SPATIO-TEMPORAL DYNAMICS OF ICHTHYOPLANKTON IN THE KOWIE ESTUARY, SOUTH AFRICA

THESIS

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By

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DECLARATION

The following thesis has not been submitted to a university other than Rhodes University, Grahamstown, South Africa. The work presented here is that of the author.

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ABSTRACT

Ichthyoplankton dynamics in the permanently open Kowie Estuary, in the warm temperate region of South Africa was investigated. The composition, abundance, distribution and seasonality of larval fishes were studied over a two year period between 2004 and 2006. Additionally, tidal exchange of ichthyoplankton and the use of frontal zones in the mouth region of the estuary were also explored between 2008 and 2009. Temporal and spatial trends in occurrence of larval fishes within the estuary and associated marina were obtained from data collected seasonally using boat-based plankton netting at 14 sampling stations along the length of the estuary. A total of 11 128 larval fishes were collected, representing 23 families and 38 taxa. Clupeidae and Gobiidae were the dominant fish families, contributing 47.0 % and 24.7 % respectively to the total catch. Estuarine resident species dominated the overall catch (91 %). A notable absence of older stage larvae and early juveniles characterised the artificial channels of the marina and estuary mouth region. This was attributed to the absence of a shallow, marginal water habitat typical of successful estuarine nursery areas. Tidal exchange of larval fishes was investigated in the Kowie Estuary using a new technique. A set of drifting light traps were set repetitively on the ebb and flood tide every second night for two consecutive 14 day periods during the peak estuarine recruitment period. A total of 553 larval fishes were caught during the study, representing nine families and 26 species. Blenniidae and Clupeidae dominated the catches. Family and species occurrence changed with tide state. Species richness (*d*) and diversity (*H'*) varied with tide and was highest on flood tides. Estuary-dependent species, such as *Omobranchus woodii* were more dominant on flood tides, whilst larvae of marine-spawned species, such as *Sardinops sagax*, were dominant on the ebb tide. Light trap catches yielded a different composition in terms of development stage / size and species, when compared to towed net studies. Towed plankton nets were again used to study the shear fronts that characterise the mouth region of the canalised Kowie Estuary. It was hypothesised that the convergence zone of the front provides feeding opportunities for ichthyoplankton. Ichthyoplankton, zooplankton and phytoplankton was collected from within and immediately outside of the convergence zone during frontal conditions. Species specific distribution trends emerged from this study. Postflexion larvae and early juvenile stages of the estuary dependent Mugilidae were only present in the foam line of the convergence zones. Some known predators of ichthyoplankton were also present in slightly higher numbers in the convergence zone (isopods) while other predators such as mysid shrimps, chaetognaths and cnidarians were more abundant out of the convergence zone. It appears that these zones may provide access to temporary food patches in the lower estuary but will be accompanied by a trade-off with increased isopod predators. The Kowie Estuary is a heavily impacted system and lack of adequate freshwater supply; artificial channelling and pollution ultimately have a negative impact of the success of this system as a nursery area. Rehabilitation of marginal areas in the lower estuary and marina is suggested as remedial action to re-establish the integrity of the nursery function this system could offer.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Estuarine variability in South Africa

Along the South African coast there are 250 functional estuaries (Whitfield 2000) and these estuaries can be broadly divided into three biogeographic regions, namely cool-temperate, warm-temperate and subtropical (Whitfield 1998). Whitfield and Lubke (1998) identify five main types of estuaries that occur in southern Africa within these biogeographic regions, namely permanently open, temporarily open/closed, river mouths, estuarine lakes and estuarine bays. Permanently open estuaries can be further characterized into saltwedge, highly stratified, partially mixed and vertically homogenous systems and these different states also fluctuate with rainfall, river flow, mouth status and tidal variation (Whitfield 1998). Estuaries are essentially the interface between marine and freshwater from the contributing river catchments (Wooldridge 1998; Schumann *et al*. 1999). This characteristic results in estuaries being highly dynamic environments, with large fluctuations over short time scales in water temperature, salinity, turbidity and flow (Whitfield 1983; Whitfield 1994a; Whitfield & Bok 1998). These dynamic physico-chemical variations in estuaries contribute to habitat heterogeneity and therefore influence fish density and abundance in South African estuarine systems (Whitfield 1999).

1.2 Nursery function of estuaries

Estuarine systems provide essential nursery areas for both estuarine and marine spawning fish species worldwide (Neira & Potter 1994; Whitfield 1998; Strydom *et al*. 2003; Perez-Ruzafa *et al*. 2004; Ramos *et al*. 2006). The majority of South African estuaries are occupied by fewer than 50 different fish families, but considerably large numbers of single / individual species populations (Whitfield 1999), with those able to adapt to environmental changes, benefiting considerably from these sheltered, food rich environment (Van der Elst & Wallace 1975).

Ichthyofauna utilizing estuaries can be divided into categories in accordance with their ability to spawn and breed in the estuarine environment (Whitfield 1998; 1999). Estuarine spawners are divided into two groups, namely those that breed in estuaries only (Ia) and those that breed in the marine and estuarine environment (Ib). Euryhaline marine species are divided into three groups. Euryhaline marine species that breed at sea, with juveniles that are dependent on estuaries as nursery areas (IIa), euryhaline marine species breeding at sea, with juveniles that are found in estuaries and the sea (IIb), and the final subgroup, where juveniles occur in estuaries but are more numerous in the sea (IIc) (Whitfield 1998). The remaining categories are marine stragglers with no dependence on estuaries (III), freshwater migrant species (IV) and catadromous migrants (V) (Whitfield 1998). The nursery function of estuaries begins during the postflexion larval stage when capable swimming abilities exist (Strydom and Whitfield 2000). Access and utilization of nursery areas by larval fish is particularly vital for survival in many commercially and recreationally important fish species (Boehlert and Mundy 1988). For this reason, larval stages are also categorised according to this estuarine dependence system so as to reflect the category from which larval stages are derived from and the juvenile status the fish will transform or settle into.

1.3 Larval fish occurrence in estuaries

Larvae of marine descent need to successfully locate estuarine nursery areas, and this process is typically facilitated by estuarine and or riverine cues which provide essential “point-source” stimuli for recruiting larval fishes (Boehlert and Mundy 1988). Movement toward nursery areas begins as a passive process from offshore adult spawning grounds and as the larvae become more developed, active swimming takes over, with the aid of tidal and wind-driven currents (Boehlert and Mundy 1988). Cues that aid in recruitment include salinity changes, temperature gradients, turbidity, olfactory stimuli and changes in water chemistry, amongst others (Boehlert and Mundy 1988; Whitfield 1994b; Barletta-Bergan *et al*. 2002). Failure of larvae to survive the planktonic stage including the ability to detect these cues for settlement and nursery areas may result in reduced recruitment and thus poor replenishment of fish stocks. Once larvae have located the nursery area movement into the estuary is dependent on the flood and ebb tidal regime. Larvae with weak swimming abilities will passively drift into the estuary with the flood tide while others can actively swim into estuaries and settle to the bottom or estuary margins to avoid predation or displacement (Beckley 1985; Whitfield 1999). Access to shallow, marginal areas where tidal flow is reduced is important to avoid early or unwanted displacement from the nursery (Beckley 1985; Whitfield 1999). After entrance into the estuary, ichthyoplankton will exploit copepod rich food resources resulting in subsequent grow out (Houde & Lovdal 1984).

1.4 Review of larval fish research in South Africa

Ichthyofaunal research in estuaries was historically focussed primarily on juvenile and adult stages of estuarine associated fish species (van der Elst & Wallace 1975; Marias & Baird 1980; Beckley 1984; Whitfield 1996). However, larval fish studies have gained momentum in recent years. The first reference to early developmental stages of fishes in estuaries was made with reference to angling species in the early 1900's where anglers first detected problems in the Swartkops Estuary (Whitfield 1998). Shortly after this, Gilchrist followed with the first larval fish descriptions of marine fish (Gilchrist 1903, 1904). This was followed decades later by descriptions of larvae of some commercially important fish larvae, such as the pilchard *(Sardinops sagax)* (Davies 1954) and anchovy *(Engraulis capensis)* (O'Toole & King 1974). Brownell (1979) then published a series of description of eggs and larvae of marine fish from the south west coast of South Africa. In 1989 further ichthyoplankton descriptions commenced, where Cambray & Bok (1989) illustrated the larval development of *Liza richardsonii* from laboratory reared specimens. Descriptions of larval development of *Argyrosomus japonicus* and *Spondyliosoma emarginatum* were then completed by Beckley (1989, 1990). In 1991, Olivar & Fortuño (1991) described numerous larval stages of fishes from the Benguela Current in the south east Atlantic. Orders described in this work included Anguilliformes, Aulopiformes, Batrachoidiformes, Clupeiformes, Cyprinodontiformes, Elopiformes, Gadiformes, Gobiesociformes, Gonorynchiformes, Myctophiformes, Ophidiiformes, Perciformes, Pleuronectiformes, Salmoniformes, Scorpaeniformes, Stomiiformes and Zeiformes. Other isolated descriptive papers have emerged in recent years on Gobiidae and Soleidae (Thompson *et al.* 2007; Strydom & Neira 2006).

Research into larval fish ecology began to take momentum when Melville-Smith & Baird published the first ichthyoplankton study of South Africa (Melville-Smith & Baird 1980). Despite some research effort in recent years on larval ecology in the surf zones (Whitfield 1989a; Harris & Cyrus 1996; Strydom 2003; Watt-Pringle & Strydom 2003; Strydom & d' Hotman 2005) and the shallow nearshore (Cowley *et al.* 2001; Strydom 2007; Pattrick & Strydom 2007), the majority of larval fish research in South Africa has been concentrated in estuaries. Larval fish assemblages in South Africa have been studied in both single (Melville-Smith and Baird 1980, Whitfield 1989b; Pattrick *et al.* 2007) and multiple estuary studies (Harris & Cyrus 2000; Strydom *et al.* 2003, Montoya-Maya & Strydom 2009). These studies have mostly occurred in warm temperate estuaries and have shed light on aspects such as tidal exchange (Beckley 1985; Whitfield 1989c; Strydom & Wooldridge 2005), effects of altered freshwater input on species occurrence in estuaries (Strydom *et al.* 2002) and habitat use and preference (Whitfield 1994b; Strydom 2003) in estuarine nurseries. Ichthyoplankton studies also extended into the subtropical estuaries with an investigation of the larval fish assemblage in the St Lucia Estuary, Richards Bay Harbour and the Kosi Estuary (Harris & Cyrus 1995; 1996; 1997) amongst others. Recently, the Mngazi Estuary situated in the subtropical-warm temperate boundary region was also studied (Pattrick *et al.* 2007). Ichthyoplankton work on the south and west coast of South Africa was fairly limited, however recently Montoya-Maya & Strydom (2009) investigated ichthyoplankton composition and distribution in nine estuaries along the cool temperate coast of South Africa.

1.5 Thesis rationale

Many estuaries along the South African coast remain poorly or completely unstudied. These vitally important fish nurseries are subjected to major anthropogenic alterations such as freshwater abstraction, impoundments, artificial canalization, pollution and over fishing. The Kowie Estuary is a permanently open estuary situated on the warm temperate coast of South Africa. The estuary flows through the coastal town of Port Alfred and is heavily impacted by freshwater abstraction, large impoundments and highly canalized lower reaches. The Kowie Estuary has no published information on the ichthyoplankton or the integrity of the nursery function of the system. This thesis intends to fill some of these research gaps by studying the spatio-temporal dynamics of ichthyoplankton in the estuary.

1.6 Thesis aims

The aims of this study were to provide information on the larval fish assemblage in the Kowie Estuary pertaining to:

1. Composition, abundance, seasonality and spatial distribution of ichthyoplankton in the Kowie Estuary and comparing these results with ichthyoplankton trends in similar estuaries and establishing the influence of artificial channels on the ichthyoplankton.
2. Tidal exchange of ichthyoplankton in the mouth of the Kowie Estuary, using a new sampling technique of drifting light traps.
3. The occurrence of ichthyoplankton in the convergence zone of shear fronts that occur in the lower reaches of the Kowie Estuary.

1.7 Thesis structure

The thesis is comprised of three content chapters preceded by a general introduction and culminating in a synthesis and conclusion. Content chapters have been written to facilitate publication at a later stage. As a result, some repetition does occur in each chapter, particularly pertaining to laboratory methods. All formatting for the thesis follows that of African Zoology.

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CHAPTER 2

SPATIAL AND TEMPORAL VARIABILITY IN THE LARVAL FISH ASSEMBLAGE OF A WARM TEMPERATE SOUTH AFRICAN ESTUARY, WITH NOTES ON THE EFFECTS OF ARTIFICIAL CHANNELING

2.1 Introduction

Nursery areas, such as estuaries and bays, are important for survival during the larval and early juvenile phase of many estuarine and marine fish species worldwide (Neira & Potter 1994; Whitfield 1998; Strydom *et al.* 2003; Perez-Ruzafa *et al.* 2004; Ramos *et al.* 2006). The dynamics of this use of estuaries by the early developmental stage fishes, as well as the mechanisms of recruitment and maintenance within these areas, have been the focus of research around the world for decades (Neira & Potter 1994; Barletta-Bergan *et al.* 2002; Perez-Ruzafa *et al.* 2004; Ramos *et al.* 2006; Aceves-Medina *et al.* 2008).

In South Africa, larval fish assemblages have been studied in both single (Melville-Smith and Baird 1980, Whitfield 1989; Pattrick *et al.* 2007) and multiple estuary studies (Harris & Cyrus 2000; Strydom *et al.* 2003, Montoya-Maya & Strydom 2009). These studies have contributed towards understanding aspects such as tidal exchange (Beckley 1985; Whitfield 1989; Strydom & Wooldridge 2005), effects of altered freshwater input on species occurrence and success in estuaries (Strydom *et al.* 2002) and habitat use and preference (Whitfield 1994; Strydom 2003) in estuarine nurseries. Despite these efforts, many estuaries and their associated anthropogenic impacts remain poorly understood.

