due to settling of pelagic phytoplankton due to the low degree of mixing in stagnant TOC estuaries. Although the current within the channel of Taylor's salt marsh is relatively strong during the flooding and ebbing phases (pers. obs.), the water covering the inter-tidal flat areas does not appear to demonstrate much mixing which may contribute to larger diatoms settling out onto the sediments. In addition the sediments of Taylor's marsh are composed mainly of clay, which is not easily re-suspended (Nozais *et. al.* 2001). The re-suspension of fine sediments increases the turbidity of water, which in turn limits light penetration and decreases epiphytic productivity (Nozias *et. al.* 2001, MacIntyre *et. al.* 1996). Microphytobenthic algal concentrations are usually higher on muddy sediments than on sandy sediments (Nozais *et. al.* 2001, Adams *et. al.* 1999). Also, it has been suggested that the consistently higher microphytobenthic algae concentrations relative to water column chlorophyll-*a* concentrations may be due to the relatively short residence time of water in the estuary (Perissinotto *et. al.* 2002). This could be especially true of a tidally dominated estuary such as the Kariega Estuary. The pelagic phytoplankton does not remain in the estuary, or in this case, the salt marsh creek, long enough to take advantage of the increased nutrient availability and hence there is a negligible increase in water column chlorophyll-*a* concentration (Perissinotto *et. al.* 2002). Microphytobenthic algae gather nutrients from the surrounding sediments and so are not affected by short water residence times (MacIntyre *et. al.* 1996).

Given the importance of microalgae for a number of different grazers, especially the mugilid fish (Whitfield and Marais 1999), it is possible that POM and water column chlorophyll-*a* concentrations are not as important as a food resource as microphytobenthic algae due to the extremely high microphytobenthic chlorophyll-*a* concentrations recorded in the salt marsh. The high concentrations recorded, coupled with the seasonality observed, suggest that this is an area of increased food availability and therefore is an important habitat within the estuary.

4.4.2. Ichthyofauna abundance and biomass

The estimates of total ichthyofaunal abundance (0.65 – 12.2 ind.10m^{-2}) and biomass (0.04 - 4.53 g.10m^{-2}) recorded during this study are within the lower range recorded by Paterson (1998) (abundance: 1.8 – 27.1 ind.10m^{-2}, standing stock: 4.0 – 86.0 g.10m^{-2}) within the same salt marsh. Although the estimates obtained here are lower than that reported for a number of international studies (see Table 4.15), it is difficult to quantify and compare the values obtained here with other studies largely due to the wide variety of sampling regimes and gear types employed. The geographic location, structure, complexity and size of the salt marsh studied all contribute to the disparities in the results. International studies, especially in North America, have generally been conducted on much larger marshes and the data presented are not generally quantitative, or presents only the values for the most commercially important or most abundant species. Interestingly, estimates of fish abundance and biomass presented here fall within the range reported for Australian salt marsh systems (e.g. Bell *et. al.* 1984 and Longeraan *et. al.* 1986). The observed pattern can possibly be attributed to the fact that both Australian and South African salt marshes are only periodically inundated thus limiting access of the fish into these systems. As with Paterson's (1998) study, there were no significant differences in abundance between the different reaches of the salt marsh in this study. The absence of any distinct spatial pattern can likely be attributed to the fact that the salt marsh can be considered as a single homogenous habitat (see above).

Table 4.15: Ichthyofaunal abundance values recorded in this study compared to other studies in various estuarine habitats.

Reference	**Physical Environment**	**Location**	**Coordinates**	**Abundance (ind.10m^{-2})**	**Standing Stock (g.10m^{-2})**
This study	Intertidal salt marsh creek (Taylor's)	Kariega River, South Africa	31° 55'0 S, 20°34'0 E	4.17	1.10
Paterson (1998)	Intertidal salt marsh creek (Taylor's)	Kariega River, South Africa	31° 55'0 S, 20°34'0 E	15	24
Minello et. al. (1994)	Salt marsh creek	Galveston Bay, USA	29°57'0 N, 94°93'0 W	170 – 1530	-
Chamberlain and Barnhart (1993)	Mitigation salt marsh	Humboldt Bay, USA	40°45'13 N, 124°12'73°W	17	-
Bell *et. al.* (1984)	Mangrove creek	Botany Bay, Australia	33°58'0 S, 151°10'0 E	9	64
Loneragan *et. al.* (1986)	Estuarine shallows	Peel-Harvey Estuary, Australia	32°36'19 S, 115°38'24 E	0.2 – 5	1 – 42
Ter Morshuizen and Whitfield (1994)	Eelgrass	Kariega River, South Africa	31° 55'0 S, 20°34'0 E	129	

4.4.3. Reproductive status and dominance

The ichthyofauna along the Eastern Cape coastline demonstrates a prolonged recruitment period that peaks in late spring and early summer (Whitfield and Marais 1999). The observed pattern reflects the extended breeding season, which is thought to be an adaptation to the unpredictability of the opening of TOC estuaries that numerically dominate along this section of the coastline (Whitfield and Marais, 1999). Recruitment into the few permanently open estuaries such as the Kariega Estuary is therefore, extended. This pattern is evident from the predominance of juveniles in all reaches of the salt marsh throughout the duration of the study. Nonetheless, a minor peak in recruitment (i.e. higher abundances and low standing stocks) was evident in November and to a lesser extent in March (Fig 4.5 and 4.6).

Following recruitment, it is thought that larval fish are retained in estuaries by immigrating on the flood tide and the rapidly settling where water current velocities are reduced (Whitfield and Marais 1999). Areas of reduced current velocity include areas of submerged aquatic vegetation such as beds of *Zostera capensis* and salt marshes. Un-vegetated areas within estuaries have lower ichthyofaunal abundance and standing stock values than vegetated areas (Beckley 1983). Areas of submerged aquatic vegetation provide cover from predation as well as food in the form of detritus and epiphytic organisms (Beckley 1983, Hanekom and Baird 1984, Connolly 1994, Ter Morshuizen and Whitfield 1994) resulting in higher abundances and standing stocks. Juveniles remain in suitable habitats until they are able to move back into the marine environment (Whitfield and Marais 1999). The clear numerical dominance of the juveniles, particularly the Mugilidae, within the fish assemblage of the salt marsh suggests that this habitat is especially important nursery area for estuarine fish.

Of the ten ranked species, only one piscivorous fish, *Elops machnata*, was caught in the salt marsh throughout the study. However, the largest specimen of this species was 27mm SL and this species may have been using the salt marsh to avoid predation by conspecifics, or it may have been washed into the salt marsh passively, on the flood tide. The remaining species were all detritovores or herbivores. The estuarine resident species *Glossogobius callidus* and *Psammogobius knysnaensis* were recorded in the salt marsh but neither species occurred at especially high densities or standing stocks.

Terapon jarbua and *Oreochromis mossambicus* are both present in the salt marsh on a highly seasonal basis. These species may utilise the salt marsh as a refuge from predation, which they might experience in the eelgrass beds. *Gilchristella aestuaria* and *Caffrogobius gilchristii* also appear to use the salt marsh as a nursery or spawning area, however these species seem to be more important in terms of dominance in the lower reaches of the salt marsh. *Gilchristella aestuaria* and *Caffrogobius gilchristii* are often associated with eelgrass beds and may not stray too far from their preferred habitat (Paterson 1998). *Terapon jarbua* was important in the middle and upper reaches but did not appear in the top-ten list in the lower reaches. Again, the presence of this species was highly seasonal and the overall small size suggests that the salt marsh performs an important nursery function. This species also feeds on benthic algae and hence may prefer the middle and upper reaches of the salt marsh where food is abundant and predation pressures are lower. *Rhabdosargus holubi* was ranked eighth and ninth in the middle and upper reaches respectively and it also appeared seasonally within the salt marsh, similar to *Oreochromis mossambicus* although *O. mossambicus* appeared to favour the upper reaches of the salt marsh. Both of these species have also been recorded in high numbers within the main estuarine environment (Whitfield 1999) although not in this study.

Psammogobius knysnaensis, and *Glossogobius callidus* both appeared to be important throughout the salt marsh. These two species are estuarine resident species and therefore probably utilise the salt marsh as a habitat within the estuary as opposed to a nursery area specifically.

4.4.4. Community composition

Nineteen species of fish, belonging to ten families, were recorded in the salt marsh during this investigation. This is less than the 25 species recorded by Paterson (1998) within the salt marsh over a period of two years. During summer, a large number of species spawn and recruit into estuarine habitats, including salt marshes (Whitfield 1998). Any intensive sampling strategy that is conducted over a long period will therefore likely result in a greater number of species being detected. Despite the differences number of species collected, the domiant taxa during the two studies are similar. Juvenile Mugilidae (<20mm SL) were dominant in both studies, contributing 74.2% and 52.9% respectively, of all individuals caught within the salt marsh. *Liza dumerilii* (20% and 2.3%), *Psammogobius knysnaensis* (10% and 3.2%) and *Mugil cephalus* (1.0% and 1.9%) were also numerically important in both studies. The dominance of various species of Mugilidae, especially the juveniles, suggests that this family of fish is able to exploit this habitat successfully. Mugilidae are in general, euryhaline and able to tolerate wide fluctuations in water temperature and salinity (Whitfield 1998). Shallow water habitats such as salt marshes are often characterised by diel fluctuations in temperature. In addition, Mugilidae are also dorso-ventrally flattened allowing them to persist in shallow waters as opposed to deep-bodied fish (e.g. *Rhabdosargus holubi*), which are restricted to deeper waters. Finally, the numerical dominance of mullet in the salt marsh may be related to the high concentrations of microphytobenthic algae that are important food source for juvenile mullet (Masson and Marais 1975, Bishop and Miglarese 1978, Whitfield 1988, Whitfield and Marais 1999; Adams *et. al.* 1999). While other species, such as *Atherina breviceps* and *Gilchristella aestuaria* have been shown to be numerically dominant within estuaries (Strydom *et. al.* 2002) their contribution to the total fish counts was low, generally accounting for < 2% of total counts. The virtual absence of these species from the marsh may be related to food availability since both *A. breviceps* and *G. aestuaria* are zooplanktivorous (Strydom *et. al.* 2002). Mugilidae on the other hand, especially the juveniles, feed mainly on microphytobenthic algae.

Studies on the ichthyofaunal assemblages within South African estuaries have demonstrated that the community is usually numerically dominated by estuarine resident species (category I), followed by the estuarine dependent species (category II) (Whitfield 1999). In agreement with the study by Paterson (1998), during this study the total ichthyofauna community was numerically (62% of the total) and by biomass (86% of the total) dominated by estuarine dependent (category II) species. Category II species tend to be euryhaline and are able to tolerate a wide range of salinities, as well as periods of hypersaline (>35 psu) conditions (Whitfield 1998). Additionally, these species tend to be highly mobile, allowing them to follow to move to areas of more favourable conditions. Euryhaline species are therefore able to effectively utilise estuaries that often have short periods of stable favourable conditions and long periods of unfavourable conditions, due to their life history characteristics (Whitfield 1998; Whitfield and Marais 1999). However, due to the large adult body size of many of these species (for example *Rhabdosargus holubi*), many are restricted to the deeper waters of the channel. Shallow habitats, such as salt marshes are only utilised while individuals are small enough to swim into the habitat. The high abundances but low biomass contributions to the totals within the salt marsh of this group supports this, explaining the dominance of juveniles in this category and the absence of adults.

In agreement with the study by Paterson (1998), category I (estuarine resident species) species were the second most numerically dominant fish group in the salt marsh during the study. Estuarine resident species tend to be stenohaline and are characterised by small adult body size, a more or less sedentary lifestyle and a limited tolerance for changes in abiotic factors, especially salinity (Whitfield 1998; Whitfield and Marais 1999). The relatively low contribution of the estuarine resident species in the salt marsh may reflect the high variability in temperature and salinity that characterise shallow water environments such as salt marshes. Finally, the high relatively high abundance and low biomass contribution to the total of this category in the salt marsh reflects the small adult body size of these individuals, but it is also possible that a greater proportion of juveniles utilise the salt marsh creek in order to avoid competition for resources with adult individuals.

The remaining estuarine utilisation categories were present in catches, but seldom contributed significantly to either the abundance or standing stock. The hyper-saline nature of this estuary, coupled with the fact that the salt marsh occurs relatively close to the mouth of the estuary may account for the low representation of freshwater species to the total fish counts in the salt marsh. It is worth noting that the proportions of each category recorded in the salt marsh during this study are also similar to the overall proportions of estuarine utilisation categories for all species of fish recorded in South Africa (Whitfield 1998). Of the 155 estuarine associated fish taxa recorded in South Africa, it is estimated that 66% belong to Categories I and II. Taylor’s salt marsh is used by all categories of fish with the exception of category Ic and Va. Table 4.5.1 compares the estuarine utilisation category proportions recorded by Paterson (1998) to this study.

Results of the numerical analyses indicated that there were no significant spatial patterns in the fish community structure with the Taylor's salt marsh. The absence of any significant spatial differences in fish community structure can likely be ascribed to the homogeneity of the physico-chemical variables in the salt marsh. Changes in the fish community were associated with changes in the numerical dominance of different species, which can be linked to the seasonal breeding cycles of individual species and their recruitment into estuaries. The numerical analyses did, however, highlight the importance of hydrodynamics in structuring the fish assemblage within the system. The numerical analyses identified a distinct fish assemblage, designated Group 3, within the upper and middle reaches of the salt marsh during the March survey when the salt marsh did not flood entirely. The distinction of this grouping from the remaining groups was largely attributed to the low abundances and biomass of fish within the two reaches of the Taylor's salt marsh.

The absence of submerged aquatic vegetation, and shallow clear water within the salt marsh creek suggests that this habitat would be ideal for piscivorous fish, which, in general, prefer open waters (Whitfield and Marais 1999). However, in both the current and Paterson's (1998) study, very low abundances of piscivorous fish were recorded within the salt marsh creeks. The only species of piscivorous fish recorded in the salt marsh creek during the current investigation was *Elops machnata*. While this species was the second most abundant species recorded throughout the study, it is unlikely that it would pose a predation threat as all individuals captured were less than 27 mm SL. In Paterson's (1998) study, the piscivorous fish species *E. machnata* and *Galeichthys feliceps* were recorded, but again at low densities. In a similar study by Paterson and Whitfield (2000), very few piscivorous fish were found either, within Galpin's salt marsh, which is upstream of Taylor's salt marsh in the Kariega River, or in the shallow water areas adjacent to the salt marsh. It has been suggested that, despite the un-vegetated nature of the creek and apparent suitability of the creek for piscivorous fish, unfavourable conditions within the salt marsh including high temperatures, salinities and shallow water which decreases foraging efficiency, renders this habitat unsuitable for piscivorous fish (Rozas and Odum 1987, Paterson and Whitfield 2000). The shallow water may also increases the susceptibility of the fish themselves to predation by other predators such as piscivorous birds (Paterson 1998). The low density and small size of piscivorous fish within the salt marsh creek suggests that ichthyofaunal predation pressure within the salt marsh is reduced. The reduced predation pressure, shallow water and high food availability, within the salt marsh may all be important factors in structuring the ichthyofaunal community; specifically the suitability of the salt marsh as a nursery area.

4.5. Conclusions

Results of the study indicate that the Taylor’s salt marsh was characterised by the virtual absence of any significant spatial and temporal patterns in selected physico-chemical and biological variables during the study. Seasonal patterns in the selected variables were, however, evident. The predominance of juveniles within the salt marsh, particularly Mugilidae, suggests that it represents an important nursery area within the Kariega Estuary. Overall, the main findings of this study are generally in agreement with the study of Paterson (1998) which was conducted in the same salt marsh ten year prior to this study.

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Chapter 5.

Salt Marsh and Eelgrass Habitats

This chapter presents the main findings of a comparative study between the fish assemblages of the Taylor's salt marsh and the adjacent eelgrass. Salt marsh habitat data was obtained by pooling the data (previous chapter) from all reaches of the salt marsh. Ichthyofaunal community composition and structures in each habitat are described and compared.

5.1. Physico-chemical and biological results

Temperature, salinity and dissolved oxygen

The mean water temperature in the marsh was 19°C and 18.8°C in the eelgrass beds. Salinity values within the salt marsh and eelgrass beds ranged from 33 to 41 (mean 35.3 ± 3.5) and from 33 to 43 (mean 36.9± 3.3), respectively (Table 5.1). Finally dissolved oxygen concentrations in the slat marsh ranged from 4.2 to 5.3 mg O_2 L^{-1} There were no significant differences in selected physico-chemical variables between the two habitats ($F_{1,\ 22}$ = 0.03, p>0.05). For both habitats there was a significant difference between summer and winter temperatures (p<0.01 for both). The results for the whole study period have therefore have been summarised in Table 5.1.

Table 5.1: Summary of the recorded range (min – max) and mean (± SD), for the whole study period, of various physico-chemical parameters in the salt marsh (data pooled n = 18) and the estuary (data pooled, n = 6).

Parameter	Estuary	Salt Marsh
Temperature (°C)	14.9 – 23.7 19.0 ± 3.4	14.8 – 24.5 18.8 ± 3.6
Salinity (psu)	33 – 41 35.3 ± 3.5	33 – 43 36.9 ± 3.3
Dissolved oxygen concentration ($mg.O_2.L^{-1}$)	4.8 – 6.1 5.4 ± 0.5	4.2 – 5.3 4.7 ± 0.35

Chlorophyll-*a* and POM

The values for the biological parameters for each sampling trip are the mean (±1 SD) after the data for all three reaches of the salt marsh was pooled (n = 9). The mean particulate organic matter (POM) and water column chlorophyll-*a* concentration values, for both the salt marsh and the estuarine habitats, fell within the expected ranges for the region (Harrison 2004). There were no significant differences in chlorophyll-*a* ($F_{1, 70} = 0.05$, $p>0.05$) or POM concentration ($F_{1, 70} = 3.83$, $p>0.05$) between the different habitats. Within the estuarine eelgrass habitat, there was no significant difference in chlorophyll-*a* ($F_{1, 16} = 0.74$, $p>0.05$) or POM ($F_{1, 16} = 0.08$, $p>0.05$) concentrations between summer and winter values. However, there were significant differences in chlorophyll-*a* between different sampling trips ($F_{5, 12} = 5.29$, $p<0.01$). May, September and November were shown to be separate from the other sampling trips. Significant differences within the salt marsh habitat have already been discussed in Chapter Four. The data for the duration of the study period is summarised in Table 5.2 below.

Table 5.2: Summary of the recorded range (min – max) and mean (± 1 SD), for the whole study period, for particulate organic matter ($g.L^{-1}$) and chlorophyll-*a* concentration ($\mu g.chl\text{-}a.L^{-1}$) in the salt marsh (data pooled, n = 54) and estuarine eelgrass habitat (data pooled, n = 18).

Parameter	Estuary	Salt Marsh
Particulate organic matter ($g.L^{-1}$)	0.02 - 0.07 0.04 ± 0.01	0.01 - 0.1 0.05 ± 0.03
Chlorophyll-*a* concentration ($\mu g.chl\text{-}a.L^{-1}$)	0.02 - 5.9 2.8 ± 1.8	0.2 - 9.2 3.0 ± 2.7

Microphytobenthic algae

Unfortunately due to logistical problems, no microphytobenthic algae samples were collected from the estuarine eelgrass beds during the sampling trip conducted in May. In the salt marsh, data from each reach was pooled (n = 6) to give a range of 183.04 – 6957.6 $\mu g.chl\text{-}a.cm^{-2}$ (mean 2695.9 ±1825.5 $\mu g.chl\text{-}a.cm^{-2}$) while in the estuary, the values varied from 676.0 - 7082.4 $\mu g.chl\text{-}a.cm^{-2}$ (mean = 3460.5 ± 1770.1 $\mu g.chl\text{-}a.cm^{-3}$). Once again, there were no significant differences in microphytobenthic chlorophyll-*a* concentration between the two habitats ($F_{1, 113} = 3.47$, $p>0.05$). Within the estuary there were significant differences between all sampled months ($F_{5, 24} = 23.69$, $p<0.0001$) but not between seasons ($F_{1, 28} = 0.36$; $p>0.05$). Within the salt marsh, there were significant differences between the months ($F_{5, 84} = 9.87$, $p<0.0001$).

5.2. Ichthyofaunal results

5.2.1. Abundance and biomass

A total of 623 individuals were caught in the eelgrass beds while 9011 individuals were caught in the salt marsh creek during the study. Total fish abundances ranged between 8.4 and

49.4 ind.10m^{-2} in the estuarine eelgrass beds and between 0.65 and 12.2 ind.10m^{-2} for the salt marsh. The highest abundances in both the salt marsh and the estuarine eelgrass beds were recorded in November (Fig. 5.1). In the salt marsh, the lowest abundances were recorded in midwinter (July), while in the estuarine eelgrass beds, the lowest abundances were recorded in summer (January, Fig 5.1). Abundance data for the salt marsh was pooled for all reaches (n = 3). There were no significant differences in abundances between sampling months within the salt marsh ($F_{5, 12} = 2.48$; $p>0.05$). When ichthyofaunal abundance data from each habitat was pooled for the duration of the study, it was found that there was a significant difference ($F_{1, 22} = 16.52$, $p<0.001$; Fig 5.2) between the two habitats.

The total biomass of fish caught in the eelgrass beds in the estuary was 1.16 kg.wwt (range: 14.46 – 472.26 g.wwt) with a mean of 192.86 ± 185.23 g.wwt. The mean standing stock of fish caught in the eelgrass was 38.57 ± 37.05 g.wwt.10m^{-2}. The estuary had standing stock values approximately one order of magnitude greater than the salt marsh (Fig 5.3). The total biomass of fish caught in the salt marsh was 0.96 kg.wwt (range: 15.50 – 467.2 g.wwt) with a mean of 159.6 ± 164.7 g.wwt. This is equivalent to a mean standing stock of 0.44 ± 0.46 g.wwt.10m^{-2}. The greatest recorded biomass occurred in November in the estuary and in May in the salt marsh. Total biomass of ichthyofauna within the eelgrass beds were significantly higher than in the salt marsh ($F_{1, 22} = 19.52$; $p<0.01$, Fig 5.4) although but there were no significant differences between different dates in either habitat ($p>0.05$ for both.) Abundance and standing stock values for each habitat are summarised in Tables 5.3 and 5.4.

Table 5.3: Mean abundance (ind.10m^{-2}) and standing stock (g.wwt.10m^{-2}) of ichthyofauna for the salt marsh and estuarine eelgrass habitats (data pooled, n = 6) for the whole study period. (Mean ± 1 standard deviation).

Habitat	Abundance (ind.10m^{-2})	Standing Stock (g.wwt.10m^{-2})
Estuary	20.8 ± 15.0	38.56 ± 37.1
Salt marsh	4.2 ± 4.1	0.4 ± 0.5

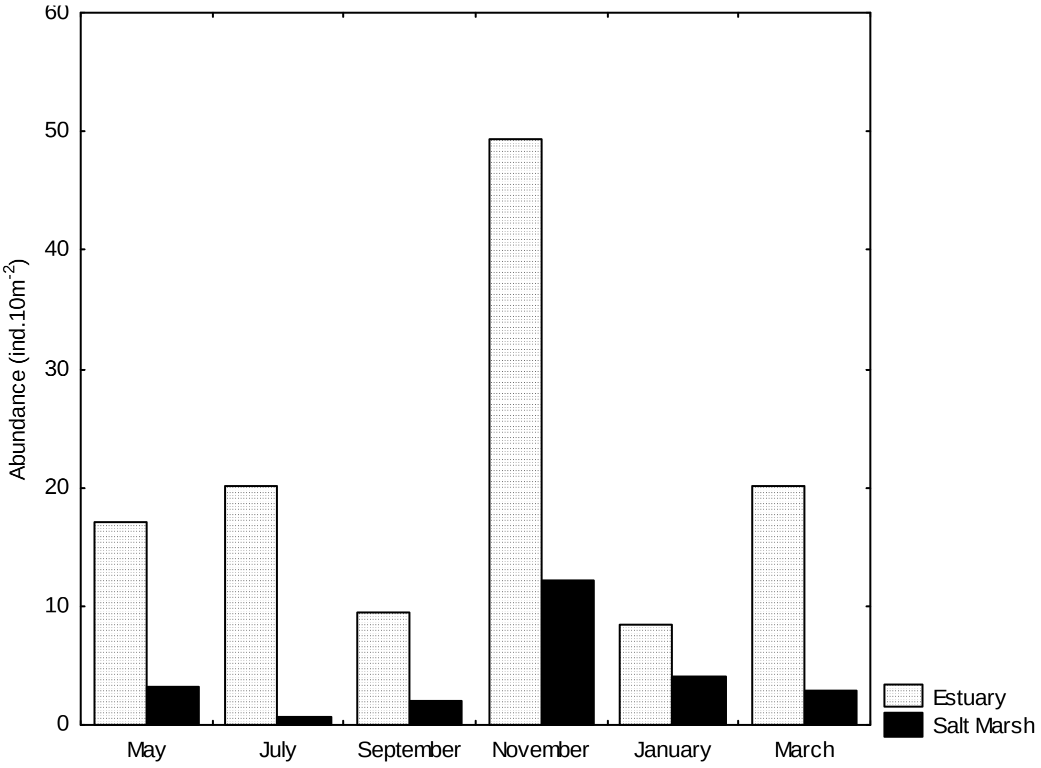


Figure 5.1: Monthly abundance (ind.10m^{-2}) recorded for the salt marsh (n = 3) and the estuarine habitats.

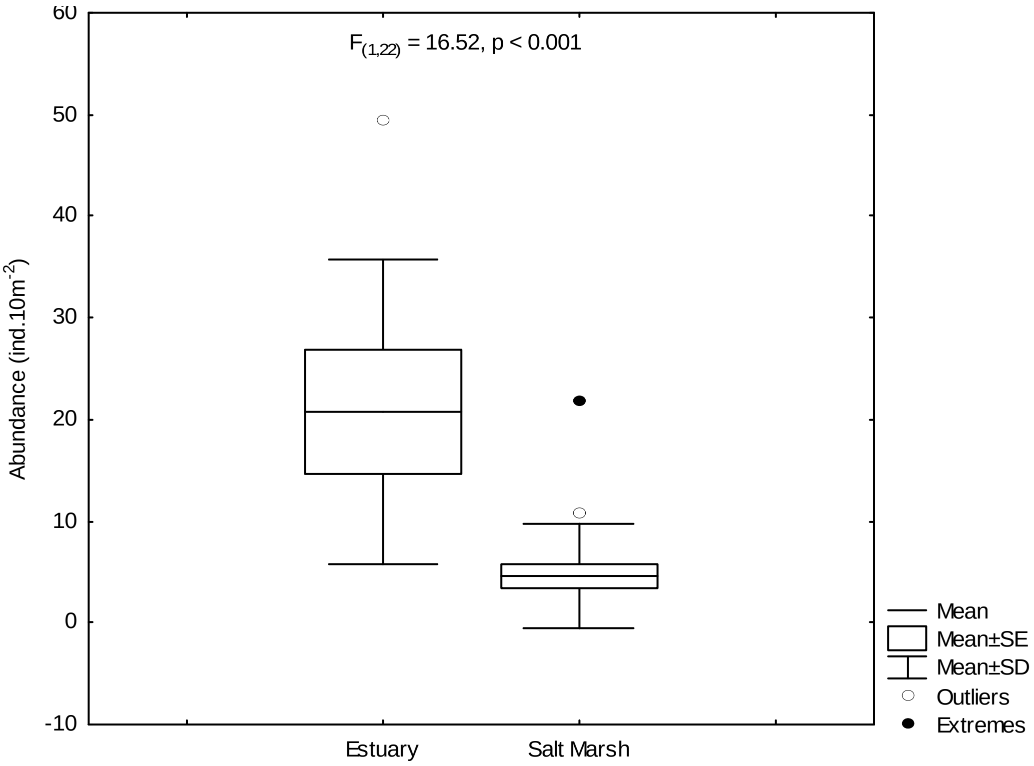


Figure 5.2: Abundance (ind.10m^{-2}) for the estuarine and salt marsh habitats for the entire study period. Data pooled (n = 6) for each habitat.