Occurrence of larval fishes in estuaries is dependent on many factors. Larval fishes either originate from within the estuary or recruit into the estuary from the surrounding marine environment (Barletta-Bergan *et al.* 2002). Estuarine triggers play an important part in assisting the larvae in locating specific nursery areas and occupying suitable habitats within the nursery (Boehlert & Mundy 1988; Whitfield & Marais 1999). Of these, salinity gradients, temperature, turbidity, catchment odours, food and habitat availability have been identified, depending on the species (Boehlert & Mundy 1988; Whitfield & Marais 1999; Strydom *et al*. 2003; Montoya-Maya & Strydom 2009). Once in the estuary, the recruiting larvae of estuarine dependent fishes will move to the bottom or estuary margins to avoid predation and displacement by strong tidal currents (Beckley 1985; Whitfield 1989; Strydom 2003).

Estuarine nursery areas along the South African coast are critical in the survival of many endemic fish species, some of which have recreational and commercial fishing value. Most South African estuaries are situated adjacent to urban areas and are subjected to the direct and indirect anthropogenic manipulation. The Kowie Estuary is such a system, situated in the town of Port Alfred.

The larval fish assemblage within the Kowie Estuary and the impacts of the artificially channelled marina are poorly studied. The effects of artificial channelling on small fish nurseries has received limited attention, (Young & Potter 2003a, b), regardless of the numerous marina developments occurring around the world. The Kowie Estuary was previously a large estuary with extensive wetland and mudflat areas in the lower reaches. The development of the marina has removed the wetland area, with the lower reaches now characterized by steep, packed stone walls and deep channels.

The objective of this study was to assess the dynamics of the larval fish assemblage in the Kowie Estuary and marina. Specific aims of the study were to determine the composition, abundance, distribution and seasonality of larval fishes in the Kowie Estuary and to assess whether the marina has an effect on the larval fish assemblage in the lower reaches of the estuary compared to similar, unaltered estuaries in the region. It is hypothesized that the larval fish abundance and diversity will follow similar spatial and temporal trends as has been found in other warm temperate systems. However, the steep-walled marina channels may alter the composition and abundance of larvae when compared with the rest of this estuarine system and unaltered neighbouring systems.

2.2 Methods

2.2.1 Study area

Larval fishes were collected from the permanently open Kowie Estuary (33°36’11”S; 26°54’10”E) situated in Port Alfred on the south east coast of South Africa (Figure 2.1). The climate in this region is classified as warm temperate, with mean annual rainfall occurring during summer (Whitfield 2000). The river is approximately 70 km long, with an average depth of 2.75 m. The summer water temperatures range from 21 °C to 29 °C and winter temperatures range from 11 to 16 °C (Hill & Allanson 1971).

The lower reaches of the Kowie Estuary are heavily impacted on by anthropogenic activities (Whitfield 2000). The mouth is characterized by an artificially-walled entrance, which branches off the main channel into three smaller, artificial channels making up the marina. The artificial sides in the estuary entrance, lower reaches and marina channels are characterized by steep, stone-packed walls sloping at a 60° angle into the sandy-bottomed estuary bed.

For the purpose of this chapter, the estuary was divided into 14 different sampling stations (Figure 2.1). These were coded as lower estuary sites (1A, B, 2C), characterized by artificial walls in the mouth region but also featuring some intertidal mud flats and sandbanks, marina channel sites (D, E, F), characterized by artificial walls, with a general absence of intertidal areas and the remaining sites occurred along the middle and upper reaches of the estuary to the ebb and flow (3 – 10) and these were characterized by natural, marginal area with large intertidal areas.

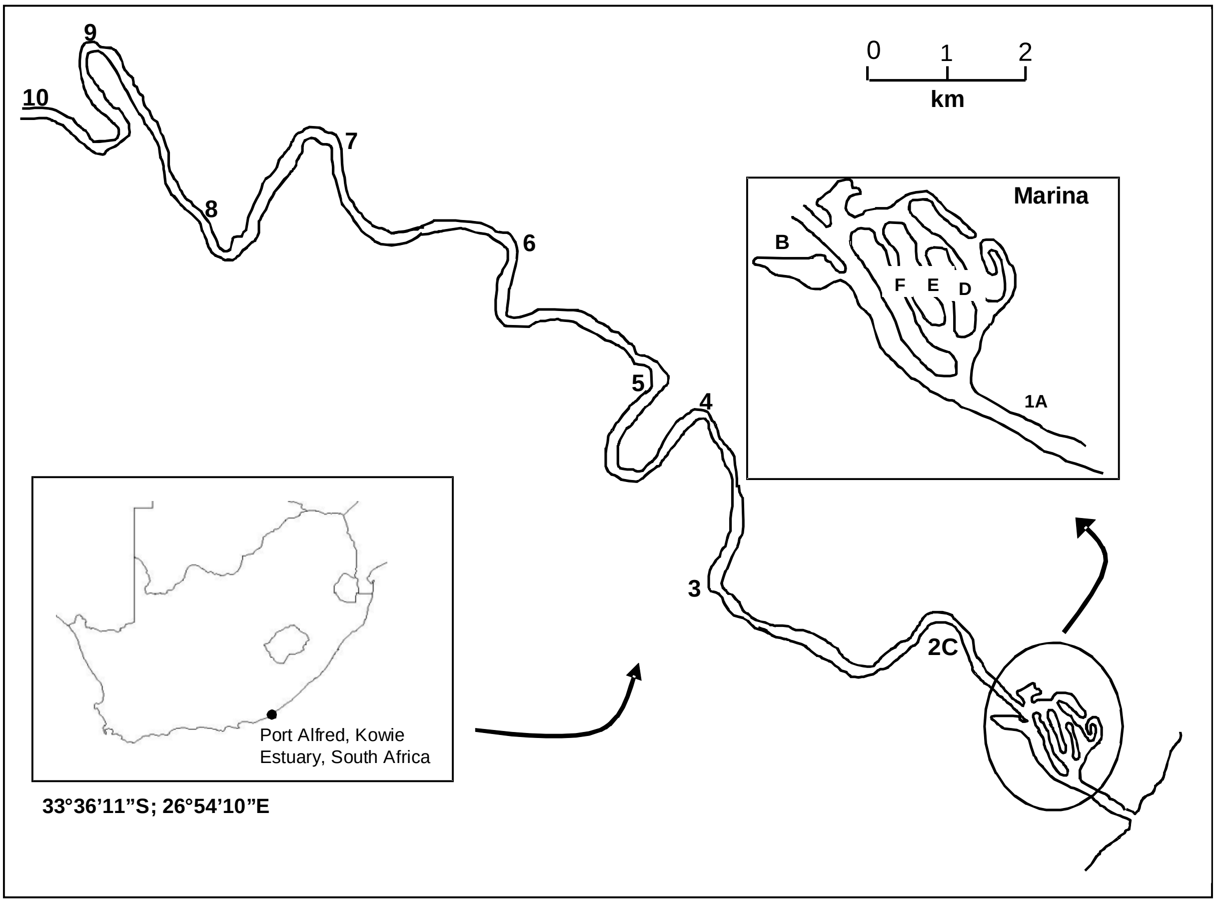

Figure 2.1 Geographical position of the Kowie Estuary, South Africa; indicating location of sampling sites used in the study.

2.2.2 Field sampling and larval identification

Plankton sampling took place over two years in January (summer), April (autumn), July (winter) and September (spring) along the entire length of the Kowie Estuary and marina. All sampling was conducted after dark on the new moon phase. Plankton towing was conducted in the sub surface waters (upper 80 cm of water column) at the 14 sampling stations using two modified WP2 plankton nets (570 mm mouth diameter and 0.2 mm mesh aperture), which were lowered simultaneously from a single hulled boat (Strydom *et al.* 2002; Pattrick *et al.* 2007). Each net was fitted with a Kahlsico 005 WA 130 flowmeter. Each tow was conducted for 3 minutes at each sampling station at a towing speed of 1-2 knots (Strydom *et al.* 2002).

The plankton nets were emptied after each tow and samples were preserved in a 10 % buffered formalin solution on site. Temperature, turbidity and salinity were measured at all 14 sampling stations using a YSI water quality meter. Water transparency was also obtained at every sampling station using a Secchi disc, for comparison with older studies in other systems (Strydom *et al*. 2003; Strydom & Neira 2006; Pattrick *et al.* 2007). All depth recordings measured using the Secchi disc were converted to an extinction coefficient (k) following the method described by Dawes (1981): $k = 1.7/D$ (Secchi depth in cm).

In the laboratory, larval fish were removed from the plankton mass, identified, counted and measured. All larvae were identified to the lowest possible taxon using Smith & Heemstra (1986), Neira *et al.* (1998) and Leis & Carson-Ewart (2000). Larvae were measured to the nearest 0.01 mm using a stereo microscope fitted with an eye piece micrometer. For larger specimens (>10 mm) Vernier calipers were used to measure body length (BL). BL was defined as notochord length in preflexion and flexion stage larvae and standard length in postflexion stage and early juveniles (Strydom 2003). All larvae that were positively identified were grouped into various estuary dependence categories (Whitfield 1998). These estuarine dependence categories are divided into five broad categories, which include estuarine resident species, estuarine dependent marine species, marine stragglers, freshwater species and catadromous species. Resident species are species that either breed in estuaries only (category Ia) or species that are resident in estuaries but can also breed at sea. Euryhaline marine species are split into three categories. These are euryhaline marine species which usually breed at sea but juveniles are dependent on estuaries for nursery grounds (category IIa). Euryhaline marine species that usually breed at sea and the juveniles occur in both the sea and estuary (category IIb). The last group of euryhaline marine species include species that breed at sea, with the juveniles occurring in estuaries but typically more abundant at sea (category IIc). Category III species are fish which are not dependent on estuaries and may occur in estuaries accidentally or opportunistically. Freshwater migrants occur typically in the upper reaches, or in areas with low salinities (IV) and lastly catadromous species (V) are species which will migrate down the estuary to breed in the sea.

2.2.3 Data treatment and analysis

Larval fish density was calculated using a predetermined calibration value for each flowmeter used, following the formula:

$$D = (N/V) \text{ x } 100 \text{ m}^3$$

Where D is the larval fish density; N is the number of larvae caught in specific tow and V is the volume of water filtered by the WP2 plankton nets in the specific tow. The estuary was split into the various salinity zones using the environmental data collected in the field following the adapted Venice system (Strydom *et al.* 2003).

Physico-chemical and biological data were tested for normality and homogeneity of variance, using a normal probability plot and Levene's test. All environmental data was non parametric in nature. Larval fish density was assessed for differences between sites, seasons, salinity zones and years using non parametric Kruskal-Wallis test. Multiple linear stepwise regression for parametric data, was used to determine whether any environmental variables had any significant relationship with larval fish density. A reduced significance level of $P < 0.01$ was used for this analysis.

Margalef's species richness and Shannon-Wiener diversity indices were determined using the DIVERSE application in the PRIMER v5.2.9 statistical software package (Clarke & Warwick 1994). Community analysis was conducted using PRIMER. Density data was Log_{10} $(x + 1)$ transformed due to the high prevalence of zero values. Estuarine resident species (category I) and marine-spawned, estuarine dependent and catadromous species (category II, III, V) were separated and two Bray-Curtis similarity matrices' were generated for this data. Two clusters in the form of a non-metric multi-dimensional scaling (MDS) plots for estuarine residents and marine spawned species were generated. ANOSIM and SIMPER were used to determine the differences and similarities between groups and species comprising these groups. A significance level of $P < 0.05$ was used for all analyses unless specified otherwise.

2.3. Results

2.3.1 Environmental variability

The physical characteristics of the water column in the Kowie Estuary varied seasonally. Salinity ranged from 25 to 35 in summer, 12.4 to 35 in spring, 16.9 to 35.3 in autumn and 21.2 to 34.7 in winter. No significant difference was found in average salinity between season (H = 4.7; *P* = 0.19) (Figure 2.2 a). Water clarity also varied with season and a significant difference in water transparency (*k)* between spring and summer, spring and winter and summer and autumn was revealed (*P* < 0.00) (Figure 2.2 b). However, water temperatures varied with season. Summer water temperatures in the Kowie Estuary ranged from 21.7 to 27.6 ˚C, spring water temperatures ranged from 18.0 to 23.2 ˚C, autumn temperatures ranged from 18.2 to 20.9 ˚C and winter water temperatures ranged from 15.0 to 16.3 ˚C. A significant difference in average water temperature was found among all seasons (H = 168.5; *P* < 0.00) (Figure 2.2 c).