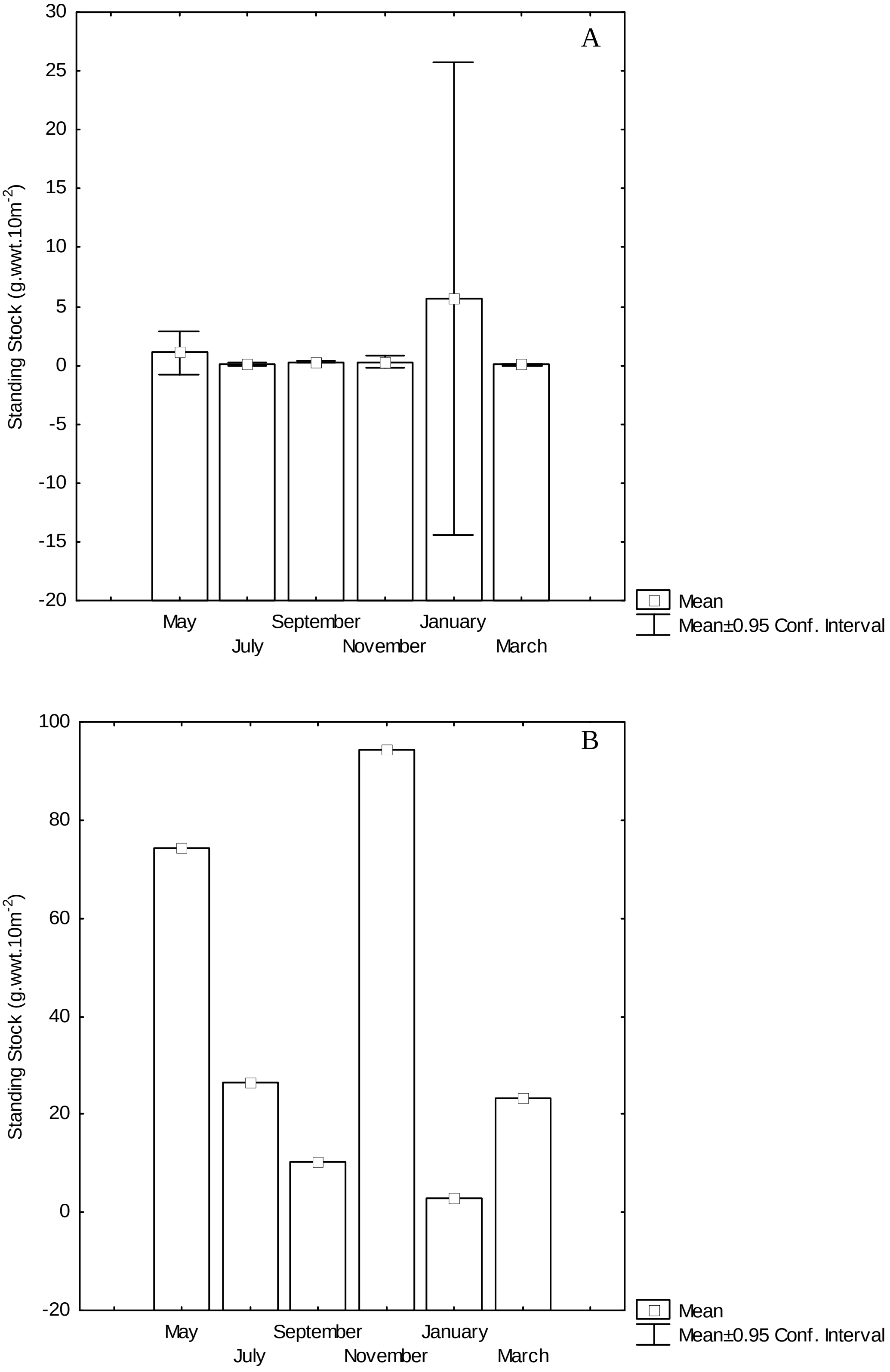


Figure 5.3: Monthly recorded standing stock ($g.wwt.10m^{-2}$) for the salt marsh (A) (n = 3; mean ± 1 SD) and the eelgrass habitats (B).

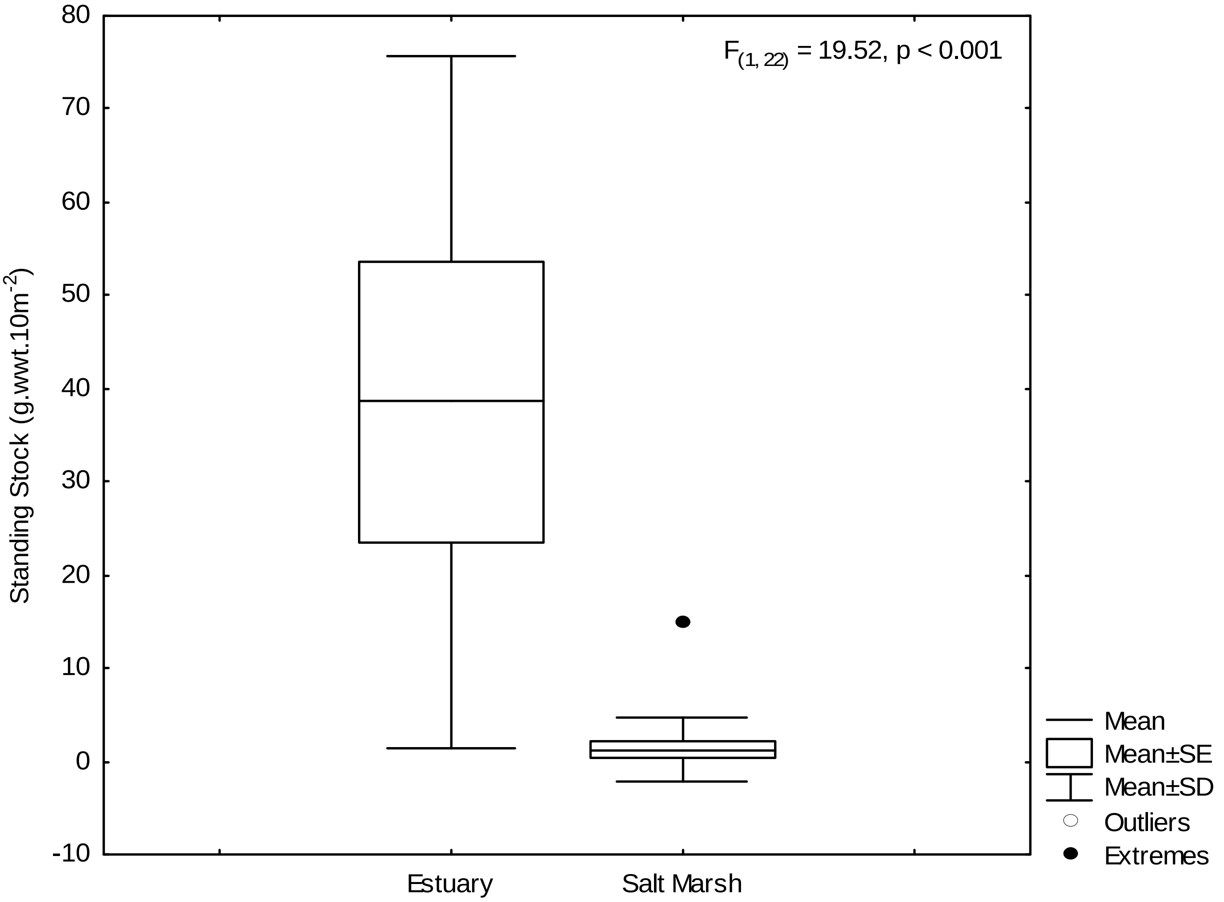


Figure 5.4: Standing stock (g.wwt.10m^{-2}) for the estuarine and salt marsh habitats for the entire study period. (Data pooled, n = 6 for eelgrass and n = 18 for salt marsh).

5.2.2. Community composition.

A total of 28 fish species were recorded from both habitats. Twenty species were caught in the estuarine eelgrass beds while 19 species were caught in the salt marsh over the duration of the study. Ten species were common to both habitats; eight were recorded only in the salt marsh and nine were restricted to the eelgrass beds (Table 5.5).

Three diversity indices; Margalef's species richness index (d), Pielou's evenness index (J') and Shannon-Weiner's Diversity index (H'), were calculated (Peet 1974) for each habitat on a monthly basis, as well as over the entire study period (data was pooled, n = 6). These were used to compare the community composition between habitats. The Shannon-Weiner and Pielou's indexes both showed that the estuarine habitat was more diverse with a higher degree of evenness than the salt marsh although the Margalef's index values were similar for both habitats (d = 2.95 verses d = 2.92 in the salt marsh; Fig 5.5). However, when looking at the estuary and all reaches of the salt marsh, there is a very strong decrease in diversity and evenness moving from the estuary towards the upper reaches of the salt marsh.

Within the estuarine eelgrass habitat, Margalef’s index values were highest in November and March (d = 1.81 and 3.03, respectively) and lowest in January (d = 1.07). The remainder of the study period showed high variability for all diversity indices (Fig 5.6). There were high degrees of evenness in May, September and March (J’ = 0.84, 0.82 and 0.81 respectively) but low degrees of evenness in all other months. The Shannon-Weiner index also showed variable results. However all three indices show very low diversity in January 2007 (J’ = 0.58, H’ = 0.94, d = 1.07) and highest diversity in March 2007 (J’ = 0.81, H’ = 2.19, d = 3.03). These results are summarised in Table 5.6.

In the salt marsh all three diversity indices show a moderate degree of diversity at the start of the study (May, July and September 2006, Fig 5.7, Table 5.7) but the lowest diversity and evenness values were observed in November 2006 (d = 1.31, H’ = 0.17, J’ = 0.07). The Shannon-Weiner and Pielou’s indices increase again in January and March 2007 to similar levels to the start of the study period. Margalef’s index shows a return to previous levels in January 2007 but then decreases dramatically again in March 2007. This may indicate some recruitment of species into the salt marsh from the adjacent estuarine areas. The low value for Margalef’s index in March 2007 may be due to a lower than expected tide which did not flood the salt marsh properly. As a result, very few individuals from very few species were caught in the salt marsh; especially the upper reaches of the salt marsh, contributing to the anomalous result in March.

Table 5.5: Fish species and their estuarine utilisation category (after Whitfield 1998) recorded for the salt marsh and the estuary throughout the study.

Scientific name	Common Name	Estuarine Utilisation Category	Estuary	Lower Reaches	Middle Reaches	Upper Reaches
Psammagobius knysnaesis	Knysna Sand Goby	Ib	X	X	X	X
Glossogobius callidus	River Goby	Ib	X	X	X	X
Caffragobius gillchristii	Prison Goby	Ib	X	X	X	
Caffragobius nudiceps	Barehead Goby	Ib	X	X		
Terapon jarbua	Thornfish	IIa	X	X	X	X
Oreochromis mossambicus	Mozambique Tilapia	IV	X	X	X	X
Liza richardsonii	Southern Mullet	IIc		X	X	X
Liza dumerilii	Groovy Mullet	IIb		X	X	X
Myxus capensis	Freshwater Mullet	Vb		X	X	X
Mugil cephalus	Flat-head Mullet	IIa		X	X	X
Liza tricuspidens	Striped Mullet	IIb				X
Gilchristella aestuaria	Estuarine Round-herring	Ia	X	X	X	
Atherina breviceps	Cape Silverside	Ib	X	X	X	X
Arothron hispidus	Whitespotted Blaasop	III	X	X		
Heteromycteris capensis	Cape Sole	IIb		X		
Mugilidae <20mm SL	Juvenile Mullet	Multiple	X	X	X	X
Clinus superciliosus	Super Klipfish	IIb	X			
Synganathus acus	Long-nosed pipefish	Ib	X			
Rhabdosargus holubi	Cape Stumpnose	IIa	X	X	X	X
Caffrogobius saldanah	Commafin goby	Unknown (I?)	X			
Diplo sargus capensis	Blacktail	IIc	X			
Elops machnata	Ladyfish/ Springer	IIa		X	X	X
Monodactylus falsiformis	Mooney	IIa				X
Fistularia commersonii	Flute nose	III	X			
Argyrosomus japonicus	Dusky Kob	IIa	X			
Diplodus cervinus hottentotus	Zebra	III	X			
Caragoides ferdau	Blue Kingfish	Unknown (III?)	X			
Lutjanus argentimaculatus	River snapper	IIc	X			

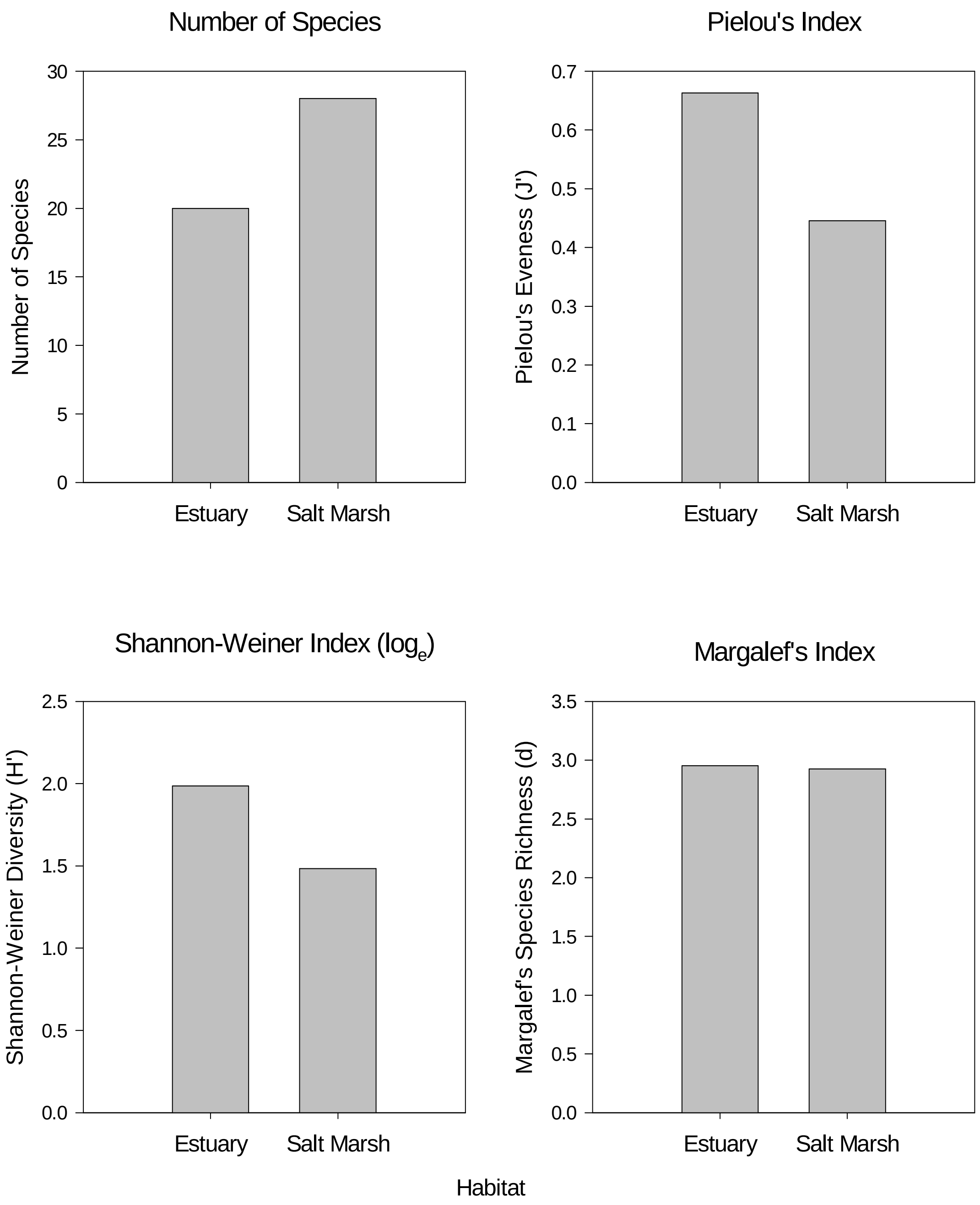


Figure 5.5: Number of species caught and diversity indices calculated for each habitat for the duration of the study period.