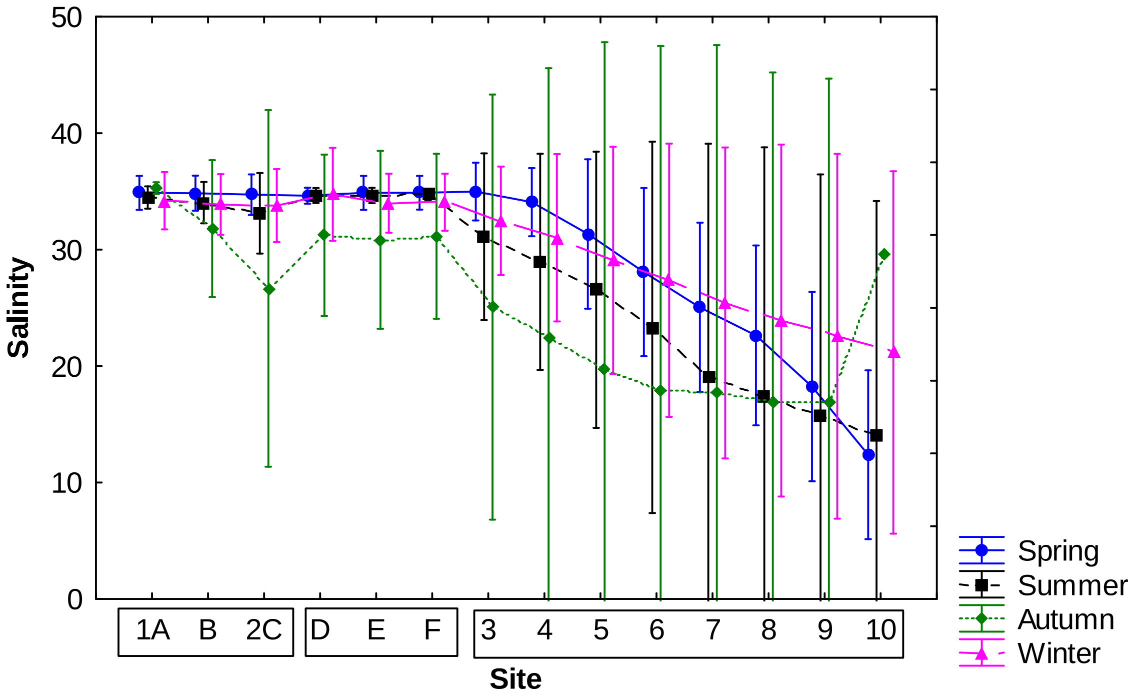

Figure 2.2a Mean salinity for all seasons, at all sites in the Kowie Estuary recorded between 2004 and 2005. Error bars indicate 95 % confidence intervals. (1A, B, 2C = mouth region of estuary; D, E, F = marina channels; 3 – 10 = middle and upper reaches).

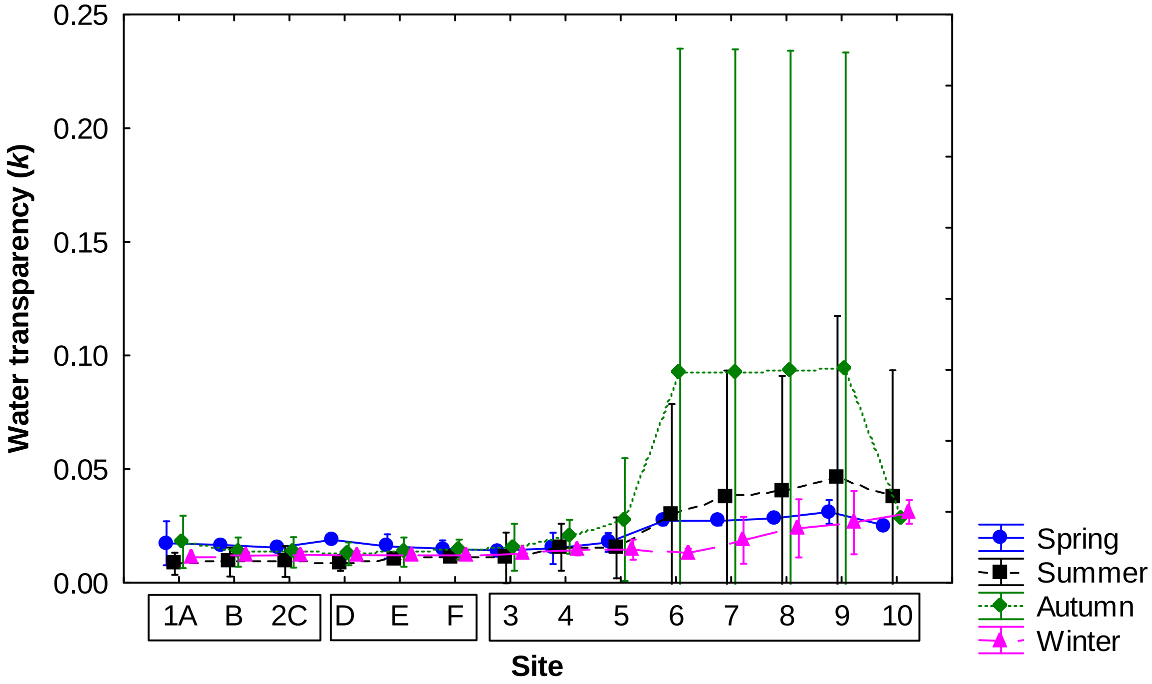

Figure 2.2b Mean water transparency (*k*) for all seasons, at all sites in the Kowie Estuary recorded between 2004 and 2005. Error bars indicate 95 % confidence intervals. (1A, B, 2C = mouth region of estuary; D, E, F = marina channels; 3 – 10 = middle and upper reaches).

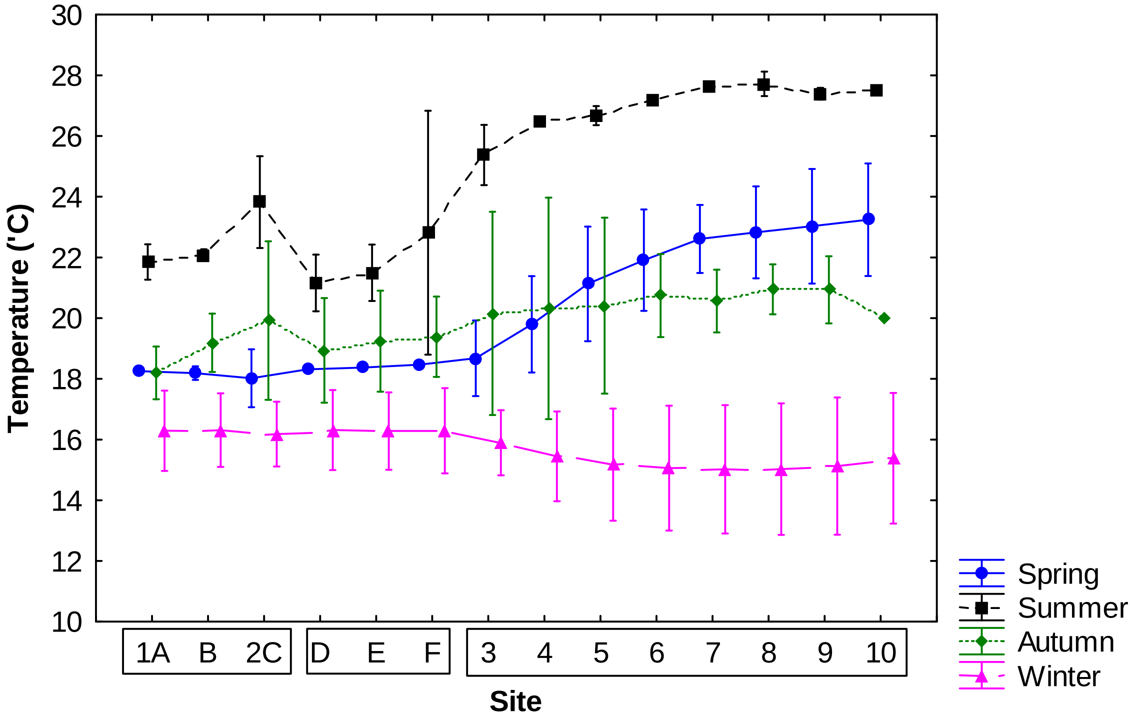

Figure 2.2c Mean water temperature (˚C) for all seasons, at all sites in the Kowie Estuary recorded between 2004 and 2005. Error bars indicate 95 % confidence intervals. (1A, B, 2C = mouth region of estuary; D, E, F = marina channels; 3 – 10 = middle and upper reaches).

Temperature showed a significant relationship with larval fish density for the assemblage as a whole in the Kowie Estuary (*P* < 0.01). However, the relationship with salinity and water clarity was not significant at this analysis level. Temperature and salinity were only found to show a significant relationship with density of *Gilchristella aestuaria* (Clupeidae), and gobiids *Caffrogobius nudiceps* and *Caffrogobius gilchristi* (*P* < 0.01). Furthermore, the multiple linear regression analyses showed that temperature, salinity and water transparency also showed some relationship with *Solea turbynei* (Soleidae) density (*P* < 0.01) in the estuary. Temperature also had a positive relationship with *Omobranchus woodii* (Blenniidae) densities and salinity had a significant relationship with *Psammogobius knysnaensis* (Blenniidae) densities (*P* < 0.01) (Table 2.1).

Table 2.1 Multiple linear regression statistics for the relationship between larval fish density and environmental variables (salinity, temperature and water transparency) for all taxa combined and the dominant species in the Kowie Estuary. r^2 = coefficient of determination, r = correlation coefficient, F = *F*-statistic, Sa = salinity, Te = temperature, Tu = turbidity (water transparency). Significance level = $P < 0.01$

Taxon	r^2	r	F	Significant variable
All taxa	0.2	0.4	16.3	Te
Dominant species				
Gilchristella aestuaria	0.3	0.5	28.3	Te, Sa
Omobranchus woodii	0.2	0.5	20.4	Te
Caffrogobius nudiceps	0.1	0.3	6.4	Te, Sa
Caffrogobius gilchristi	0.1	0.3	8	Te, Sa
Psammogobius knysnaensis	0.1	0.3	9.4	Sa
Solea turbynei	0.3	0.5	26.2	Te, Sa, Tu
Blenniid 1	0.02	0.1	1.4	

2.3.2 General species composition and estuary association

A total of 11 125 larval and early juvenile fishes were caught in this study, representing 23 fish families and 38 different species. A small number of families dominated the catch in the Kowie Estuary. Gobiidae made a significant contribution to the overall catch in both the marina (83 %) and the estuary (72 %), followed by Blenniidae (marina 12 %; estuary 13 %). The family Soleidae made the next significant family contribution in the estuary sites (8 %), but made an insignificant contribution in the marina. Other families which made significant contributions to both regions of the Kowie include Syngnathidae, Clupeidae and Gobiesocidae (Figure 2.3).

Gilchristella aestuaria, (Clupeidae) contributed 47.04 % to the total catch with *Caffrogobius gilchristi* (Gobiidae) contributing 24.7 %. Other Gobiidae species, namely *Caffrogobius nudiceps* and *Psammogobius knysnaensis* contributed 10 % and 3.92 % respectively. The marine spawned species, *Solea turbynei*, contributed 2.66 % to the total catch and was primarily found in the upper reaches of the estuary (Table 2.2).

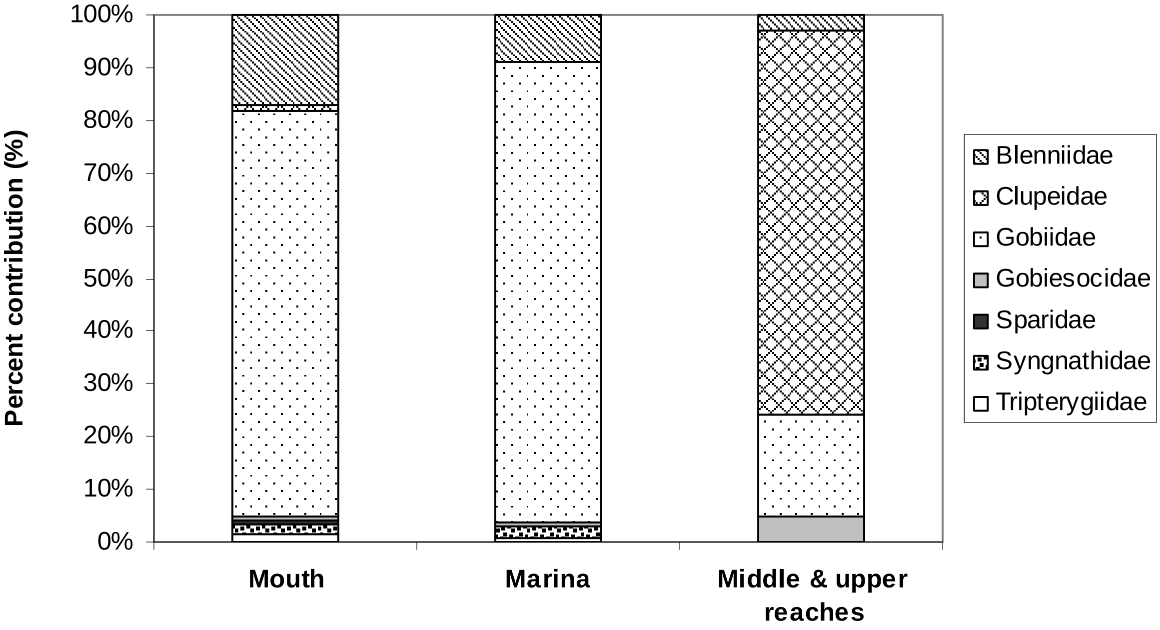

Figure 2.3 Family composition of larval fishes in the mouth (1A, B, 2C), marina channels (D, E, F) and middle and upper reaches of the estuary (3 – 10) showing percent contribution of the different family groups represented in the estuary during the study (2004 – 2005). Families contributing < 1 % to overall catch are excluded.

The catch was dominated by estuarine resident species (category I), contributing a total of 91 % to the total catch. Marine dependents (category II) followed, contributing 4 % to the total catch and marine stragglers (category III) contributed 1 % to the total catch over the study period.