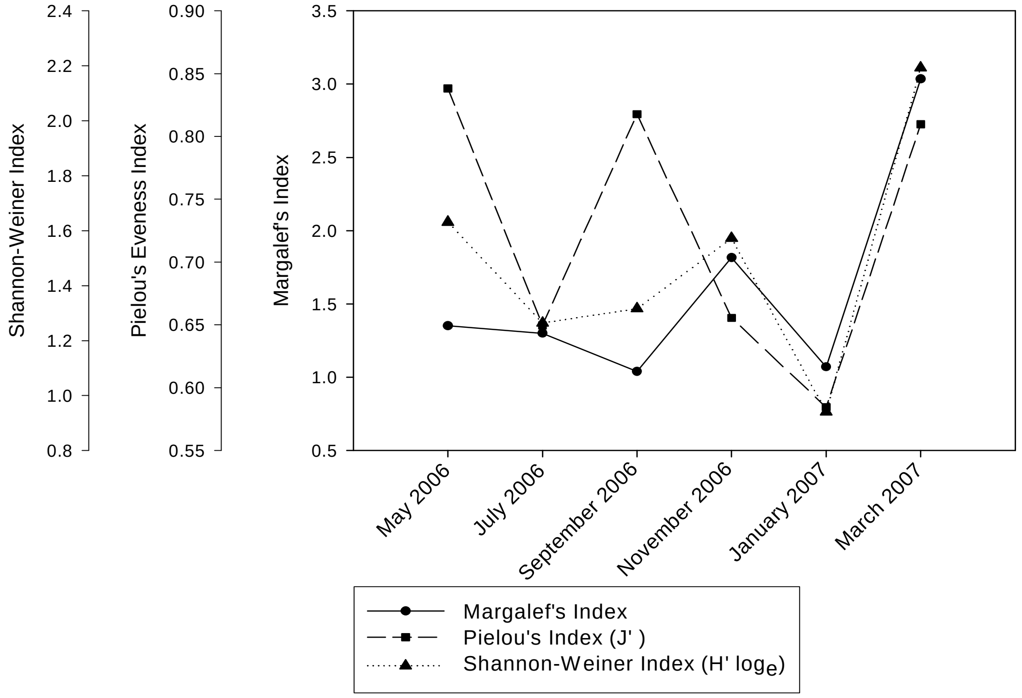


Figure 5.6: Monthly calculated diversity indices for the estuarine eelgrass beds.

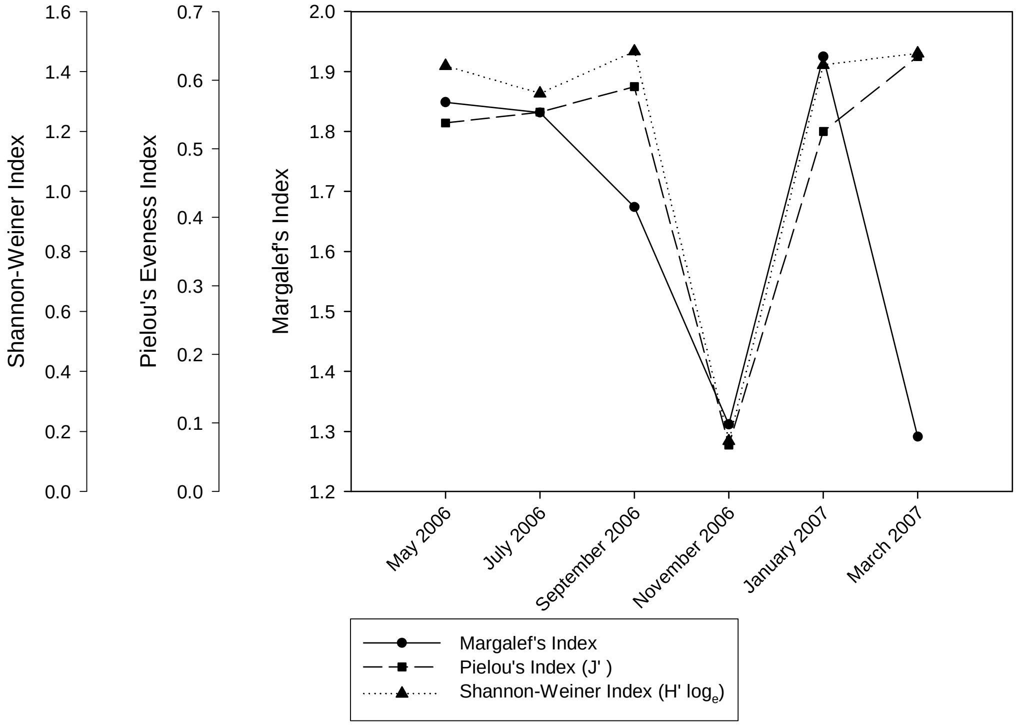


Figure 5.7: Monthly diversity indices for the salt marsh (data pooled, n = 3).

In both habitats, the largest number of species were recorded in the summer months (November: 11 and 12; January: five and 15, respectively). However, the catches were dominated by one or two species only. In the estuary in November, *Rhabdosargus holubi* contributed 45% of the total catch while in January; juvenile Mugilidae (<20mm SL) contributed 71% of the total catch. Within the salt marsh habitat, in both November and January, the catch was predominantly composed of juvenile Mugilidae (97% and 61%, respectively). Figure 5.8 shows the number of species caught on each sampling trip in each habitat. The predominance of one or two species per trip results in low diversity and evenness values (see figure 5.7). With the exception of March 2007, the salt marsh appears to be utilised by a greater number of species at any one time than the eelgrass beds in the estuary.

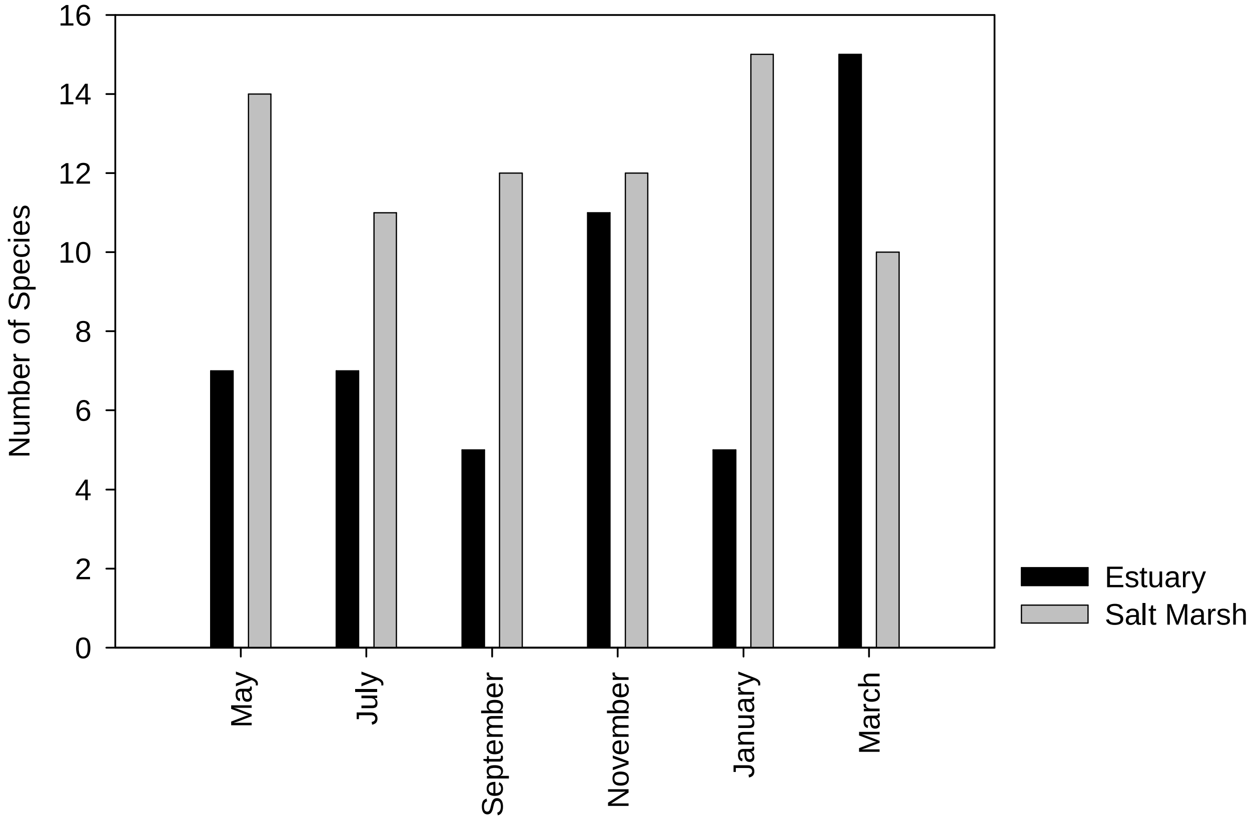


Figure 5.8: Number of fish species caught each month, in each habitat.

5.2.3. Estuarine utilisation

The estuarine utilisation categories for fish species caught in the salt marsh and the estuary throughout the study were determined as described previously. The percentage contribution of each category, in terms of abundance and standing stock, to the total caught in each habitat is presented in Table 5.8 and Fig 5.9 A and B. Small Mugilidae (<20mm SL) are not included in this data set as the different species may belong to different categories (Whitfield 1998).

Of the total number of fish caught, 62% of the salt marsh individuals (85% of the standing stock) and 56% of the eelgrass individuals (43% of standing stock) belonged to category II, (i.e. those individuals which rely on estuarine systems as a breeding or nursery area). More specifically category IIa species, including *Terapon jarbua, Mugil cephalus, Rhabdosargus holubi* and *Elops machnata,* dominated the catches in terms of abundances throughout the study. In total, category IIa species accounted for 51% of all individuals caught in the salt marsh and 41% of individuals caught in the estuarine eelgrass beds. The contribution of this category towards the total standing stock was, however, only 15% in the salt marsh and 17% in the eelgrass beds. True estuarine species (category I); those that can complete their lifecycle within the estuary, were the second most numerically dominant group comprising 20% of the individuals, 21% of standing stock, caught in the salt marsh and 41% of the individuals, 54% of standing stock, caught in the eelgrass beds. Together, categories I and II accounted for 82% of fish caught in the salt marsh and 98% of the estuarine eelgrass beds. The contribution of these groups to the total standing stock was 83% and 98%, of the total respectively.

Catadromous species that were recorded during this study all belonged to the facultative rather than the obligative group (category Vb as opposed to Va), and do not require a freshwater phase for their development. This group was only found within the salt marsh and was represented by the Freshwater mullet, *Muyxus capensis* which contributed 14% of the salt marsh individuals. The only freshwater (category IV) species found in either habitat during the study was the tilapia, *Oreochromis mossambicus*. This species contributed 3% towards the abundance of the salt marsh species and 1% of the eelgrass species. Marine stragglers (category III) accounted for less than 1% of all individuals caught in both habitats. Category Vb accounted for 13% of the standing stock in the estuary while categories (III and IV) contributed less than 5% towards the standing stock in both habitat.