Table 2.2 Species composition, seasonal density, body length, developmental stage (dev. stage) and estuary association (est. assoc) of larval fishes caught in the Kowie Estuary study. Pr = preflexion, Fl = flexion, Po = postflexion, Ju = juvenile

Family	**Species**	**Mean density (range) (No. / 100 m^3)**								**Body length (mm)**		**Dev. Stage**	**Est. assoc.**
		Summer		**Autumn**		**Winter**		**Spring**		**Mean**	**Range**		
	All species combined	**938.8**	**(30.8-29441.0)**	**80.5**	**(0-706.1)**	**45**	**(0-332.2)**	**451.8**	**(0-3925.8)**				
Ambassidae	*Ambassis gymnocephalus*	0.0	-	0.5	(0-10.5)	0	-	0	-	23. 6	20.0-27.3	Po	IIb
Anguillidae	*Anguilla mossambica*	0	-	0.1	(0-4.8)	0	-	0.05	(0-2.9)	43	32.7-43	Le	V
Atherinidae	*Atherina breviceps*	2.7	(0-98.8)	0.7	(0-8.5)	0.1	(0-3.9)	1.3	(0-14.2)	10.9	3.3-25.7	Pr, Fl, Po	Ib
Blenniidae	*Omobranchus woodii*	13.6	(0-85.0)	0.2	(0-5.4)	0	-	11.6	(0-66.5)	4.1	3.3-10.1	Pr, Fl, Po	Ia
	Blenniid 1	30.8	(0-709.6)	16.6	(0-260.4)	3.6	(0-40.5)	0.5	(0-11.2)	4	1.9-13	Pr, Po	-
Clinidae	*Clinus superciliosus*	0	-	0.38	(0-20.7)	0	-	0	-	17.5	7.1-17.5	Po	Ib
Clupeidae	*Etrumeus whiteheadi*	0.8	(0-26.2)	0.6	(0-7.2)	0	-	0	-	23.7	9.4-32.8	Pr, Fl, Po	III
	Gilchristella aestuaria	684.6	(0-29243.4)	43.8	(0-630.1)	0.39	(0-12.0)	182.4	(0-3765.0)	15.5	1.0-70	Pr, Fl, Po, Ju	Ia
Cyprinidae	Cyprinid 1	0.26	(0-6.3)	0	-	0	-	0	-	4	3.3-4.5		IV
Elopidae	*Elops machnata*	0.7	(0-15.7)	0.2	(0-5.8)	0	-	0.2	(0-4.8)	34.9	15.4-47.6		IIa
Engraulidae	*Engraulis japonicus*	0.5	(0-19.7)	0.5	(0-13.0)	0	-	0	-	18.8	13.0-26.0		III
Gobiidae	*Caffrogobius gilchristi*	118	(0-2025.8)	2.1	(0-31.9)	0.25	(0-5.6)	168.8	(0-1892.6)	3.6	1.4-25.2	Pr, Fl, Po	Ib
	C. nudiceps	51.9	(0-1119.4)	4.3	(0-38.3)	9.3	(0-73.1)	42.8	(0-406.8)	4.6	1.7-19.24	Pr, Fl, Po	Ib
	Glossogobius callidus	12.4	(0-146.3)	0.7	(0-8.9)	0	-	6	(0-147.2)	7.8	2.3-19.6	Po, J	Ib
	Psammogobius knysnaensis	10	(0-162.1)	1.5	(0-42.1)	1.4	(0-27.0)	29.8	(0-228.9)	2.8	12.5-20.8	Pr, Po	Ib
	Redigobius dewaali	0.3	(0-16.5)	0.2	(0-4.3)	0	-	0.5	(0-11.7)	3.3	1.9-8.3	Pr, Fl, Po	Ib
	Gobiid 1	0	-	0	-	0	-	1	(0-23.7)	4.2	1.8-4.2	Pr	-
	Gobiid 2	0	-	0	-	0	-	0.1	(0-4.3)	2.8	3.8	Pr	-
Gobiesocidae	*Eckloniaichthys scylliorhiniceps*	2.4	(0-25.1)	0.1	(0-4.4)	0.4	(0-18.5)	0.3	(0-7.4)	5.6	3.1-11.4	Pr, Fl, Po	III
Haemulidae	*Pomadasys olivaceum*	0	-	0.5	(0-12.9)	0.4	(0-12.1)	0	-	18.6	15.4-24.4	Po	III
Hemiramphidae	*Hyporhamphus capensis*	0.6	(0-9.7)	0.2	(0-4.4)	0	-	0	-	21.3	3.4-33.5	Po, Ju	IIc
Monodactylidae	*Monodactylus falciformis*	0.3	(0-12.3)	1.9	(0-12.0)	0.1	(0-4.0)	0.2	(0-5.1)	11.1	3.2-17.4	Po, Ju	IIa
Mugilidae	Liza sp.	0.3	(0-10.5)	0.2	(0-10.0)	0.3	(0-11.8)	0.1	(0-4.2)	17.5	10.6-21.1	Po	-
	Myxus capensis	0.1	(0-5.2)	0.1	(0-4.3)	0.5	(0-18.5)	0	-	21.4	20-23.1	Po	V

Table 2.2 cont. Species composition, seasonal density, body length, developmental stage (dev. stage) and estuary association (est. assoc) of larval fishes caught in the Kowie Estuary study. Pr = preflexion, Fl = flexion, Po = postflexion, Ju = juvenile

Family	**Species**	**Mean density (range) (No. / 100 m^3)**								**Body length (mm)**		**Dev. Stage**	**Est. assoc.**
		Summer		**Autumn**		**Winter**		**Spring**		**Mean**	**Range**		
Percophidae	Percophid 1	0	-	0.2	(0-9.2)	0	-	0	-	5.5	5.5	Po	-
Sciaenidae	*Argyrosomus japonicus*	0.1	(0-5.3)	0	-	0	-	0	-	4.1	5	Pr	IIa
Serranidae	Serranid 1	0	-	0.0	(0-2.2)	0	-	0	-	8.9	9.3	Po	-
Soleidae	*Heteromycteris capensis*	0	-	0	-	0.3	(0-9.2)	1	(0-23.8)	4.2	2.2-25.7	Pr, Po	IIb
	Solea turbynei	0.1	(0-4.8)	0.2	(0-8.9)	22.8	(0-318.2)	0.5	(0-28.4)	8.2	1.9-18.4	Pr	IIb
	Soleid 1	0.4	(0-7.3)	0.2	(0-11.5)	0	-	1.8	(0-59.3)	3.5	1.25-5.2	Pr	-
Sparidae	*Diplodus capensis*	0	-	0.2	(0-5.2)	0.4	(0-9.9)	0.6	(0-16.9)	14.9	10.4-19.8	Po	IIc
	Diplodus cervinus	0	-	0.1	(0-5.4)	0.3	(0-11.8)	0.1	(0-2.9)	15.3	10.4-19.8	Po	III
	Rhabdosargus holubi	0.1	(0-4.3)	0.4	(0-5.2)	0.8	(0-11.8)	0.5	(0-12.7)	18.3	10.4-22.8	Po	IIa
Syngnathidae	*Syngnathus temminckii*	4.4	(0-65.9)	2.8	(0-36.3)	0.8	(0-18.5)	1.9	(0-10.8)	12.8	10-34.3	Pr, Po	Ib
Tetraodontidae	*Amblyrhynchotes honckenii*	0.1	(0-3.4)	0	-	0	-	0	-	4.7	4.7	Pr	III
Tripterygiidae	Tripterygiid 1	3.4	(0-64.8)	1	(0-19.3)	0.1	(0-5)	0	-	12.8	3.4-23.9	Pr, Fl, Po	-
Unidentified	Unidentified 1	0	-	0.1	(0-4.9)	0	-	0	-	6.2	6.2	Pr	-
	Unidentified 2	0	-	0.2	(0-9.2)	0	-	0	-	5.5	5.5	Pr	-

2.3.3 Spatial and temporal trends in species composition and estuary association

Species contribution at each site in the Kowie Estuary indicates that there is high dominance within the estuary and a clear switch of this dominance from the lower sites to the middle and upper reaches. *Caffrogobius gilchristi* (category Ib) dominates the lower reaches of the estuary whilst *Gilchristella aestuaria* (category Ia) dominates in the upper reaches (Figure 2.4). Species diversity decreases and dominance by *G. aestuaria* increases toward the upper reaches. Marina sites (D, E, F) as well as the artificial mouth area (B, 2C) were dominated by fewer species than the remaining sites in the estuary.

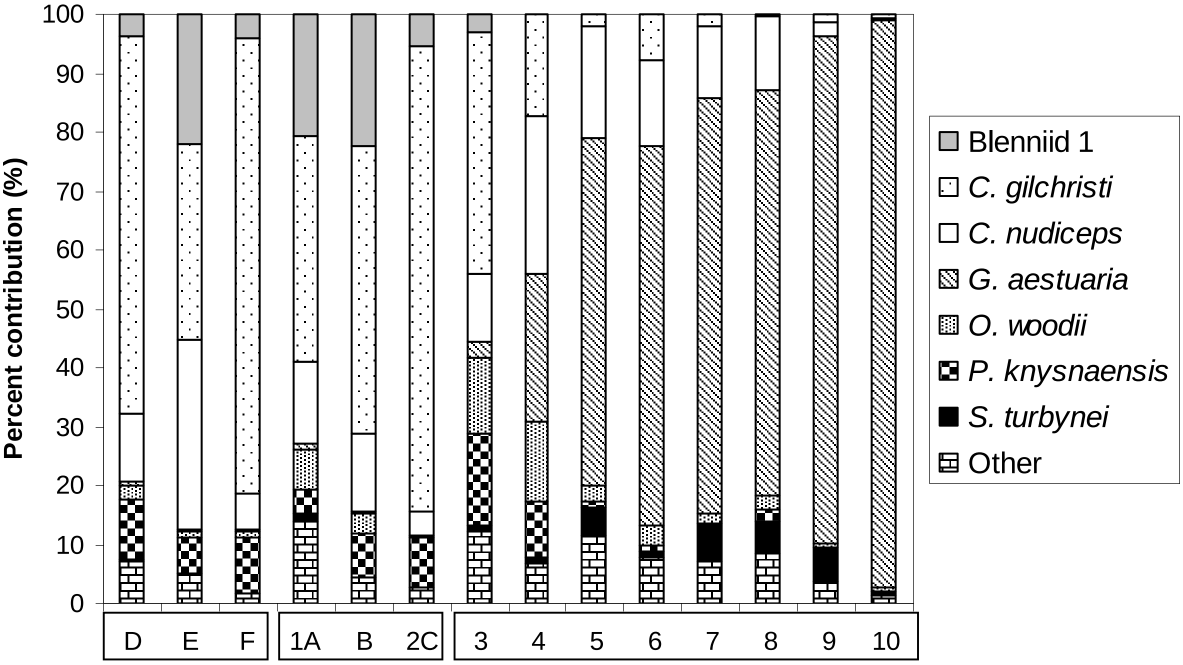

Figure 2.4 Percentage contribution of species at all sites in the Kowie Estuary in 2004 and 2005. Only species which contributed over 3 % individually to the total catch were included, the remaining species were grouped as “other” as their contribution to overall catch was negligible. Brackets indicate the three zones in the estuary (D, E, F = marina; 1A, B, 2C = lower reaches, 3 – 10 = middle and upper reaches).

Estuarine residents were (I) present throughout the year in both 2004 and 2005 in the Kowie Estuary. Similarly, estuarine dependent (II) species were found throughout the estuary in all seasons in 2004 and 2005. These species were more abundant in the upper estuary sites and almost absent from the lower reaches and marina. Marine stragglers (III) were confined to the middle and lower reaches (Sites 1A – 7) and absent from the upper reaches, except in winter, where their range was slightly extended into site 9. Freshwater migrants (IV) were present in the upper reaches in all seasons. A small number of catadromous species (V) were found in the mouth in spring and summer (Table 2.3).

Table 2.3 Seasonal presence (x) or absence ( ) of fishes in various estuary dependent categories (Whitfield 1998) at all sampling stations in the Kowie Estuary (2004 and 2005). Sp = spring, Su = summer, Au = autumn, Wi = winter.

		Site													
		D	E	F	1A	B	2C	3	4	5	6	7	8	9	10
Estuarine residents	Sp	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Category I	Su	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Au	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Wi	x	x	x	x	x	x	x	x	x	x	x	x	x	
Estuarine dependents	Sp		x				x	x	x		x	x	x	x	x
Category II	Su				x						x	x	x	x	x
	Au						x		x	x	x	x	x	x	
	Wi	x						x	x	x	x	x	x	x	x
Marine stragglers	Sp				x										
Category III	Su			x	x						x	x			
	Au	x	x	x	x	x	x				x	x			
	Wi	x							x				x	x	
Freshwater species	Sp														
Category IV	Su								x			x	x		
	Au														
	Wi														
Catadromous species	Sp				x										
Category V	Su				x										
	Au									x			x		
	Wi									x				x	

Seasonal use of the estuary by individual species was evident (Figure 2.5). Generally, Gobiid species were present throughout the year, except, *Redigobius dewaali* and *Glossogobius callidus*. Some marine spawned species such as *Rhabdosargus holubi* and *Solea turbynei* were also present in the system in all seasons.

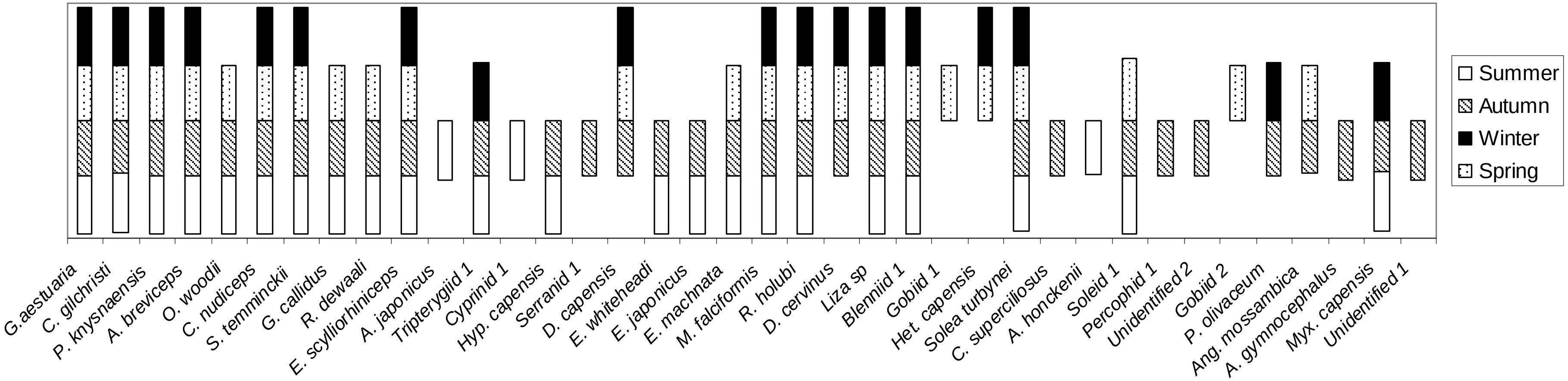

Figure 2.5 Seasonal presence and absence of all species caught in the Kowie Estuary in 2004 and 2005. Some species were present throughout the year, however many species were only present seasonally.