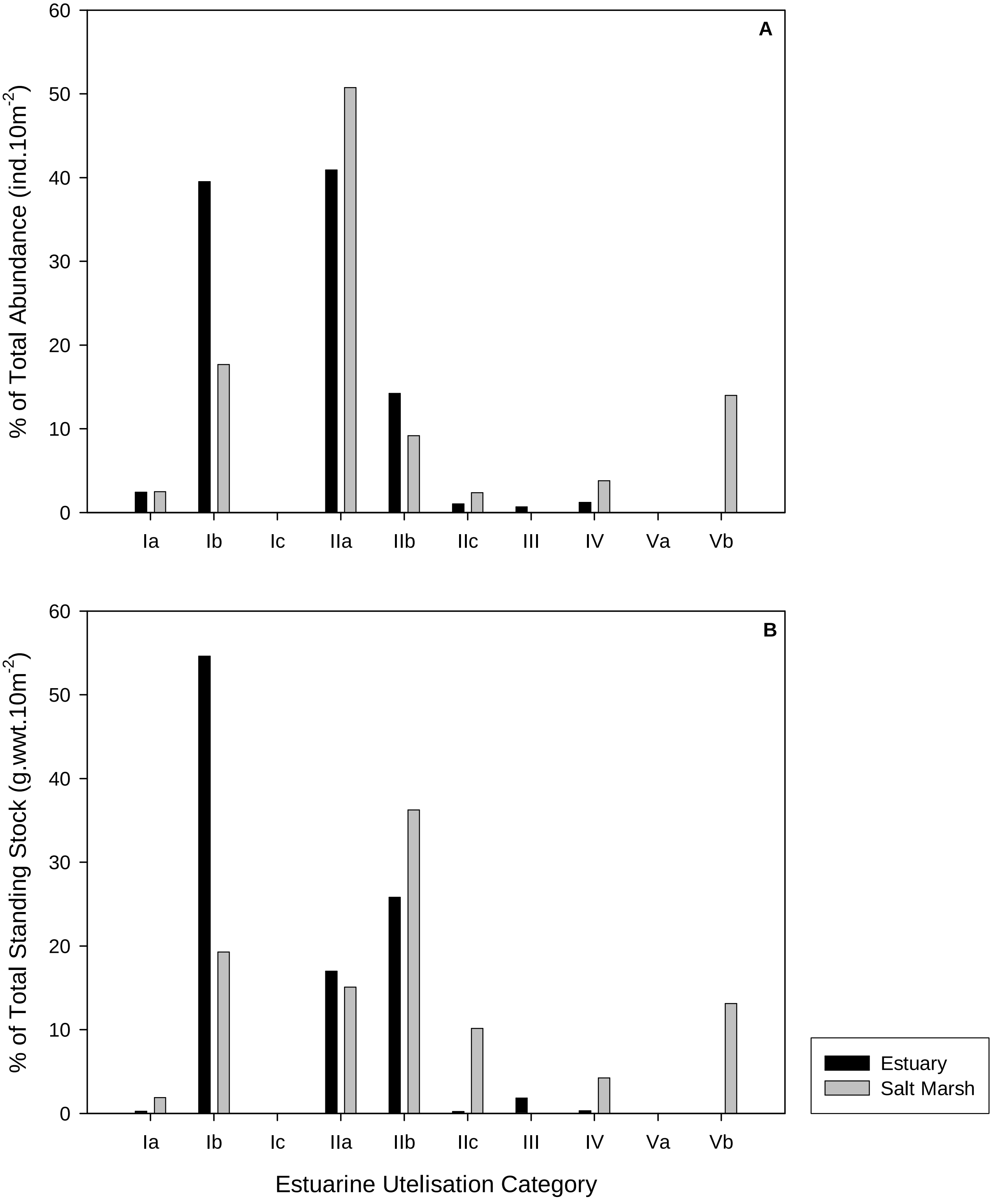


Figure 5.9: Percent contribution of each estuarine utilisation category to the total for abundance (ind.10m^{-2}) (A) and standing stock (g.wwt.10m^{-2}) (B) of the ichthyofauna in the estuarine and salt marsh habitats.

Table 5.8: Comparison of proportions ichthyofaunal abundances and standing stock belonging to the estuarine utilisation categories (after Whitfield 1998)

		This study		Paterson (1998)	
Category	**Description**	**Abundance %**	**Standing Stock %**	**Abundance %**	**Standing Stock %**
I	True estuarine species that breed in the estuary and complete their lifecycle within the estuary	20	7	30	5
II	Euryhaline marine species, which breed at sea, but which show varying degrees of dependence estuaries as juveniles.	62	86	52	87
III	Marine species, infrequently found in estuaries, they are not dependent on estuaries for any stage of their lifecycle.	<1	<1	<1	<1
IV	Freshwater species, which can breed either in the freshwater, or the estuarine environment.	4	1	<1	<1
V	Species, which use the estuary purely in transit between the marine and freshwater environments.	14	5	17	7

5.2.4. Reproductive status

The reproductive status of individuals caught within the salt marsh and estuarine eelgrass beds was determined as described in Chapter Four. All specimens of Springer (*Elops machnata*), Thornfish (*Terapon jarbua*), Mozambique tilapia (*Oreochromis mossambicus*) Cape Stumpnose (*Rhabdosargus holubi*) and the small Mugilidae (<20mm SL) captured were juveniles. *Elops machnata* was not recorded in the estuarine eelgrass beds throughout this study. The temporal patterns in abundance and standing stock shown by the remaining species are related to seasonal breeding and recruitment into the estuary and salt marsh. High abundances but low standing stocks, such as occurred during the summer months, are indicative of large numbers of juveniles present within the habitats. The temporal patterns of maturity for those fish species caught within Taylor’s salt marsh and the estuarine eelgrass beds are illustrated in Figures 5.10 to 5.12 and compared to the size at which sexual maturity is obtained (Whitfield 1998).

The Knysna sand goby (*Psammogobius knysnaensis*) and the River goby (*Glossogobius callidus*), two estuarine resident species (category I), which are able to complete their life cycles entirely within the estuary, show a distinct seasonal pattern in size. In the salt marsh, juveniles were predominant during the summer months with a few adults present in spring (September) and summer (November). However, in the eelgrass beds, adults dominated the catch in the summer months (November, January and March) with smaller sub-adults recorded in autumn (September) and juveniles dominating in winter (May and July).

The Prison goby, *Caffrogobius gilchristii*, did not show distinct seasonal trends in sexual maturity in either habitat. *Caffrogobius nudiceps*, the Barehead goby was only recorded in the salt marsh on one occasion but was present on all sampling trips, except January, within the eelgrass beds. This species also did not have a distinct seasonal pattern in maturity. Both species are estuarine resident species (category I).

Within the estuarine eelgrass beds, the Super Klipfish (*Clinus superciliosus*) and the Longsnout Pipefish (*Sygnathus acus*), showed a much higher proportion of adult individuals present in the catch. *S. acus* is a true estuarine species (category Ib) and the presence of adults in the catch is expected. *C. superciliosus* adults were present in all sampling trips except for September and November when juveniles were numerically dominant. However, *C. superciliosus* belongs to estuarine dependent category (IIb) where adults are typically found at sea where they breed, and juveniles are predominantly found in estuaries. The presence of adults of *C. superciliosus* within the eelgrass habitat throughout the year may be related to the hydrodynamics (i.e. marine dominance) of the Kariega Estuary. The reduced freshwater inflow, and marine dominated nature of this estuary, especially towards the mouth region, leads to salinity values which seldom deviate from that of sea water (Paterson 1998), allowing adults of *C. superciliosus* to exploit the estuarine eelgrass habitat.

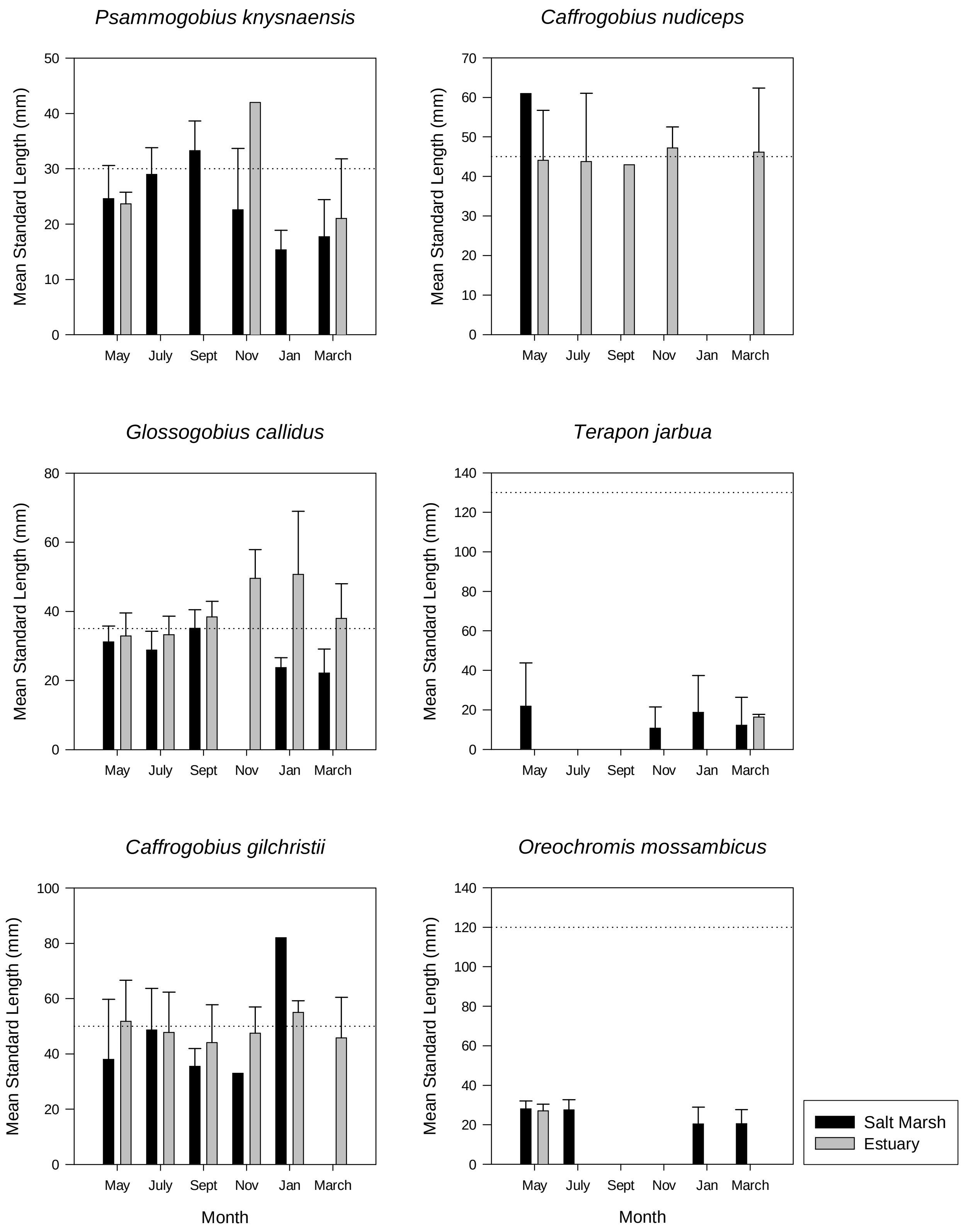
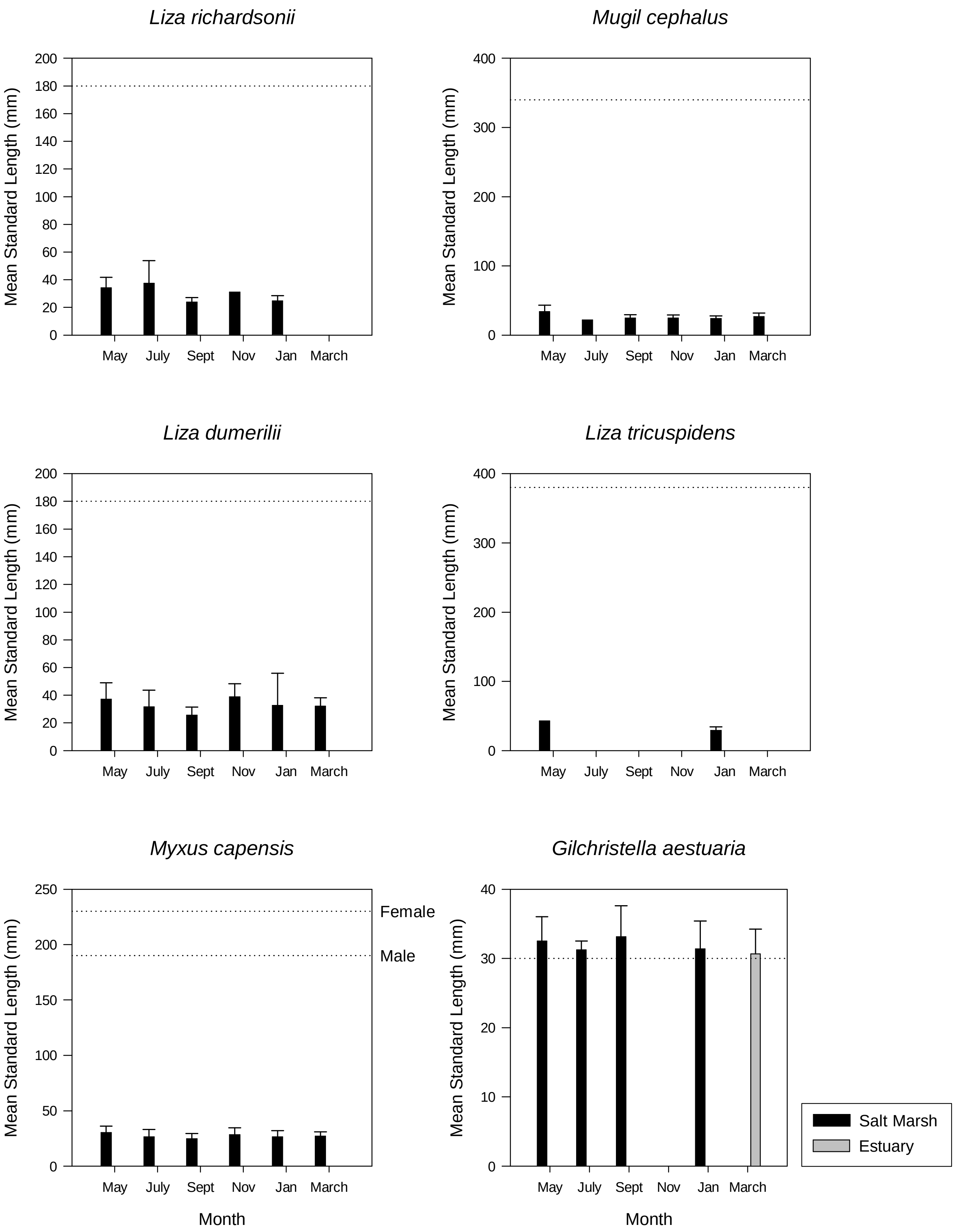


Figure 5.10: Mean monthly size (mm SL ± 1 SD) for various species of fish recorded in Taylor's salt marsh and the estuarine eelgrass habitat (Data pooled n = 6). Dotted line indicates size (mm SL) at which sexual maturity is obtained. (Obtained from the literature).



Liza richardsonii

Mugil cephalus

Liza dumerilii

Liza tricuspidens

Myxus capensis

Gilchristella aestuaria

Figure 5.11: Mean monthly size (mm SL ± 1 SD) for various species of fish recorded in Taylor's salt marsh and the estuarine eelgrass habitat (Data pooled n = 6). Dotted line indicates size (mm SL) at which sexual maturity is obtained. (Obtained from the literature).