No significant inter-annual difference was found in larval fish density in spring or summer catches. However, a significant inter-annual difference in larval fish catch was found in autumn (H = 14.9; $P > 0.05$) and winter (H = 22.3; $P > 0.05$) (Figure 2.6) of the two study years.

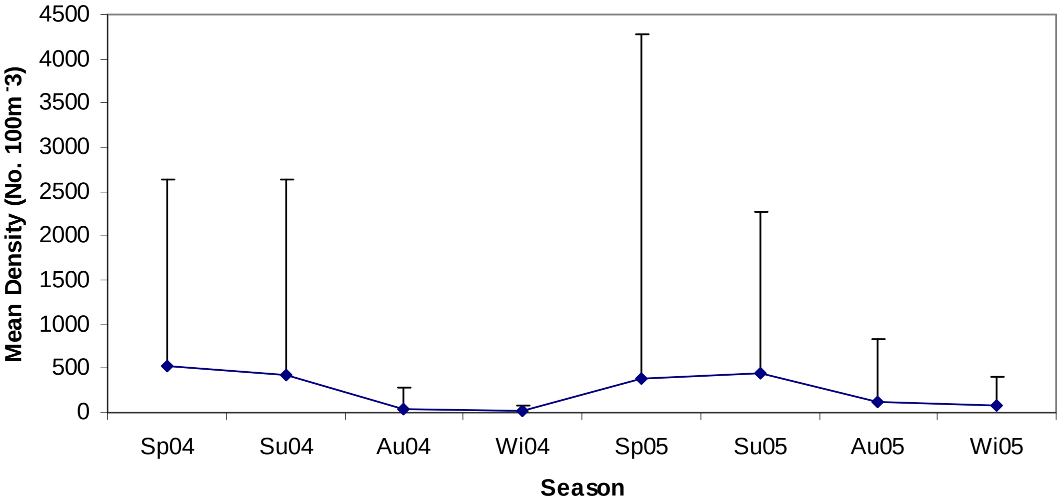

Figure 2.6 Mean (range) larval fish density recorded sequentially per season in 2004 and 2005 in the Kowie Estuary. Sp = spring, Su = summer, Au = autumn, Wi = Winter, 04 = 2004, 05 = 2005. Bars indicate range.

However, significant differences in larval fish density occurred between different seasons on an inter-annual basis. Summer and winter, summer and autumn, spring and autumn and spring and winter ($P > 0.05$) yielded the greatest variability. No significant differences in density were evident between the warmer months (summer and spring) and between the cooler months (winter and autumn). Mean summer larval fish densities were 938.8 larvae per 100 m^3 (29 441.0 – 30.8), followed by spring 451.8 larvae per 100 m^3 (3925.8 – 0), autumn 80.5 larvae per 100 m^3 (706.0 – 0) and winter 45 larvae per 100 m^3 (332.2 – 2).

No significant difference was found in larval fish density between different sites along the length of the estuary (H = 16.3; P = 0.24). Furthermore, no significant difference was found when comparing overall larval fish density between the lower estuary (1A, B, 2C), marina (D, E, F) and main channel (3-10) ($P > 0.05$).

Larval fish densities did vary with salinity zones in the estuary ($H = 12.87$; $P = 0.005$). A significant difference was found to exist in larval fish density between the euhaline and mesohaline salinity zones ($P = 0.013$). Larval fish density in the mesohaline zone was the highest, at 577.7 larvae per 100m^3 (3925.8 – 9.51), followed by the oligohaline zone, with 461.0 larvae per 100m^3 (1543.0 – 14.8), the euhaline zone, with 211.6 per 100m^3 (2245.7 – 0) and the polyhaline zone with 181.9 larvae per 100m^3 (936.6 – 0) respectively.

2.3.4 Spatial and temporal variation in development stage and body length

Preflexion larvae numerically dominated the larval fish catches in the Kowie Estuary during the study period, followed by flexion, postflexion larvae and early juveniles. Spring and summer months were characterized by higher numbers of preflexion larvae. Contributions of flexion, postflexion and early juveniles typically increased in autumn and winter (Figure 2.7).

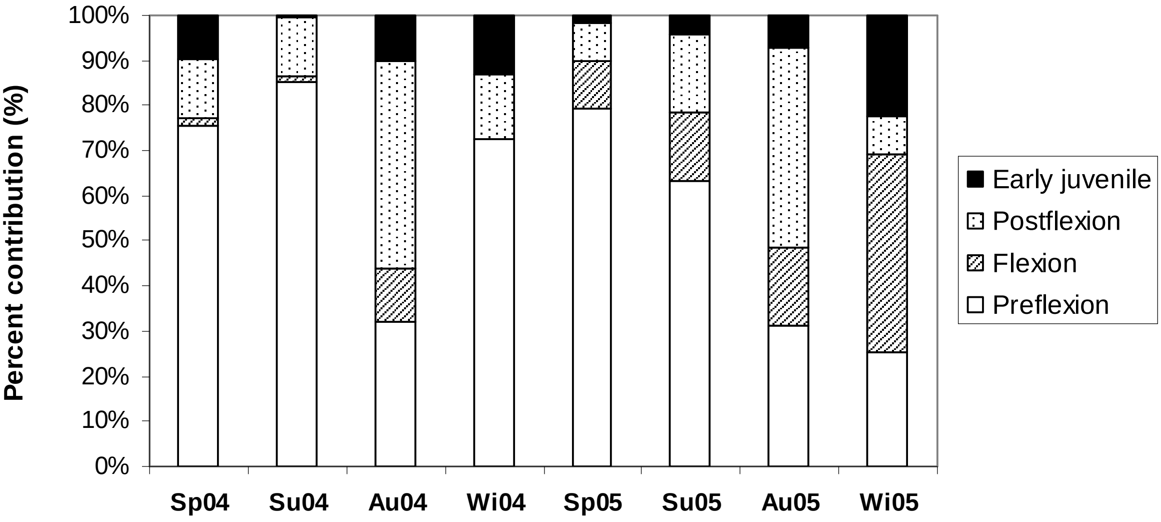

Figure 2.7 Temporal trends in development stage in the Kowie Estuary. Sp = spring, Su = summer, Au = autumn, Wi = winter, 04 = 2004, 05 = 2005, e.g. Sp04 = Spring 2004.

Lower estuary sites, particularly the marina sites (D, E, F) were almost entirely dominated by preflexion larvae. Post flexion and early juvenile fishes were restricted to upper reaches, and absent or not reflected in mouth and marina site catches (Figure 2.8).

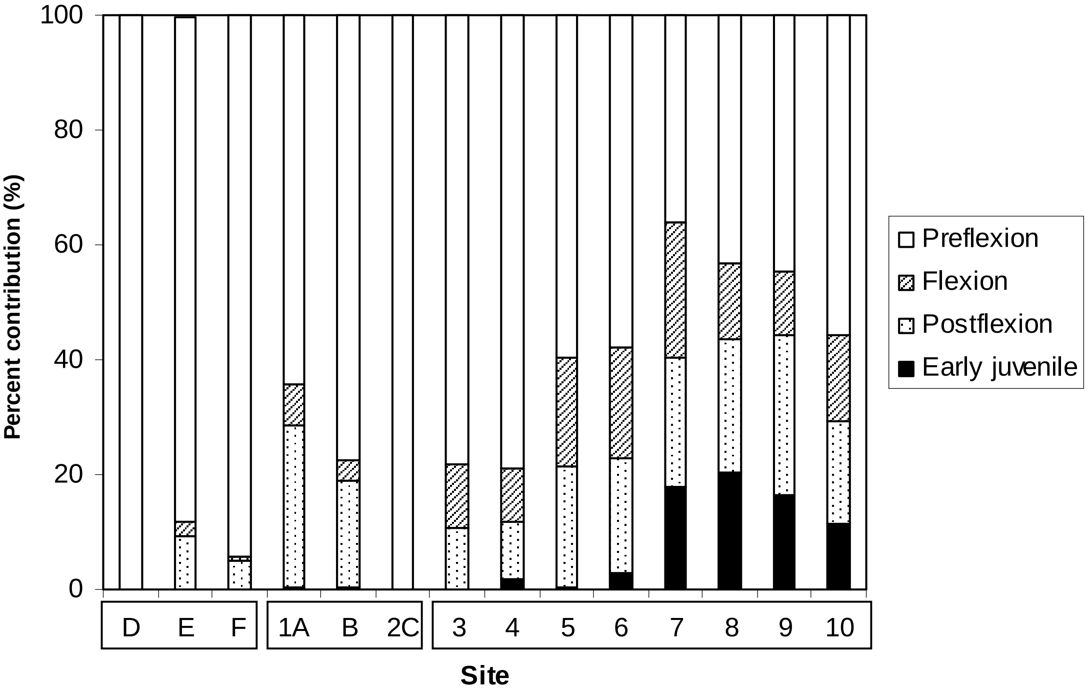

Figure 2.8 Spatial variation of all developmental stages of larval fishes, including early juveniles, at all sites in the Kowie Estuary in 2004 and 2004. Brackets indicate marina sites (D, E, F), lower estuary (1A, B, C) and middle and upper reaches (3 – 10). Marina sites are not continuous with the lower, middle and upper reaches.

There was a large range in mean body length of the dominant species in the Kowie Estuary, except for Blenniid 1, where specimens collected ranged only from 1.3 to 1.9 mm. Of the remaining top seven species, *Caffrogobius gilchristi* larvae recorded had a mean body length of 3.6 mm (range 1.4 – 25.2), *Caffrogobius nudiceps* had a mean body length of 4.4 mm (1.7 - 21.2), *Gilchristella aestuaria* recorded in the estuary had a mean body length of 15.5 mm (1.0 – 70.0), *Omobranchus woodii* mean body length was 4.1

mm (3.3 – 10.1), *Psammogobius knysnaensis* 2.8 mm (1.3 – 20.8) and *Solea turbynei* had a recorded mean body length of 8.2 mm and ranged from 1.9 – 18.4 mm. A good representation of all larval and early juvenile size classes were evident for recorded species in the Kowie Estuary.

2.3.5 Community analysis

A community analysis approach was used to assess relationships between season, salinity zone and site in the Kowie Estuary. Upper sites in the Kowie Estuary showed least similarity to lower estuary and marina sites and similarity increased the closer sites were together (SIMPER). Sites 1A to 4 in the lower reaches were dominated the gobiid by *Caffrogobius nudiceps*. Site 5 had an equal contribution of *C. nudiceps* and the estuarine round herring, *Gilchristella aestuaria*, whereas sites 6 to 10 were dominated by *G. aestuaria* (SIMPER). As a result of the overwhelming dominance of estuary resident species, two clusters, based on estuarine residents and marine spawned species were assessed separately and shown in a Bray-Curtis similarity dendrogram (Figure 2.9). Clusters in the dendrogram were sorted and difference between groups in the clusters where determined using ANOSIM. It was found that there were significant differences in upper reaches sites and lower artificial mouth and marina sites. The difference reduced the closer the sites were.

The multidimensional scaling plot (MDS) (Figure 2.10a) indicates that there are clear groupings in response to location, especially main channel sites (3-10) versus marina (D, E, F) and lower (1A, B, 2C) channel sites for estuarine residents in the Kowie Estuary.

The MDS generated for marine spawned and catadromous species shows communities are not significantly shaped by location (Figure 2.10b).