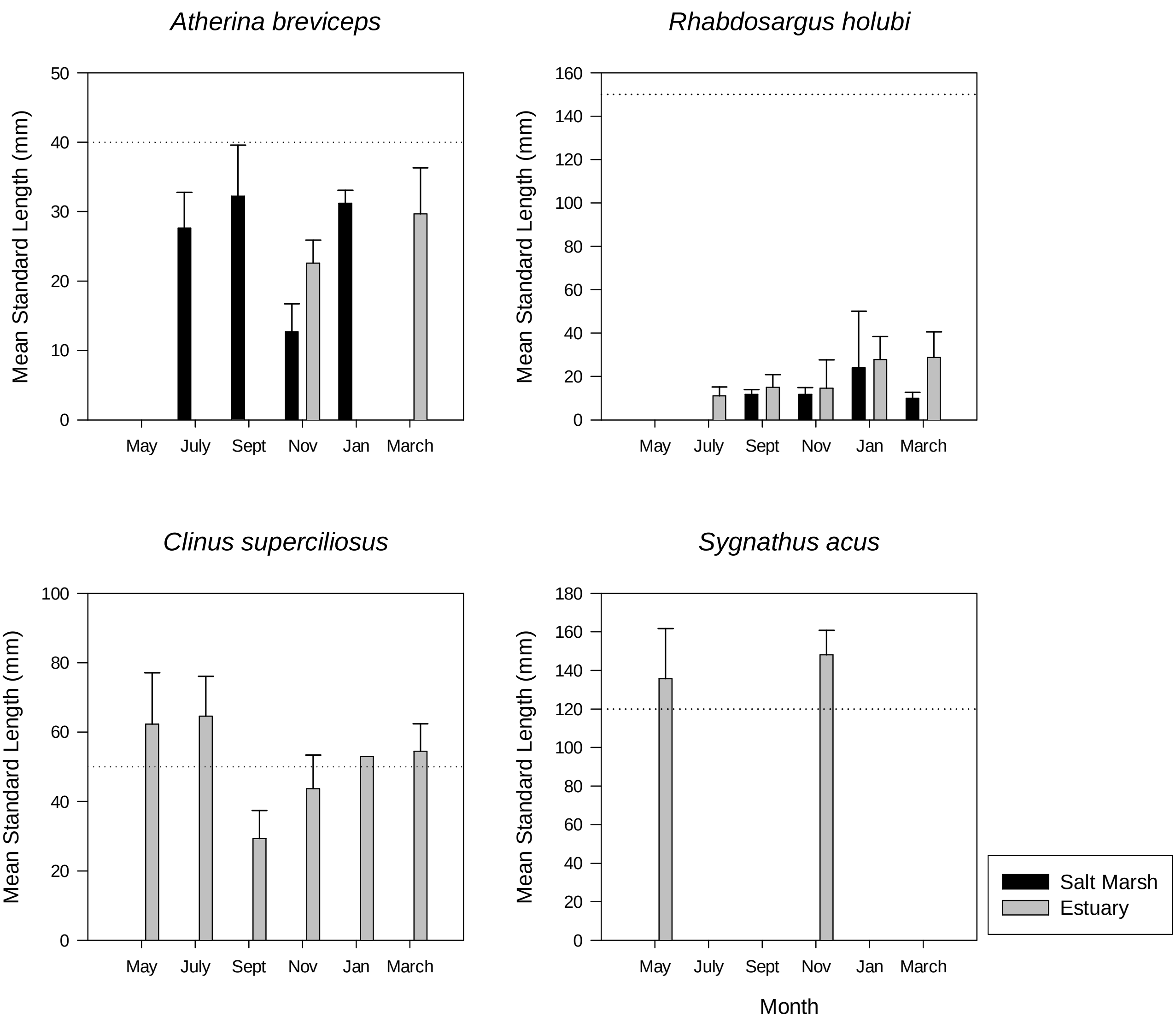


Figure 5.12: Mean monthly size (mm SL ± 1 SD) for various species of fish recorded in Taylor's salt marsh and the estuarine eelgrass habitat (Data pooled n = 6). Dotted line indicates size (mm SL) at which sexual maturity is obtained. (Obtained from the literature).

5.2.5. Dominance

To determine the relative importance or dominance of each species within each habitat, the species were ranked as described in Chapter Four. Once again, although the juvenile Mugilidae (<20mm SL) are comprised of a number of different species, for the purposes of this analysis, the group was treated as a 'species'.

The top ten species in each habitat are listed in Tables 5.9 and 5.10 below. Only two species were common to both habitats; the juvenile Mugilidae (<20mm SL) and the River goby, *Glossogobius callidus.* Within the salt marsh, the juvenile Mugilidae were the most dominant 'species' by an order of magnitude (see Table 5.9). The presence of a further three species of mullet in the top ten (*Liza dumerilii, Myxus capensis* and *Mugil cephalus*) suggest that the salt marsh is an important habitat for this family of fish. In the eelgrass beds, the dominant species was the goby *Caffrogobius gillchristii*. However, within the eelgrass beds, there isn't a specific family which dominates the habitat in the same was as the Mugilidae dominate the salt marsh.

Table 5.8: Top ten species by rank for Taylor's salt marsh (data pooled from all trips and all reaches).

Rank	Species	Estuarine Utilisation Category	Abundance (ind.10m^{-2})	Standing Stock (g.wwt.10m^{-2})	% of habitat total	Frequency of occurrence	Total
1	*Mugilidae <20mm SL*	-	18.58	0.50	74.2%	100%	**20.8**
2	*Elops machnata*	IIa	2.04	0.04	8.1%	50%	**2.7**
3	*Liza dumerilii*	IIb	0.57	0.77	2.3%	100%	**2.4**
4	*Myxus capensis*	Vb	0.90	0.28	3.6%	100%	**2.2**
5	*Psammagobius knysnaesis*	Ib	0.79	0.24	3.2%	100%	**2.1**
6	*Mugil cephalus*	IIa	0.49	0.11	1.9%	100%	**1.6**
7	*Terapon jarbua*	IIa	0.49	0.12	2.0%	67%	**1.3**
8	*Liza richardsonii*	IIc	0.15	0.22	0.6%	83%	**1.2**
9	*Glossogobius callidus*	Ib	0.22	0.05	0.9%	83%	**1.1**
10	*Oreochromis mossambicus*	IV	0.24	0.09	1.0%	67%	**1.0**

Table 5.9: Top ten species by rank for the estuarine habitat (data pooled from all trips).

Rank	Species	Estuarine Utilisation Category	Abundance (ind.10m^{-2})	Standing Stock (g.wwt.10m^{-2})	% of habitat total	Frequency of occurrence	Total
1	*Caffragobius gillchristii*	Ib	24.60	58.39	19.7%	100%	**84.2**
2	*Rhabdosargus holubi*	IIa	45.20	37.16	36.3%	83%	**83.6**
3	*Clinus superciliosus*	IIb	16.40	59.52	13.2%	100%	**77.1**
4	*Synganathus acus*	Ib	2.00	37.75	1.6%	33%	**40.1**
5	*Glossogobius callidus*	Ib	10.40	15.95	8.3%	100%	**27.4**
6	*Caffragobius nudiceps*	Ib	5.60	13.05	4.5%	83%	**19.5**
7	*Mugilidae <20mm SL*	-	8.60	0.18	6.9%	50%	**9.3**
8	*Arothron hispidus*	III	0.60	4.21	0.5%	33%	**5.1**
9	*Gilchristella aestuaria*	Ia	2.80	0.62	2.2%	17%	**3.6**
10	*Argyrosomus japonicas*	IIa	0.60	1.80	0.5%	17%	**2.6**

5.2.6. Numerical analysis

An analysis of similarity (ANOSIM) was used to investigate the abundances of different species in each habitat. ANOSIM showed that there was a significant difference ($R = 0.911$, $p = 0.02$) in community composition between the different reaches of the salt marsh. A hierarchical cluster analysis showed three distinct groups, designated Groups 1 to 3, of ichthyofauna at the 40% similarity level (Fig 5.13). Group 1, with the exception of the November sampling trip, comprised of all the salt marsh samples. Group 3 was composed of all the eelgrass samples. An exception was recorded for the January trip, which, together with the November data from the salt marsh, comprised Group 2. This pattern was confirmed using multidimensional scaling (Fig 5.14). A SIMPER analysis indicated that the differences between the three groupings could be ascribed to temporal changes in the numerical dominance of different species, rather than the presence or absence of different species in each habitat. The most numerically dominant species in each group, identified with the hierarchical cluster analysis are presented in Table 5.10 below.

Table 5.10: SIMPER determined contribution of each species (average abundance) to the groups identified in the hierarchical cluster analysis (Primer, Fig 5.13).

Group	Species	Average Abundance
Group 1	Mugilidae (<20 mm SL)	1.34
	Myxus capensis	0.17
	Psammogobius knysnaensis	0.16
	Liza dumerilii	0.11
	Mugil cephalus	0.09
	Glossogobius callidus	0.04
Group 2	Mugilidae (<20mm SL)	8.94
Group 3	*Caffrogobius gilchristii*	4.84
	Rhabdosargus holubi	8.80
	Clinus superciliosus	3.24
	Glossogobius callidus	1.96
	Caffrogobius nudiceps	1.12

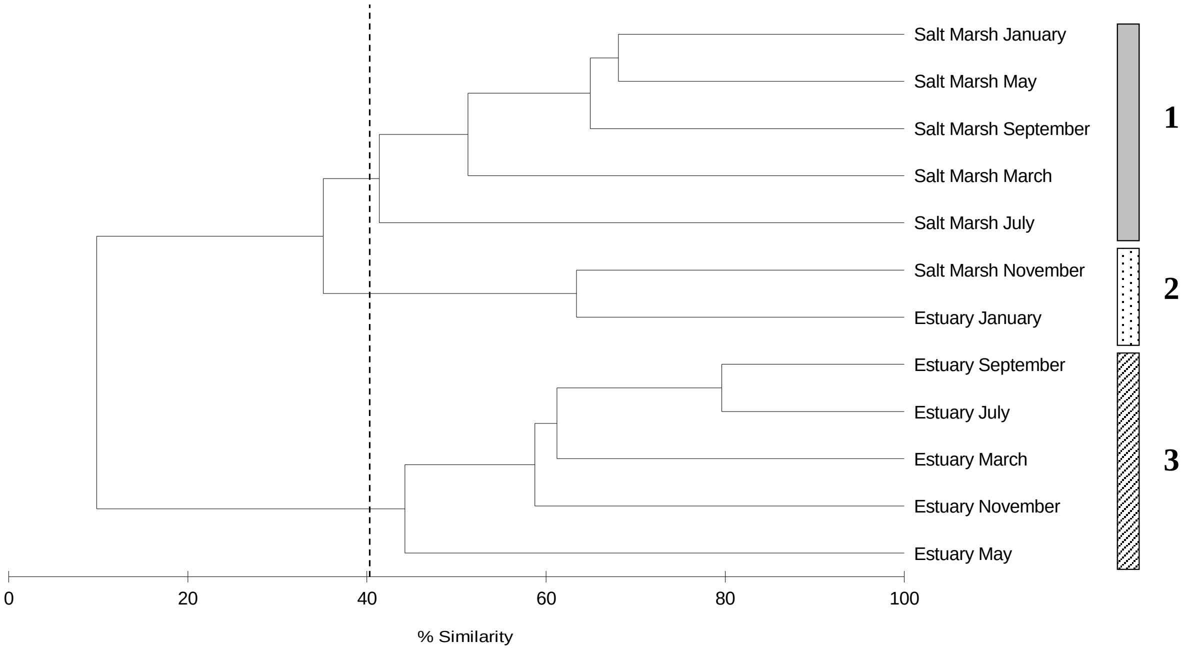


Figure 5.13: Cluster analysis (group linkage) for abundances (ind.10m-2) in each habitat. Data was log (x+1) transformed 40% similarity level is indicated.

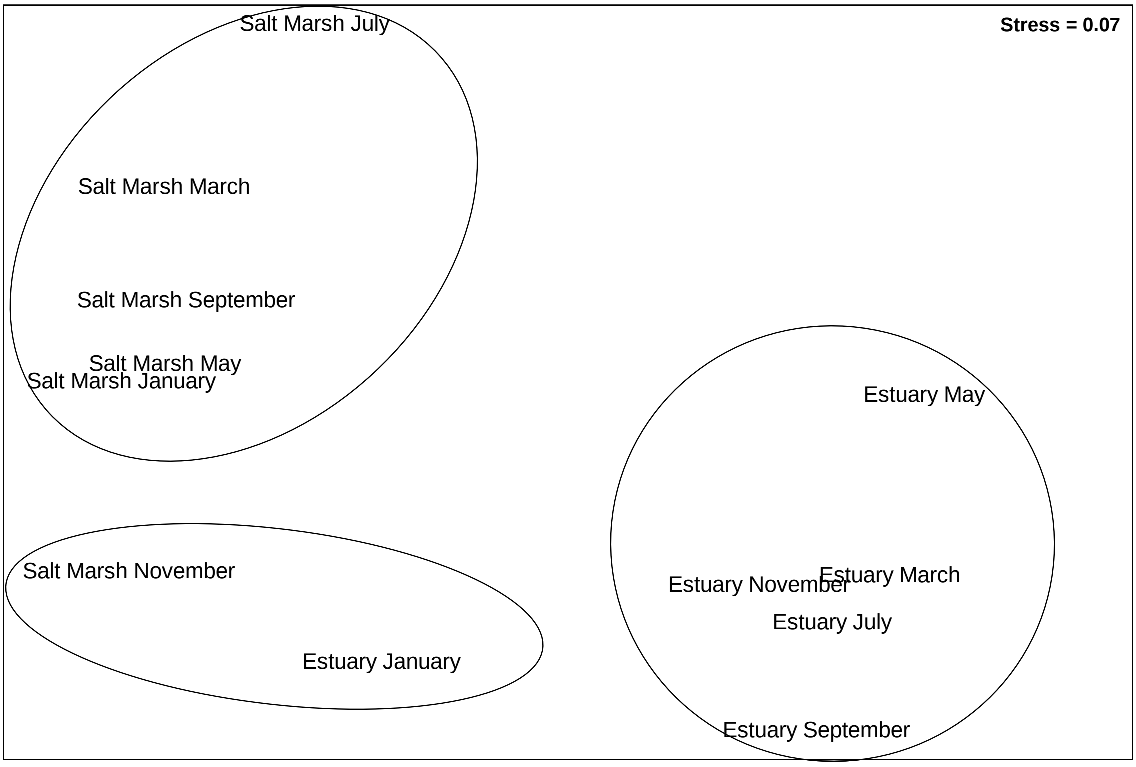


Figure 5.14: Multidimensional scaled (MDS) plot of abundance (ind.$10m^{-2}$) data for each habitat. 1, 2 and 3 refers to the groups formed in the hierarchical cluster analysis (Fig 5.14).