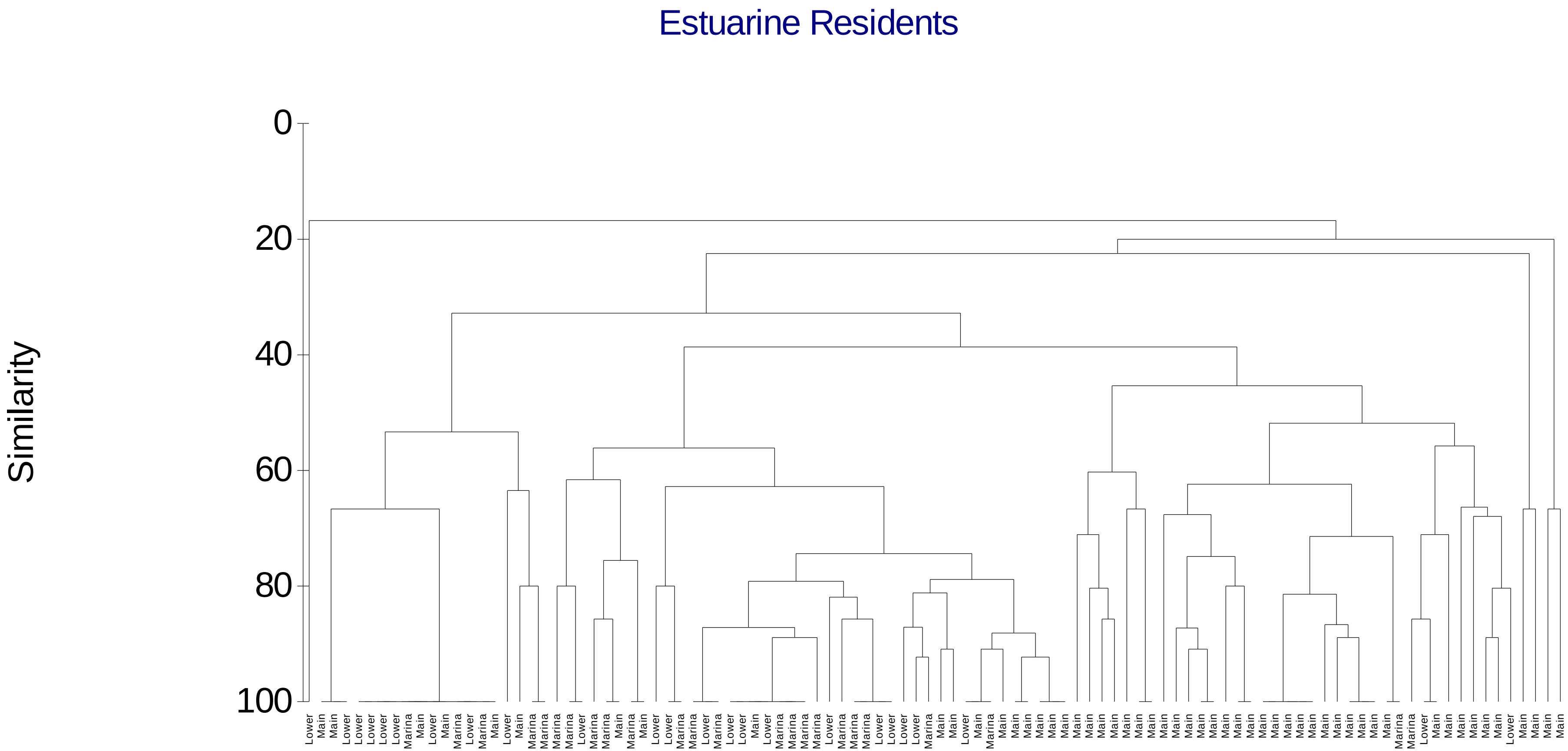

Figure 2.9a Bray Curtis similarity dendrogram indicating percentage similarity of samples, measured by the presence or absence of estuarine residents (category I) in the Kowie Estuary in 2004 and 2005. R = 0.178 (Significance level 0.1 %)

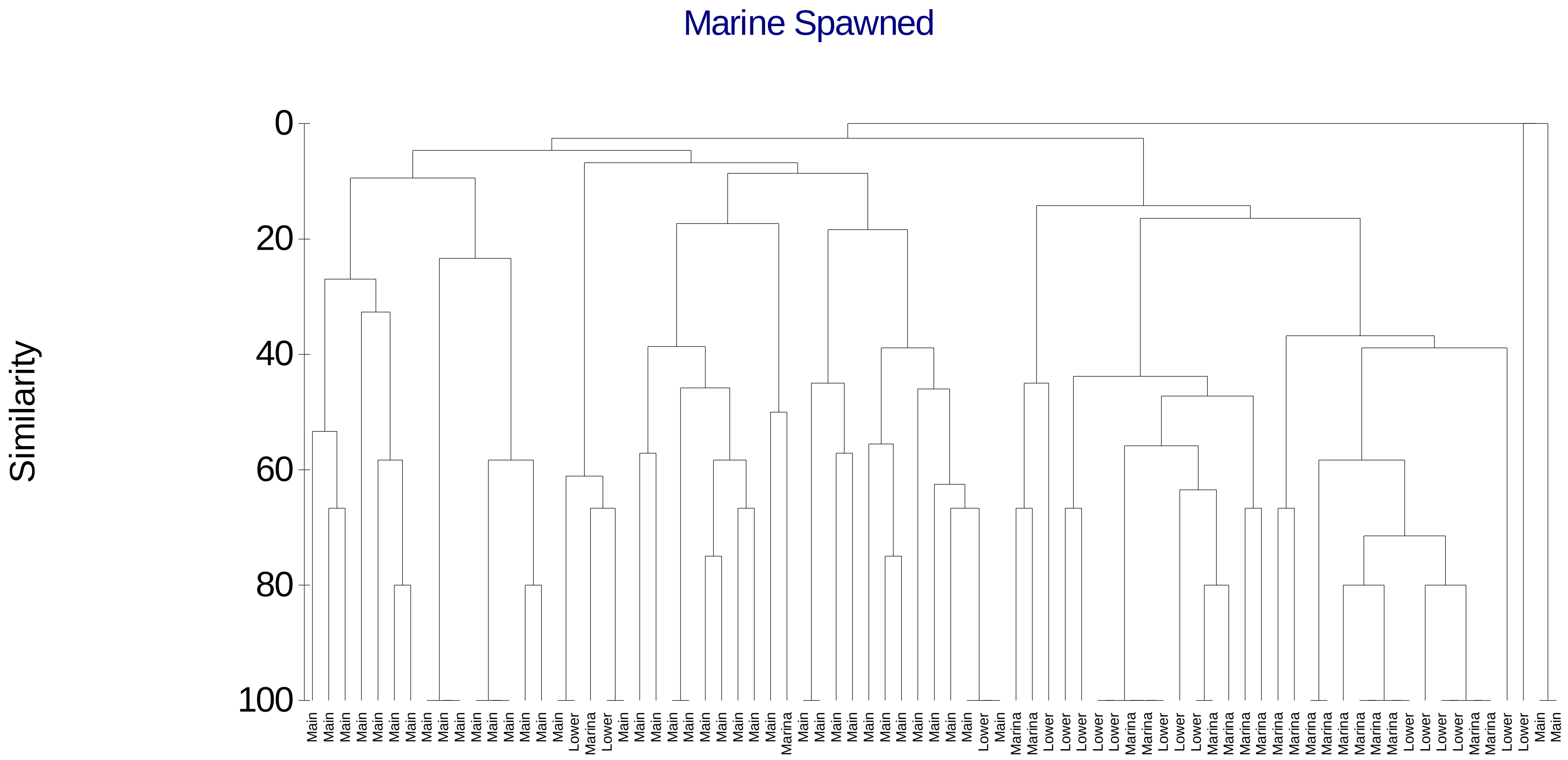

Figure 2.9b Bray Curtis similarity dendrogram indicating percentage similarity of samples, measured by the presence or absence of marine spawned species and catadromous species (categories II, III, V) in the Kowie Estuary in 2004 and 2005. R = 0.178 (1.7 % Significance level).

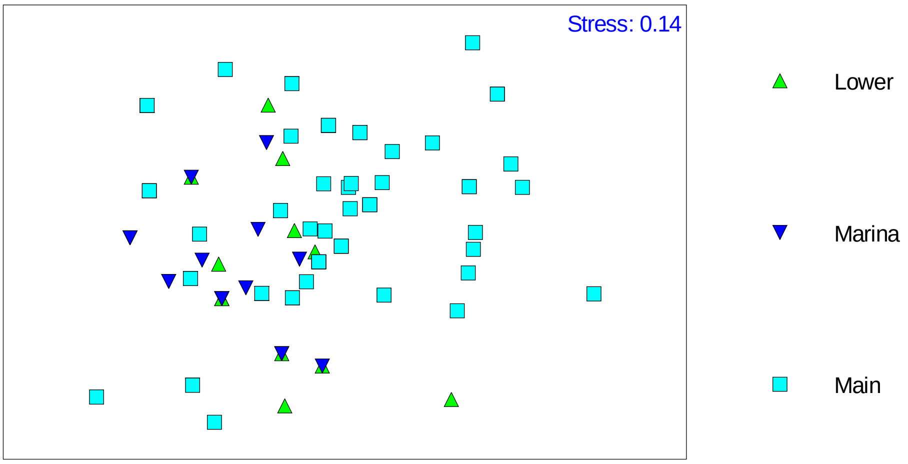

Figure 2.10a Multi dimensional scaling plot (MDS) of estuarine resident species in the Kowie Estuary for all species (Stress 0.14).

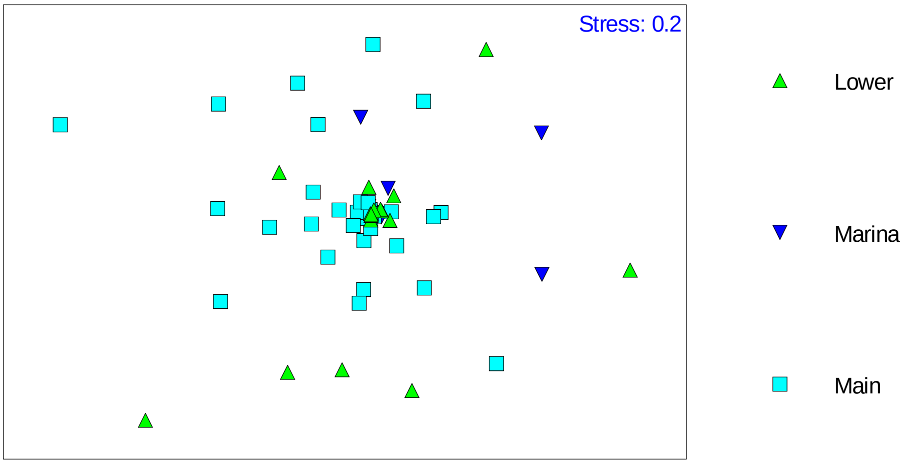

Figure 2.10b Multi dimensional scaling plot (MDS) of marine spawned species in the Kowie Estuary for all species (Stress 0.2).

2.3.6 Temporal and spatial variation in species richness and diversity

Species richness and diversity varied with season and year in the Kowie Estuary (Table 2.4).

Table 2.4 Species richness and diversity in all seasons and years sampled in the Kowie Estuary in 2004 and 2005.

	Species richness (*d*)	Species diversity (*H*')
SEASON		
Spring 04	0.49	1.32
Summer 04	0.48	1.32
Autumn 04	0.44	1.31
Winter 04	0.43	1.35
Spring 05	0.36	1.22
Summer 05	0.38	1.30
Autumn 05	0.44	1.46
Winter 05	0.45	1.29

Species richness and species diversity also varied spatially in the Kowie Estuary over the study period. Overall, when the marina channel sites (D, E, F) were compared to the lower estuary sites (1A, B, 2C) and main channel sites (3-10) it was found that the main channel sites had the highest species richness (*d* = 3.34), followed by the lower channel sites (*d* = 3.25) and marina channel sites (*d* = 2.25) respectively. Species diversity overall was found to be highest in the lower channel sites (*H'* = 1.46), followed by the marina channel sites (*H'* = 1.34) and the main estuary channel sites (*H'* = 1.31). More specifically, within the marina, site E, the central marina channel site, had the highest richness and diversity (*d* = 2.35; *H'* = 1.51), followed by site D (*d* = 1.79; *H'* = 1.28) and site F (*d* = 1.73; *H'* = 1.15). Within the lower reaches specifically, the first site in the estuary, 1A, had the highest richness and diversity (*d* = 2.98; *H'* = 1.70). In the main estuary channels, richness and diversity at different sites were similar, however site 6 had the highest richness (*d* = 2.89) followed by sites 7 (*d* = 2.74), 8 (*d* = 2.70), 4 (*d* = 2.43), 9 (*d* = 2.36), 5 (*d* = 2.31) and 3 (*d* = 2.20), with the upper most site, site 10, having both the lowest richness and second lowest diversity (*d* = 1.29, *H'* = 1.11). In terms of species diversity, site 4 had the highest (*H'* = 1.69), followed by 3 (*H'* = 1.59), 5 (*H'* = 1.40), 6 (*H'* = 1.38), 8 (*H'* = 1.21), 7 (*H'* = 1.28), 9 (*H'* = 1.02). The Kowie Estuary is characterized by high dominance and low evenness (Figure 2.11), with *C. gilchristi* and

G. aestuaria dominating the catches in the Kowie Estuary in 2004 and 2005. Due to this high dominance the estuary had an uneven (*J*) distribution.

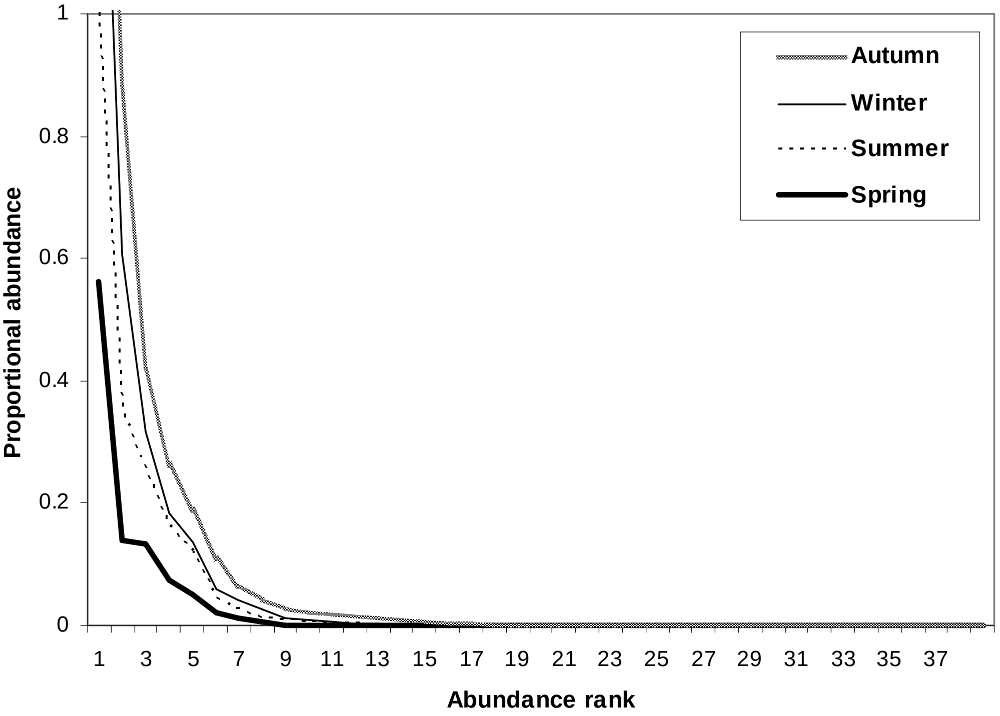

Figure 2.11 Rank abundance curve indicating species richness (*d*), diversity (*H'*) and species evenness (J) for the Kowie Estuary in spring, summer, autumn and winter in 2004 and 2005.

2.4 Discussion

Temporal and spatial variations in temperature (˚C), water clarity (*k*) and salinity were evident in the Kowie Estuary during the study period. Peak larval fish densities occurred in summer and spring, coinciding with warmer water temperatures, seasonal fish spawning and peak recruitment (Whitfield 1998; Whitfield & Marais 1999; Strydom *et al*. 2003). Multiple linear regression revealed that some species had a significant relationship with some environmental variables (Table 2.1), however r^2 values were low, indicating high variability. Whilst low r^2 values are typical for plankton samples, its poses limits for interpretation and validity of results.

The larval fish catch over the study period comprised 23 fish families and 38 taxa. Species diversity is typically higher in permanently open estuaries such as the Kowie and much lower in intermittently open systems (Strydom *et al.* 2003). Similarly, a composition study on a Mediterranean coastal lagoon, found that species diversity and richness was highest in channels that connected directly to the sea and less so in “confined” areas of the lagoon (Perez-Ruzafa *et al.* 2004). Higher catches of resident species such as *Omobranchus woodii*, *Psammogobius knysnaensis*, *Caffrogobius gilchristi* and *Gilchristella aestuaria* in the Kowie Estuary appears typical for a permanently open temperate South African systems (Strydom *et al.* 2003). The marina sites had similar trends in terms of benthic gobiid species compared to the rest of the estuary. However, marine stragglers where almost completely excluded from the marina sites and mostly preflexion larvae occurred in the artificial marina channels. The marina and lower estuary sites appeared to be quite sterile, with low diversity and abundances, compared to the rest of estuary and compared to the lower reaches of other similar estuaries.

Catadromous species were restricted to the upper sites of the system, whilst marine stragglers occurred sporadically in the lower, middle and upper reaches. Typically, stragglers were confined to the lower reaches of estuaries (Whitfield 1998; Strydom et al. 2003; Pattrick et al. 2007). This result is not typical for estuaries with an adequate freshwater supply (Strydom et al. 2003). A study conducted where freshwater species are restricted to upper reaches and marine migrants in lower reaches, was also found by Pattrick *et al.* (2007) in the Mngazi Estuary and Montoya-Maya & Strydom (2009) in south and west coast estuaries, in South Africa. A similar trend occurred in the Caete River Estuary in Northern Brazil, where it was found that marine larval species were restricted to the mouth region whilst freshwater species were predominantly confined to the upper reaches (Barletta-Bergan *et al.* 2002). These trends indicate typical spatial distribution of species along a salinity gradient in estuaries depending on species salinity tolerance. In the absence of a continual baseflow of freshwater and therefore a more homogenous salinity-environment, less tolerant marine species are able to penetrate further upstream as happened in the Kowie Estuary during restricted river flow periods.

Marine straggler species such as *Etrumeus whiteheadi, Engraulis japonicus, Ecklonaichthys scylliorhiniceps, Pomadasys olivaceum, Diplodus capensis, D. cervinus, Syngnathus temminckii and Amblyrhynchotes honckenii* were all present in the middle to upper reaches of the Kowie Estuary. The marine spawned *Solea turbynei*, made a notable contribution to the overall catch in the estuary. Furthermore, early developmental stages of these Soleids, occurred persistently in the upper reaches of the system for reasons unclear. These preflexion *S. turbynei* larvae were probably easily swept from nearby spawning areas up the estuary through the permanently open, deep channelled mouth with the dominant flood tide and so became entrained in the system.

Estuarine resident species dominated the catches in the Kowie Estuary (91 %), followed by euryhaline marine species which contributed 4 % to the total catch. The marine contribution to overall catch is lower in the Kowie than in neighbouring systems. A study by Strydom *et al.* (2003) showed that permanently open estuaries were dominated by estuarine dependent marine species (category II) (47 %), and estuarine residents (category I) (50 %) dominated the catches in intermittently open estuaries. The estuarine resident, *Gilchristella aestuaria,* contributed 47.6 % of the total catch. The dominance of *G. aestuaria* in temperate South African estuarine systems is typical as has been found in numerous past studies (Harris *et al.* 2001; Strydom *et al.* 2002; Pattrick *et al.* 2007). In the present study, peaks in densities of *G. aestuaria* occurred in the summer months. These peaks probably coincide with productivity peaks associated with lower salinities and freshwater input which trigger spawning of this species (Strydom *et al.* 2002). Past studies have found that *G. aestuaria* is most commonly found in high densities in areas of low salinities and in freshwater rich systems (Strydom *et al.* 2002; Pattrick *et al.* 2007).

Salinity zones play an important role in structuring larval fish density patterns and species occurrence in temperate South African estuaries. The mesohaline zone (5-15) was the region of highest mean density. Typically, the mesohaline zone in estuaries is associated with the river-estuary interface (REI) and is generally a region of high productivity (Wooldridge & Bailey 1982; Snow *et al.* 2000; Strydom *et al.* 2003). As in the Kowie Estuary, Pattrick *et al.* (2007) found that the mesohaline zone in the Mngazi Estuary supported the highest densities of larval fish. Similarly, Strydom *et al.* (2003) and Montoya-Maya & Strydom (2009) found that the mesohaline zone had significantly higher densities of larval fish and early juveniles. Access to these regions of high productivity is thought to influence the feeding of larval fish (Govoni *et al.* 1985; Strydom *et al.* 2003). Exposure to this favourable, food rich environment influences growth rates, which reduces the pelagic larval duration therefore, larvae have a greater chance of avoiding predation, accessing settlement habitats and ultimately reaching maturity (Searcy & Sponaugle 2000; Bergenius *et al.* 2005). The REI zone is essentially a frontal zone that is created between fresh and saline water bodies and in response to high concentrations of suspended particulate matter (Snow *et al.* 2000). Thus, food patches are directly related to water stratification and the fact that the mesohaline zone is most typically associated with the REI zone may explain why this salinity zone is a region characteristic of food patches (Govoni *et al.* 1985; Searcy & Sponaugle 2000). For these reasons, the REI zone probably forms the basis for ecological functioning in estuaries (Snow *et al.* 2000; Strydom *et al.* 2003) and is vital for the larval phase of fishes, particularly those of resident species and category II marine species relying on estuarine nurseries.

The lower reaches of the Kowie Estuary including the mouth and marina channels (sites 1A, B, 2C, D, E and F) are all sites that have artificial stone-packed walls. Species found in the plankton in this area were almost entirely preflexion larvae, with the switch to flexion, postflexion and early juvenile fish only occurring much further up the estuary. This is not a typical finding for permanently open estuaries. The lack of flexion and postflexion larvae as well as early juveniles may be as a result of the undesirable habitat that has been created by the artificial walling in the mouth region and marina of the Kowie Estuary or higher predation in these channels as a result of habitat changes.

Refuge such as aquatic plants and shallow marginal waters in estuaries are particularly important for larval and juvenile fish to avoid displacement and predation by piscivores (Strydom 2003; Strydom & Wooldridge 2005). It has been found that estuaries that are comprised of more substrata and aquatic vegetation typically have higher species diversity (Whitfield 1999; Strydom 2003). Additionally, a lack of habitat heterogeneity that comes with artificial channelling has been found to reduce species numbers, as was the case in an Australian estuary with a deepened artificial channel (Young & Potter 2003a, b). It appears that a similar problem occurs in the Kowie marina with the prevalence of preflexion larvae and reduced species diversity compared to the lower reaches of other unaltered estuaries in the region (Whitfield 1994; Strydom *et al*. 2003). Additionally, as a result of the steep walled lower reaches, predation increases significantly due to a lack of shallow refuge habitat. This phenomenon is termed ‘deep water predation’. Typically, shallow, vegetated areas provide refuge, with an increase in water depth resulting in an increase in predator size and thus predation pressure (Manderson *et al*. 2004).

The urban nature of the Kowie Estuary also means that pollution, in and around the water ways, also negatively affect the system (Whitfield 1998; 1999). Freshwater abstraction for urban use, loss of nursery habitat in the lower reaches and local pollution from town and harbour activities all affect the quality of nursery area in the Kowie Estuary. As is typical for most fish populations, the success of the larval phase underpins the success of the fish population (Lemberget & McCormick 2009). Since estuarine recruitment in temperate South Africa occurs at the larval and juvenile phase in the early development of fishes (Strydom *et al*. 2003), if recruitment at the larval phase fails as a result of poor habitat availability for refuge in the lower reaches of a permanently open estuary, this leaves the juvenile fish stock in the estuary reliant on the success of juvenile recruitment into the estuary from the ocean. Fishing pressure is a major cause of mortality at this stage of development in the Kowie Estuary (N.A Strydom, pers. comm.). The extent of this loss to local fish stocks is as yet, not quantified.

2.5 Acknowledgements

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CHAPTER 3

TIDAL EXCHANGE OF LARVAL FISHES IN THE KOWIE ESTUARY, USING DRIFTING LIGHT TRAPS

3.1 Introduction

Estuaries are important nursery areas for young fishes worldwide (Neira & Potter 1994; Whitfield 1998; Strydom *et al*. 2003; Perez-Ruzafa *et al*. 2004; Ramos *et al*. 2006). Recruitment into temperate, South African estuaries often takes place as early as the postflexion stage in larval development (Strydom & Whitfield 2000). These larval fishes rely on both active swimming and passive tidal movements to aid their passage into nursery areas and maintain their position there (Whitfield 1989; Strydom & Wooldridge 2005; Aceves-Medina *et al*. 2008). The ebb and flood tides play an important role in exchange of larval fishes between estuary and ocean with significant energetic benefits occurring for larvae by "hitching a ride" on the tides (Trnski 2001).

International studies have mostly focused on the role of tidal stream transport on recruitment of larval fish into nursery areas and the influence of vertical and horizontal migrations on the movement of recruiting larvae in the estuary (Boehlert & Mundy 1988; Trnski 2001; Aceves-Medina *et al*. 2008). South African research focusing on the use of the tidal cycle by larval fish into nursery areas is limited to a few studies on tidal exchange in specific South African estuaries (Melville-Smith *et al*. 1981; Beckley 1985; Whitfield 1989; Strydom & Wooldridge 2005). The benefits of tidal transport are twofold but can also expose larvae to undesirable habitats (Boehlert & Mundy 1988). The avoidance of advection on the ebb or flood tide, which may expose larvae to unfavourable environments in nurseries is also poorly understood (Boehlert & Mundy 1988). In order to prevent being swept out to sea on ebb tides and swept up estuary on flood tides, larvae need to move to the shallow marginal water of an estuary, and out of the zone of displacement of reversing tides, in order to avoid displacement and ensure maintenance within ideal areas of the estuary (Beckley 1985; Whitfield 1989; Trnski 2001; Strydom and Wooldridge 2005).

Common methods used for assessing tidal exchange of small fishes include towed nets (Melville-Smith *et al*. 1981; Beckley 1985; Strydom & Wooldridge 2005), fine meshed seines (Beckley 1985) and fixed nets (Trnski 2001). It has been suggested that these methods are best used in combination in order to reduce individual gear selectively (Doherty 1987; Choat *et al.* 1993; Hickford & Schiel 1999; Strydom 2003). The use of drifting light aggregation devices as an alternative or to supplement net studies has yet to be determined in estuaries. Sampling for larval fish using light traps, although pioneered in the 1980's, is still a fairly under utilized technique and may prove to be especially useful for sampling shallow, slow flowing waters (Doherty 1987). Light traps function by exploiting the positive phototactic response displayed by many larval fish species (Doherty 1987; Hickford & Schiel 1999; Beckley and Naidoo 2003; Marchetti *et al.* 2004). In South Africa, the use of light aggregation devices to sample larval fishes is limited and was first conducted in KwaZulu Natal by Beckley & Naidoo (2003) in the Durban harbour. The first study to use light traps as a sampling method in estuaries was conducted by Strydom (2003) and proved to be a successful technique in shallow water in estuaries. The current study is the first of its kind in the world to use drifting traps to assess tidal exchange of larvae in estuaries.

The objective of this study was to investigate tidal exchange of larval fishes in the mouth of the permanently open Kowie Estuary. Specific aims of the study were to determine the composition and abundance of larval fish on ebb and flood tide states in the mouth of the Kowie Estuary. Furthermore, Thorrold (1992) found that static traps may exclude larvae that are not able to enter the trap due to the velocity of the surrounding water. Therefore, this study also aims to assess the suitability of a drifting trap in tidal flow. Additionally, results of the current study will be compared to the known larval fish composition in the mouth of the Kowie Estuary, which was determined using WP2 plankton nets. Results of tidal exchange of larval fishes in other temperate South African estuaries will also be compared to the trends in exchange of species in the mouth of the Kowie Estuary.

3.2 Methods

3.2.1 Study area

Larval fishes were collected from the mouth region of the permanently open Kowie Estuary (33°36’11”S; 26°54’10”E) situated in Port Alfred on the south east coast of South Africa (Figure 3.1). The climate in this region is classified as warm temperate, with a bimodal rainfall pattern occurring in autumn and spring (Whitfield 2000). The lower reaches of the estuary are heavily impacted by anthropogenic activities (Whitfield 2000) including the marina, which is characterized by artificial stone-packed walls. The river is approximately 70 km long, with an average depth of 2.75 m. The summer water temperatures range from 21 °C to 29 °C and winter temperatures range from 11 °C to 16 °C (Hill & Allanson 1971).