5.3. Discussion

5.3.1. Physico-chemical and biological parameters.

All physico-chemical parameters fell within the expected range for the region (Harrison 2004). There were no significant differences in physico-chemical parameters between the two habitats. There were however, seasonal trends with highest temperatures and lowest dissolved oxygen concentrations were recorded in summer. Biological parameters (POM, water column and microphytobenthic chlorophyll-*a* concentrations) recorded in this study were also within the expected range. Trends have been discussed in detail in Chapter Four and are therefore, not discussed here.

5.3.2. Ichthyofaunal abundance and biomass

As already discussed in chapter four, the estimates of total ichthyofaunal abundance and standing stock within the salt marsh during this study are generally within the lower range recorded in a previous study (Paterson 1998) within the same marsh. Similarly, within the estuarine eelgrass beds, abundances (8.4 – 49.4 ind.10m^{-2}) were within the range recorded by Paterson (1998) (65.5 ± 56.0 ind.10m^{-2}) in the same estuarine system. The mean standing stock recorded in this study (38.6 ± 37.0 g.wwt.10m^{-2}) was also within the range (47.8 ± 28.3 g.10m^{-1}) recorded in the eelgrass beds in Paterson's (1998) study. Overall, abundance and standing stock values were greater in the eelgrass beds than in the salt marsh. This trend may be due to the presence of larger adult individuals contributing a greater proportion of the catch within the eelgrass beds, whereas juveniles dominated the catch in the salt marsh.

On the other hand, values presented for the eelgrass beds are substantially lower than those recorded in the larger, permanently open Great Fish River Estuary within the same geographic region (Whitfield and Harrison 2003). The reduced abundance and standing stock of ichthyofauna associated with Taylor's salt marsh and adjacent eelgrass beds may reflects the marine dominance of the Kariega Estuary. Several studies have demonstrated the importance of freshwater inflow in promoting the recruitment of marine species into estuaries (Whitfield *et. al.* 1994; Whitfield 1999; Whitfield and Harrison 2003). Typically, estuaries that have been subject to long-term reductions in freshwater inflow have significantly altered biotic, especially ichthyofaunal, characteristics (Baird and Heymans 1996, Whitfield *et. al.* 2005). Species, which favour the more constant, marine-like environments, tend to dominate these freshwater deprived systems (Whitfield *et. al.* 2005). Periodic floods, or periods of increase freshwater flow due to high rainfall, such as occurred in the Eastern Cape in the summer of 2006/2007 (pers. obs.), can affect the ichthyofaunal abundances and standing stock of estuaries. The effect of freshwater is confirmed by the differences the temporal abundance patterns of ichthyofauna recorded in the estuarine eelgrass beds and the salt marsh. There was a marked decrease in ichthyofaunal abundances in the eelgrass beds from November (49.4 ind.10m^{-2}) to January (8.4 ind.10m^{-2}). The highest and lowest abundances in this habitat occurred during the summer months. The maximum abundances recorded in November 2006 may by due to an increased freshwater signal in the estuarine waters prompting increased larval and juvenile recruitment. However, in January 2007, when minimum abundances in the eelgrass beds were recorded, the eelgrass habitat may have become more unsuitable due to increased fluctuations in salinities and possibly a reduction in the size of the eelgrass beds. Both of these factors could have been as a result of increased freshwater inflow due to the period of high rainfall in the area since August 2006.

The salt marsh on the other hand, is a transient habitat and as such is probably relatively unaffected, in the long term, by factors such as rainfall. The salt marsh is only inundated at high tides, and due to the position of the salt marsh within the estuary, the water, which floods the marsh, is marine in origin. The catchment for the stream that feeds into the salt marsh is small and any fresh water signals that may have been produced by the high rainfall would probably move through the system very quickly, or would be swamped by the marine water entering the system. Minimum ichthyofaunal abundances in this system (0.65 ind.10m^{-2}) occurred in midwinter (July) while maximum ichthyofaunal abundances occurred in November (12.2 ind.10m^{-2}). This pattern may be a reflection of increase recruitment during the summer months. The decrease in ichthyofaunal abundances in January, therefore, may be as a result of the reduced abundances in the main estuary.

5.3.3. Community composition

A total of 28 species from 18 families were caught during the study. Ten species were common to both habitats. Again these values are less than the 41 species from 24 families recorded within the salt marsh during a two year study of Paterson (1998). On the other hand, the results for the eelgrass beds are in agreement with the findings Strydom *et. al.* (2003), which recorded 24 species of fish in the same system.

In terms of the diversity indices within the eelgrass beds, the values for Margalef's index (d) recorded in this study are lower then value calculated for the Kariega Estuary by Strydom *et. al.* (2003). A value of 4.91 was recorded in that study for the estuary as compared to 2.95 recorded in this study. During this study, the Margalef's index values for the salt marsh (d = 1.29 to 1.92) were at the lower end of the range reported by Paterson (1998) (d ≈1.75 and ≈3.25). The lower values calculated in this study likely reflects the limited temporal component of the study. The pelagic region, and bare unvegetated bottom areas within the estuary as well as regions with different types of submerged aquatic vegetation and submerged structures such as rocks, were not sampled during this study. This may lead to certain species, which favour these habitats not being sampled, and hence the diversity indices calculated in this study do not reflect calculations for the estuary as a whole, but rather, the two habitats that were investigated.

The Shannon-Weiner index (H’ = 0.78) recorded by Strydom *et. al.* (2003) is considerably lower than the values calculated for this study (H’ = 1.99 and 1.48 in the eelgrass and salt marsh respectively). The range (H’ ≈ 0.7 to ≈ 2.0) recorded by Paterson (1998) within the salt marsh habitat is similar to that recorded in the salt marsh in this study (H’ = 0.17 to 1.48). The same is true for Pielou’s index, the range of values calculated for both studies overlap. The temporal patterns in diversity were somewhat different between the current study and that of Paterson (1998). In this study, the lowest diversity indices were recorded in midsummer (November) whereas in Paterson’s (1998) study the highest diversity indices were recorded in summer and lowest diversities recorded in winter. Although diversity indices were low in winter in the current study, the minimum observed in midsummer may be as a result of the dominance of a single species in the catch in November. *Rhabdosargus holubi* dominated the catch in the eelgrass beds and the juvenile Mugilidae (<20mm SL) dominated in the salt marsh. The dominance of a single species may be due to increased recruitment of that species into the estuary as a whole, and the suitability of the particular habitat to juveniles of that species. *Rhabdosargus* species are often associated with *Zostera capensis* beds (Beckley 1984) and the presence of a number of species of the family Mugilidae within the salt marsh suggests that this family is particularly suited to that habitat. The increased recruitment may be due to the increased freshwater signal within the estuary due to the large amounts of rain receive in the region.

5.3.4. Estuarine utilisation

The proportions of each estuarine utilisation category recorded in this study are equivalent to those recorded by Paterson (1998) and Strydom et al. (2003). Category II (estuarine dependent) species dominated the catch in this study and in that of Paterson (1998) in both habitats. 62% of individuals in the salt marsh and 56% of the individuals in the eelgrass beds in this study belonged to category II. Category II species also dominated the standing stock in the typically contributing between 54% (Paterson 1998) and 61% (this study) of the total standing stock within the eelgrass beds and between 5% (Paterson 1998) and 21% (this study) in the salt marsh.

Category I species are the second most dominant group in terms of abundances within the salt marsh and eelgrass beds, typically contributing between 20% and 42% respectively (this study) and 31% and 55% respectively (Paterson 1998) to the total abundances. Standing stock contributions of category I species within the two habitats are also generally the most dominant after the contribution made by category II species. In Paterson’s (1998) study, standing stock values contributions by category I species in the salt marsh and eelgrass habitats were 5% and 43% respectively. In the current study, contributions were 21% and 55% respectively.

Categories III, IV and V did not contribute significantly to the abundance or standing stock totals in either habitat. This is in agreement with Paterson’s (1998) findings and the overall totals for South African ichthyofauna (Whitfield 1998). The absence freshwater straggler species, with exception of *Oreochromis mossambicus* which is know to have a wide range of salinity tolerances (Whitfield 1998; Whitfield and Marais 1999), in either habitat is due to the marine dominated nature of the system. The penetration of freshwater species into estuarine habitats is limited by the salinity tolerance of specific species (Whitfield and Marais 1999).

5.3.5. Reproductive status and dominance

Temporal and spatial trends in reproductive status and dominance within the salt marsh habitat have already been presented in detail in Chapter Four. Juveniles of a number of species of fish numerically dominated all regions of the salt marsh. Peaks in abundance were recorded in summer, coinciding with the reported peaks in breeding and recruitment of a number of fish species. The family Mugilidae was dominant throughout the salt marsh, although, *Psammogobius knysnaensis, Glossogobius callidus*, *Terapon jarbua* and the sparid *Rhabdosargus holubi* were also present in the dominance rankings.

In the estuarine eelgrass beds three species topped the rankings. *Caffrogobius gilchristii, Rhabdosargus holubi* and *Clinus superciliosus* all whom have previously been demonstrated to be l strongly associated with eelgrass beds (Whitfield 1998). *Caffrogobius gilchristii, C. nudiceps* and *Clinus superciliosus* were more important in terms of standing stock than abundance; although *C. nudiceps* is not as highly ranked. *Rhabdosargus holubi* on the other hand was more important in terms of abundance. This suggests that the eelgrass habitat is important for juveniles of

Rhabdosargus holubi but is utilised by larger sub-adults and adults of *Caffrogobius gilchristii, C. nudiceps* and *Clinus superciliosus.* Eelgrass beds are areas of increased macro-crustacean abundance and biomass, which are important prey items for *Caffrogobius gilchristii, C. nudiceps* and *Clinus superciliosus* (Whitfield 1998). These species are all cryptically patterned ambush predators and the eelgrass bed provides cover and increased food availability (Whitfield 1998). In addition the eelgrass specialist, *Sygnathus acus* was highly ranked within the eelgrass habitat. The goby, *Glossogobius callidus* was present in the eelgrass beds on every sampling occasion. This species is an estuarine resident and the relatively high abundances and standing stock values of this species suggests that the eelgrass beds area suitable habitat for this species. The remaining species contributed relatively little to the eelgrass ranked species; although it is interesting to note the presence of a marine straggler, *Arothron hispidus* in this habitat.

Results of the numerical analyses indicate that the salt marsh and eelgrass beds were characterised by distinctive ichthyofaunal assemblages. These different assemblages appear to be the result of several factors including food availability (elevated microphytobenthic algal stocks), water depth and the apparent availability of refuge areas against predation.

5.4. Conclusion

Taylor’s salt marsh and the adjacent eelgrass beds within the main estuarine channel are not significantly different to each other in terms of the selected physico-chemical parameters investigated. The ranges for these parameters were also within the expected ranges for the geographical location of the study. Biological parameters were also within the expected ranges, with the exception of microphytobenthic algae concentrations, which were higher than previously recorded. Abundance and standing stock values were within the lower range reported by previous studies and are consistent with the freshwater deprived nature of the Kariega Estuary. Analysis of the community composition and structure showed that although both habitats are dominated by juveniles, mostly belonging to category I and II, the salt marsh and eelgrass beds are distinct habitats with a distinct species assemblage. The salt marsh therefore, can be considered to be an important microhabitat within the estuary as a whole.

Chapter 6. General Discussion

Research into the structure and functioning of salt marshes is still in its infancy in South Africa. It is difficult to compare the results obtained in this study to other international studies. Studies on salt marshes worldwide have employed a wide range of sampling strategies and gear types; in addition, salt marshes in different geographic regions have different fundamental structural differences. The majority of research on salt marshes has been conducted in North America, specifically on the east and Gulf coasts (Paterson 1998). North American salt marshes are typically one order of magnitude larger, have a more complex network of inter-tidal creeks and flats, and have more frequent and longer inundation periods (Paterson 1998; Cattrijsse and Hampel 2006). As a consequence, North American salt marshes are accessible to fish, and other fauna, for longer periods of time, and more often (Paterson 1998). There has been some research conducted in European, Australian and Asian salt marshes, which are more comparable to South African salt marshes. In these areas, as in South Africa, only a portion of the salt marsh is flooded on a normal high tide and spring high tides are necessary to flood the salt marsh completely (Cattrijsse *et. al.* 1994, Paterson 1998; Jin *et. al.* 2006). The inundation period is relatively short and this restricts the access of the salt marsh to the ichthyofauna. However, despite differences in survey approach, geographic location, marsh structure, physical complexity, inundation and accessibility of salt marshes worldwide, a number of similarities can be described.

6.1. Community composition

The east coast of South Africa is composed primarily of Indo-Pacific ichthyofauna (Smith and Heemstra 1986). Dominant ichthyofaunal families recorded in this study were the Mugilidae, Elopidae, Gobidae and Sparidae. Studies in South African salt marshes (including this study), have demonstrated that ichthyofauna catches are predominantly composed of marine transient species (category II) which breed in estuaries but complete their lifecycle at sea (Whitfield 1998). A similar trend has been observed in north American salt marshes were the majority of fish caught were marine transient species (Cain and Dean 1976; Weinstein 1979; Rountree and Able 1992).

In contrast, studies in Australia (e.g. Thomas and Connolly 2001) have shown that the catches within estuarine salt marshes are dominated by estuarine resident species (category I, after Whitfield 1998) of the Ambassidae and Gobidae families. In addition, Sparidae, Mugilidae and Sillaginidae families contributed substantially to the catch (Thomas and Connolly 2001). Estuarine resident species belonging to the Mugilidae and Gobidae were also important in a survey of an

Asian salt marsh by Jin *et. al.* (2006), along with sea-perch species of the family Lateolabracidae. The dominance of the estuarine dependent species in the current study, as opposed to the estuarine resident species, is a reflection of the marine dominated nature of the Kariega Estuary (Whitfield 1998). Euryhaline estuarine resident species are generally unable to withstand large fluctuations in salinity and temperature, such as occur in the salt marsh, especially in the standing pools in summer months.

In this study, a greater number of species were recorded in the salt marsh than in the adjacent estuarine eelgrass beds. However, although large numbers of species have been recorded within salt marshes, any one catch is usually dominated by one or two species (e.g. Rountree and Able 1992, Paterson 1998, Thomas and Connolly 2001) resulting in lower diversity indices for the salt marsh compared to the eelgrass beds. Juvenile Mugilidae (<20mm SL), which were treated as a ‘species’ in the analyses, were numerically dominant on all occasions. This ‘species’ contributed up to 97% of the total catches within the salt marsh. In the eelgrass beds, no single species or family of ichthyofauna dominated any one catch. In Thomas and Connolly’s (2001) study, it was found that the catches were usually dominated by one or two species that contributed between 50% and 80% of the abundance. Jin *et. al.* (2006) found a similar pattern where three species contributed >95% of the total catch. The same trends are true in American salt marshes (see Rountree and Able 1992).

6.2. Reproductive status and nursery function

The distinct seasonal trends observed in abundances during this investigation, peaking in the summer months, within the salt marsh and eelgrass habitats emphasises the importance of breeding and recruitment periods to temporal patterns in ichthyofaunal community structures. During periods of recruitment a species may be numerically dominant, but the contribution of the species towards standing stock totals may be minor. This is best illustrated in the salt marsh habitat by the numerical dominance of juvenile Mugilidae (<20mm SL); in mid- (November) and late summer (March).

The prevalence of juvenile individuals in catches within the salt marsh, suggests that the habitat is a potential nursery area (Bosch and Turner 1987). The other accepted pre-requisites for nursery areas are; increased availability of food and refuge from predation (Bosch and Turner 1987, Paterson and Whitfield 2000). Salt marshes should provide sufficient food to counteract the energetic costs associated with entering salt marshes (Madon *et. al.* 2001). In the current study, the high microphytobenthic algal concentrations suggest that it is an available food resource; though it was not investigated whether or not juvenile fish were actually feeding while they were in the salt marsh. However, other studies have shown that fish do move into salt marshes to feed (e.g. Hollingsworth and Connolly 2006) and that there are significant energetic advantages in doing so (Madon *et. al.* 2001). The un-vegetated nature of the inter-tidal salt marsh creek initially suggests that there is little cover for juvenile fish and that predation pressures within the salt marsh would be high. Areas of submerged aquatic vegetation, especially eelgrass (*Zostera capensis*) beds are acknowledged as areas of reduced predation pressure (Beckley 1983). The physical complexity provided by the vegetation deters large piscivorous fish from entering the habitat and provides cover for juvenile fish (Beckley 1983). Other studies have suggested the shallow water depths within salt marsh provide protection for small juvenile fish, despite the absence of vegetation cover, because larger individuals are physically unable to utilise the habitat (Bosch and Turner 1984; Kneib 1987; Cattrijsse *et. al.* 1997). It is important to note that the only piscivorous species recorded within Taylor's salt marsh was *Elops machnata*, but that the small size of all individuals recorded suggests that predation by ichthyofauna was effectively absent. Studies in South Africa by Paterson (1998) and Paterson and Whitfield (2000), and Europe (Mathison *et. al*. 2000) have also described the absence of piscivorous fish from salt marsh creeks

6.3. Habitat heterogeneity

Results of the present study and that of Paterson (1998) indicated that the ichthyofaunal community composition in the salt marsh is markedly different to the adjacent eelgrass (*Zostera capensis*) beds. This suggests that, in the Kariega Estuary, the salt marshes and eelgrass beds are distinct microhabitats within the estuary and contribute to the overall heterogeneity of the estuary. Specifically they are notable additional nursery areas for a variety of fish species. This is important in terms of overall ichthyofaunal diversity as it has been shown that estuaries with a wide range of microhabitats tend to have higher species diversity overall, than those estuaries which have limited types of microhabitats (Beckley 1983; Strydom *et. al.* 2003).

6.4. Further studies

Although a start has been made in understanding the ichthyofaunal community structure and composition of salt marshes in South Africa, further research is needed in order to determine the role played by salt marshes within estuaries in South Africa. This study has described the temporal and spatial patterns of a salt marsh located near the mouth of a single marine dominated estuary. Investigations into ichthyofaunal community composition in salt marshes located in different reaches, estuaries and sections of the South African coastline, will help to increase the understanding of the importance of this habitat within estuarine ecosystems.

Studies of ichthyofaunal community composition of salt marshes located on the west coast of South Africa (e.g. Langabaan) would provide a useful comparison to salt marshes studied on the east coast. Current information on South African salt marshes indicates that they are similar in terms of ichthyofaunal abundances and standing stocks as well as overall community composition, to salt marshes located in Australian estuaries. More information on salt marsh ichthyofaunal community structure and composition, from different regions of South Africa will increase our understanding of South African salt marsh as well as allowing is to place them in a global context.

The short duration of access to the salt marsh by fish may be an important factor in structuring which fish are found within the salt marsh. Investigations into feeding by fish within salt marshes, either through gut content, isotope or fatty acid analysis should provide additional information support the theory that salt marshes provide areas of increased food availability. Investigations, over both the short-term (for example, diel) and long-term, into the faunal community composition, including micro- and macro-invertebrates, energy flows and the use of salt marshes by other animals including birds, reptiles and mammals will help to place the functioning of salt marshes within a broader ecological context.

Chapter 7. References

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Appendix : Additional Tables

Chapter Four

Table 4.1 Physico-chemical and biological results for each reach of Taylor's salt marsh for the whole study period (data pooled, n = 6; mean ± 1 standard deviation).

Reach	Temperature (°C)	Dissolved Oxygen ($mg.O_2.L^{-1}$)	Salinity (psu)	Chlorophyll-*a* (mg.chl-*a*.L^{-1})	Particulate Organic Matter ($g.L^{-1}$)	Microphytobenthic algae (µg.chl-*a*.cm^{-2})
Lower	18.4 ± 3.6	5.2 ± 0.6	36.5 ± 1.6	2.7 ± 2.3	0.04 ± 0.01	3073.4 ± 1455.4
Middle	18.9 ± 3.7	4.5 ± 0.4	37.2 ± 4.1	3.6 ± 3.0	0.06 ± 0.03	2000.0 ± 1832.1
Upper	19.1 ± 3.9	4.4 ± 0.5	37.0 ± 5.1	2.7 ± 2.7	0.05 ± 0.03	3014.3 ± 1999.9

Table 4.2: Physico-chemical and biological results for each sampling trip for all reaches of Taylor’s salt marsh (mean ± 1 standard deviation).

Month	Region	Temperature (°C)	Dissolved Oxygen (mg.O$_2$.L^{-1})	Salinity (psu)	Chlorophyll-*a* (mg.chl-*a*.L-1) n=3	Particulate Organic Matter (g.L^{-1}) (n = 3 St Dev < 0.03)	Microphytobenthic algae (mg.chl-*a*.cm^{-3}) n=5
May	**Lower**	15.0	5.1	38	0.5 ± 0.4	0.04	1041 ± 358
	Middle	15.3	4.0	38	0.3 ± 0.1	0.04	432 ± 190
	Upper	14.1	4.9	40	0.4 ± 0.1	0.03	535 ± 264
July	**Lower**	15.1	5.9	38	5.0 ± 4.3	0.05	3872 ± 1396
	Middle	15.7	4.7	44	3.6 ± 4.8	0.1	3474 ± 2052
	Upper	16.9	5.2	46	0.7 ± 0.1	0.06	4924 ± 1031
September	**Lower**	16.3	6.0	38	2.5 ± 0.1	0.02	3843 ± 1204
	Middle	16.6	4.7	34	3.3 ± 0.5	0.03	2241 ± 1567
	Upper	16.9	3.9	34	4.2 ± 0.3	0.04	4456 ± 1140
November	**Lower**	18.9	4.8	35	2.6 ± 0.8	0.04	2566 ± 1188
	Middle	20.2	4.9	34	8.1 ± 0.9	0.03	1465 ± 529
	Upper	21.5	4.4	33	7.7 ± 0.7	0.03	2385 ± 1914
January	**Lower**	23.7	4.4	35	1.3 ± 0.5	0.06	3847 ± 1316
	Middle	24.7	4.6	34	1.8 ± 0.5	0.06	3007 ± 3021
	Upper	25.0	4.4	34	2.3 ± 0.04	0.06	2780 ± 2535
March	**Lower**	21.4	4.8	35	4.4 ± 2.2	0.03	3272 ± 933
	Middle	20.7	4.0	39	4.6 ± 0.7	0.1	1380 ± 509
	Upper	20.3	3.9	35	0.9 ± 0.3	0.1	3005 ± 1024

Table 4.3: Monthly ichthyofaunal abundances (ind.10m^{-2}) recorded for each reach of Taylor's salt marsh.

	May	July	September	November	January	March
Lower	1.78	0.59	0.97	10.76	1.08	2.34
Middle	5.52	0.85	0.89	21.68	6.78	3.70
Upper	3.54	0.55	6.19	3.45	8.13	3.58

Table 4.4: Monthly recorded ichthyofaunal standing stock (g.wwt.10m^{-2}) for each reach of Taylor's salt marsh.

	May	July	September	November	January	March
Lower	1.90	0.15	0.31	0.32	0.23	0.04
Middle	0.75	0.07	0.32	0.50	1.01	0.07
Upper	0.49	0.12	0.30	0.08	0.89	0.03

Table 4.6: Number of species recorded and diversity indices for each reach of Taylor's salt marsh and the adjacent eelgrass beds throughout the study (Data pooled, n = 6).

Region	Number of Species	Total number of Individuals (n)	Margalef's Index (d)	Pielou's Index (J')	Shannon-Weiner Index (H')
Estuary	20	623	2.95	0.66	1.99
Lower	17	3300	1.98	0.44	1.23
Middle	14	3823	1.58	0.33	0.86
Upper	14	1888	1.72	0.48	1.27

Table 4.7: Number of species recorded and diversity indices calculated for each sampling trip in the lower reaches of Taylor's salt marsh.

Region	Number of Species	Total number of Individuals (n)	Margalef's Index (d)	Pielou's Index (J')	Shannon-Weiner Index (H')
May	13	333	2.07	0.75	1.92
July	9	112	1.70	0.76	1.67
September	12	183	2.11	0.90	2.24
November	10	2028	1.18	0.07	0.17
January	9	204	1.50	0.74	1.63
March	9	440	1.31	0.87	1.90

Table 4.8: Number of species recorded and diversity indices calculated for each sampling trip in the middle reaches of Taylor's salt marsh.

Region	Number of Species	Total number of Individuals (n)	Margalef's Index (d)	Pielou's Index (J')	Shannon-Weiner Index (H')
May	8	535	1.11	0.49	1.02
July	5	82	0.91	0.33	0.53
September	8	86	1.57	0.85	1.76
November	6	2103	0.65	0.06	0.11
January	13	658	1.85	0.47	1.21
March	6	359	0.85	0.48	0.86

Table 4.9: Number of species recorded and diversity indices calculated for each sampling trip in the upper reaches of Taylor's salt marsh.

Region	Number of Species	Total number of Individuals (n)	Margalef's Index (d)	Pielou's Index (J')	Shannon-Weiner Index (H')
May	8	263	1.26	0.36	0.74
July	5	41	1.08	0.61	0.99
September	7	459	0.98	0.33	0.63
November	7	256	1.08	0.23	0.45
January	12	603	1.72	0.59	1.47
March	3	266	0.36	0.39	0.43

Table 4.10: Comparison of percentage contribution of each ichthyofaunal estuarine utilisation categories to total abundance (ind.10m^{-2}) and standing stock (g.wwt.10m^{-2}) for each reach of Taylor's salt marsh.

Category	**Description**	**Abundance (%)**			**Standing stock (%)**		
		Lower	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**
I	True estuarine species that breed in the estuary and complete their lifecycle within the estuary	12	6	1	12	8	1
II	Euryhaline marine species which breed at sea, but which show varying degrees of dependence estuaries as juveniles.	18	22	20	45	11	5
III	Marine species, infrequently found in estuaries, they are not dependent on estuaries for any stage of their lifecycle.	0.04	0	0	0	0	0
IV	Freshwater species which can breed either in the freshwater or the estuarine environment.	0.9	0.6	2	0.05	7	4
V	Species which use the estuary purely in transit between the marine and freshwater environments.	7	3	4	7	3	3

Chapter Five

Table 5.4: Abundance (ind.10m^2), and standing stock (g.wwt.10m^2) per month for the salt marsh (data pooled, n = 3) and estuarine eelgrass beds (Mean ± 1 standard deviation).

Month	Region	Abundance (ind.10m^{-2})	Standing Stock (g.wwt.10m^{-2})
May	Estuary	17	7.43
	Salt Marsh	3.2 ± 1.9	0.13 ± 0.1
July	Estuary	20.2	2.67
	Salt Marsh	0.7 ± 0.2	0.012 ± <0.1
September	Estuary	9.4	1.12
	Salt Marsh	1.99 ± 3.1	0.031 ± <0.1
November	Estuary	49.4	9.53
	Salt Marsh	12.2 ± 9.2	0.032 ± <0.1
January	Estuary	8.4	1.99
	Salt Marsh	4.1 ± 3.8	0.5 ± 0.8
March	Estuary	20.2	2.33
	Salt Marsh	2.96 ± 0.8	0.0043 ± <0.1

Table 5.6: Number of species recorded monthly and calculated diversity indices for the estuarine eelgrass habitat.

Region	Number of Species	Total number of Individuals (n)	Margalef's Index (d)	Pielou's Index (J')	Shannon-Weiner Index (H')
May	7	85	1.4	0.8	1.6
July	7	101	1.3	0.6	1.3
September	5	47	1.0	0.8	1.3
November	11	247	1.8	0.7	1.6
January	5	42	1.6	0.6	0.9
March	15	101	3.0	0.8	2.2

Table 5.7: Number of species recorded monthly and calculated diversity indices for Taylor's salt marsh. (Data pooled, n = 3).

Region	**Number of Species**	**Total number of Individuals (n)**	**Margalef's Index (d)**	**Pielou's Index (J')**	**Shannon-Weiner Index (H')**
May	14	1132	1.8	0.5	1.4
July	11	235	1.8	0.6	1.3
September	12	714	1.7	0.6	1.5
November	12	4388	1.3	0.1	0.2
January	15	1442	1.9	0.5	1.4
March	10	1065	1.3	0.6	1.5