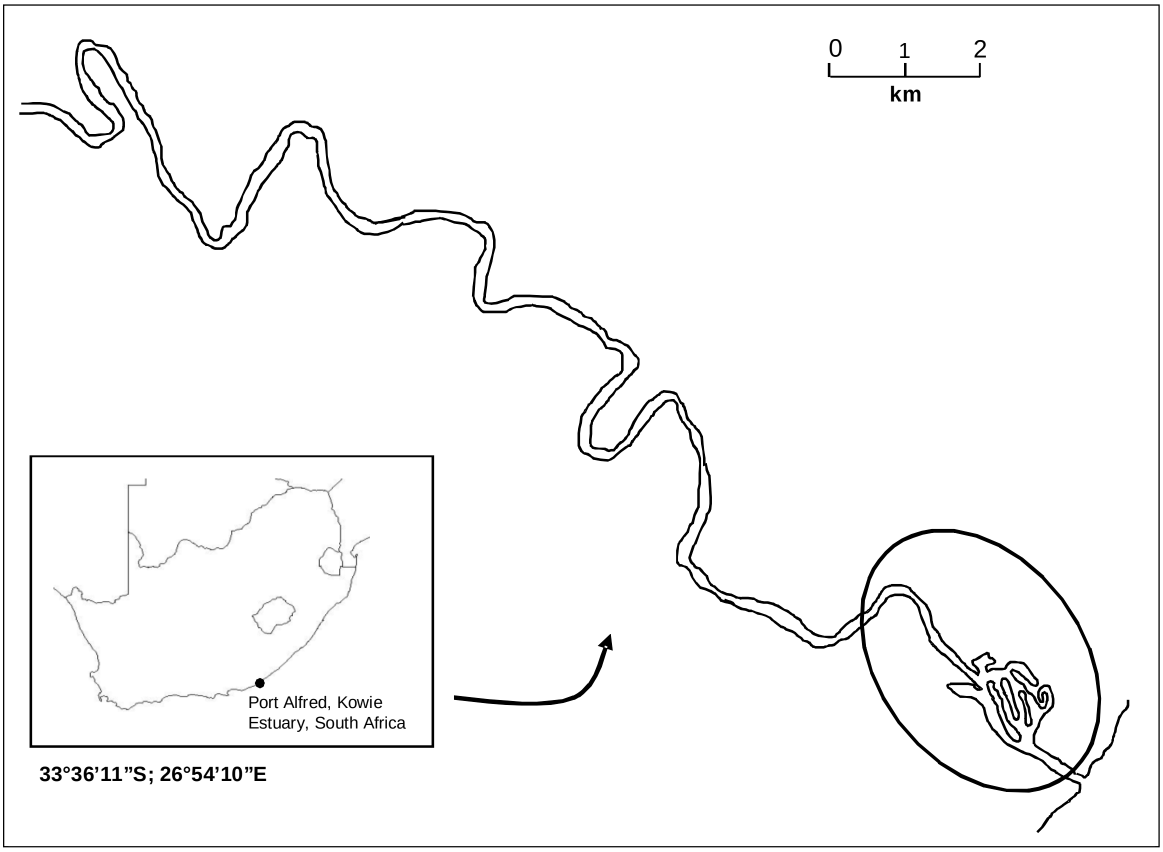

Figure 3.1 Geographical position of the Kowie Estuary, South Africa. Tidal exchange confined to the lower reaches and mouth of the estuary.

3.2.2 Field sampling and larval identification

Sampling was conducted using two light traps designed for estuarine application in shallow water (Strydom 2003). The perspex trap housing is comprised of two main compartments. The lower part of the trap contained the removable collection box where larvae were housed after capture. The sides of this removable box each had smaller mesh windows, in order to allow water to drain when removed from the water. This section of the trap also contained another smaller inner box, which served as the waterproof area and contained a 12 V 12 amp/h battery. The trap was switched on before deployment and then sealed (Strydom 2003). The upper part of the trap contained the sealed 8 watt fluorescent tube. Additionally, four sub surface entrance slits were present on each side of the upper compartment. Larvae would enter through the slits in the upper compartment and be drained through numerous circular holes into the bottom compartment of the trap. The trap was floated by a large styrofoam float (Strydom 2003).

Sampling commenced two hours after the turn of the ebb and flood tide and repeated four times per tide. The trap was deployed for 30 minutes at a time. All sampling took place between sunset and sunrise and was conducted every second night over two weeks coinciding with the dark moon period. Sampling was confined to lower and mouth regions of the estuary. Two replicate sampling trips took place from the 25 August 2008 to the 6 September (survey one) and the 23 September to the 5 October 2008 (survey two). For the purpose of this study, the two different sampling months are referred to as survey one and survey two respectively. These dates were chosen in order to coincide with peak recruitment into estuaries in the region (Strydom *et al.* 2003).

The light trap was lowered off the edge of a boat in the middle channel and left to drift with the tide for a 30 minute period at a time, ensuring minimal disturbance of the trap by the boat. The trap was emptied and contents preserved in 10 % buffered formalin solution after each 30 minute trapping interval.

A Global Positioning System (GPS) was secured to the top of the trap in order to determine distance travelled (m) as well as moving average (km) and overall average (km) per 30 minute deployment of the light trap. Additionally, at the start and end of each deployment, the physico chemical readings were noted using a YSI 6600 Multiprobe to measure salinity, temperature (°C) and turbidity (NTU).

In the laboratory the larval fish were separated from the remaining plankton and sorted, identified and measured. The larvae was identified to the lowest possible taxon in accordance with Smith & Heemstra (1986); Neira *et al.* (1998), Leis & Carson-Ewart (2000). Larvae were measured to the nearest 0.01 mm using a dissecting microscope fitted with an eye piece micrometer. For larger specimens, which were too big to be measured using the micrometer, vernier calipers were used to measure body length (BL). BL is defined as notochord length in preflexion and flexion larvae and standard length in postflexion and early juveniles (Strydom 2003). Larval fish catches were expressed as catch per unit effort (CPUE), where unit effort was defined as number of larvae per 30 minute deployment.

All larvae that were positively identified were grouped into estuary dependence categories (Table 3.1) according to Whitfield (1998):

Table 3.1 Categories of fish that utilize southern African estuaries (Whitfield 1998).

Categories	Description of categories
Ia	Estuarine species, breeding only in estuaries
Ib	Estuarine species that breed in estuaries and in the marine environment
IIa	Euryhaline marine species that usually breed at sea, juveniles are dependent on estuaries for nursery grounds
IIb	Euryhaline marine species that usually breed at sea, juveniles occurring in estuaries but also in the sea
IIc	Euryhaline marine species that usually breed at sea, juveniles occurring in estuaries but more abundant in the sea
III	Marine stragglers not dependent on estuaries
IV	Freshwater species
V	Catadromous species

3.2.3 Data analysis

All data was tested for homogeneity of variance and normality. Data that did not conform were analysed using non parametric methods. The statistical software package, STATISTICA 8.0 was used for all analyses. Environmental data, including salinity, temperature (°C) and turbidity, were tested for differences between ebb and flood tide and separated into survey one and survey two.

Biological data was also divided into survey one and two and analyzed accordingly after being tested for normality using a Levene's test and normal probability plots. Differences in species numbers and occurrence between the ebb and flood tide was investigated using one way ANOVA's.

Community analysis was conducted using the statistical software package, PRIMER v5.2.9. Group average hierarchical cluster analysis was used to determine if patterns existed in larval fish assemblage in relation to tide, sampling day and survey one and two. Densities were presence/absence transformed and Bray-Curtis similarity matrices were generated for tide. ANOSIM and SIMPER were used to determine similarities and dissimilarities between groups of samples. Margalef's species richness (d) and Shannon-Wiener's diversity (H') were used to describe the larval fish assemblages throughout the study. A significance level of $P < 0.05$ was used for all analyses unless otherwise stated. In terms of ANOSIM, an R value = 0 indicates that similarities between and within different groups are the same. An R = 1 indicates that all samples within a group were more similar to each other than any samples from other groups. SIMPER determines an individual components contribution toward dissimilarity within groups, the higher the value the more within site variability (Rees *et al.* 2004).

3. 3 Results

3.3.1 Environmental variability

No significant difference between the ebb and flood tide occurred for salinity (F = 1.22; P = 0.27) and water temperature (H = 1.68; P = 0.20) for survey one. However, turbidity was found to be significantly different on the ebb and flood tide (F = 5.08; P = 0.03), with the flood tide having a higher turbidity than the ebb.

No significant difference between environmental variables on the ebb and flood tide for survey two occurred during the study (salinity H = 2.85; $P = 0.09$, water temperature F = 0.36; $P = 0.55$ and turbidity F = 2.16; $P = 0.15$) (Figure 3.2).

No specific environmental parameters had a significant relationship with overall larval fish CPUE in the Kowie Estuary over the study period. However, mean temperature did influence *Omobranchus woodii* CPUE ($P < 0.05$). Abundance of *Myxus capensis* showed a significant relationship with turbidity ($P < 0.01$) (Table 3.2).

Table 3.2 Multiple linear regression for larval fish CPUE versus environmental variables for all taxa and the dominant species in the Kowie Estuary lower reaches. r^2 - coefficient of determination, r = correlation coefficient, F = *F*-statistic, Te = temperature, Tu = turbidity

Taxon	r^2	r	F	Significant variable	Significance level
All taxa	0.021	0.145	0.773	-	0.05
Dominant species					
Omobranchus woodii	0.089	0.298	3.508	Te	0.05
Sardinops sagax	0.005	0.068	0.166	-	0.05
Clinus superciliosus	0.022	0.147	0.793	-	0.05
Cirrhibarbis capensis	0.053	0.23	2.016	-	0.05
Myxus capensis	0.077	0.278	3.007	Tu	0.01

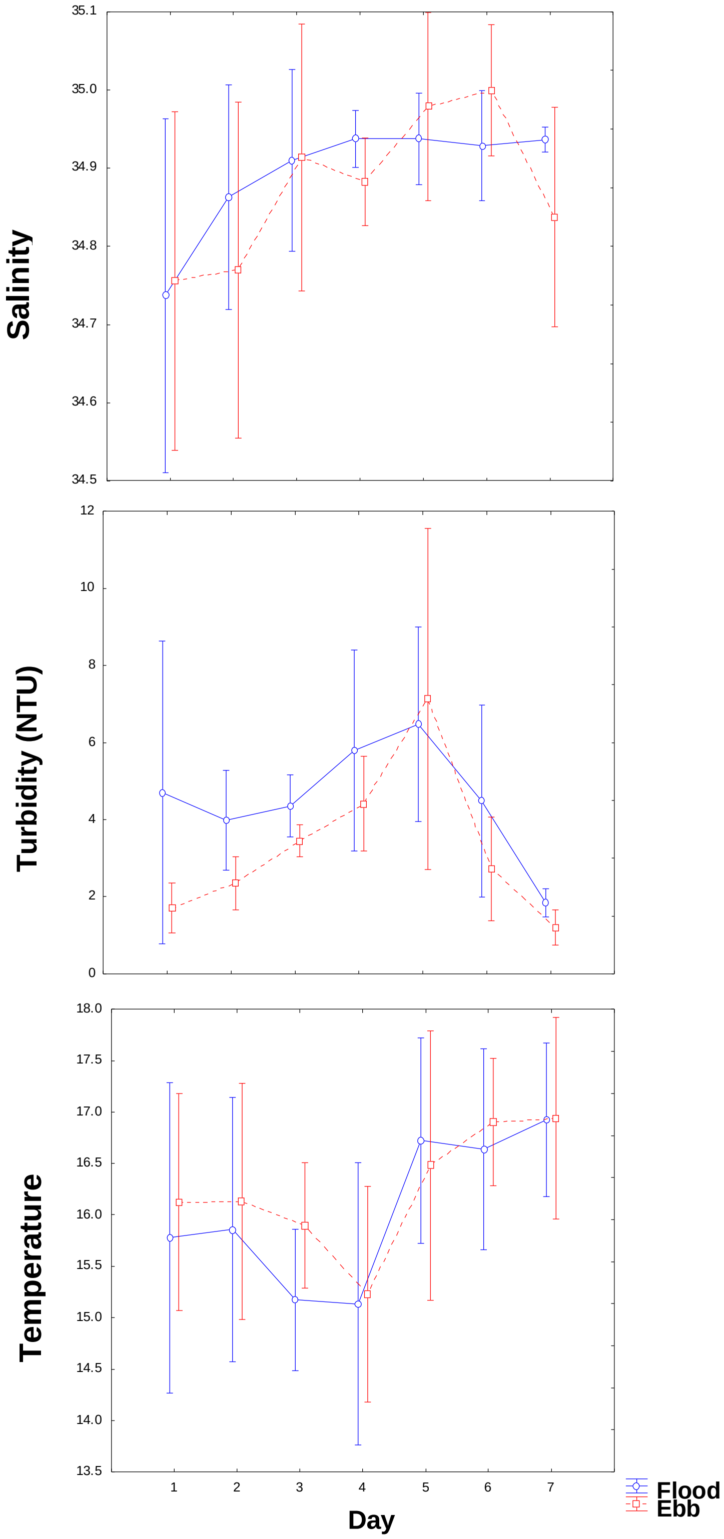

Figure 3.2 Mean environmental variability in the lower reaches of the Kowie Estuary during survey one and two in August and September 2008. Error bars indicate 95 % confidences intervals.

For both survey one and two, the light trap covered more distance on the ebb tide, although not significantly (*P* > 0.05) (Figure 3.3).

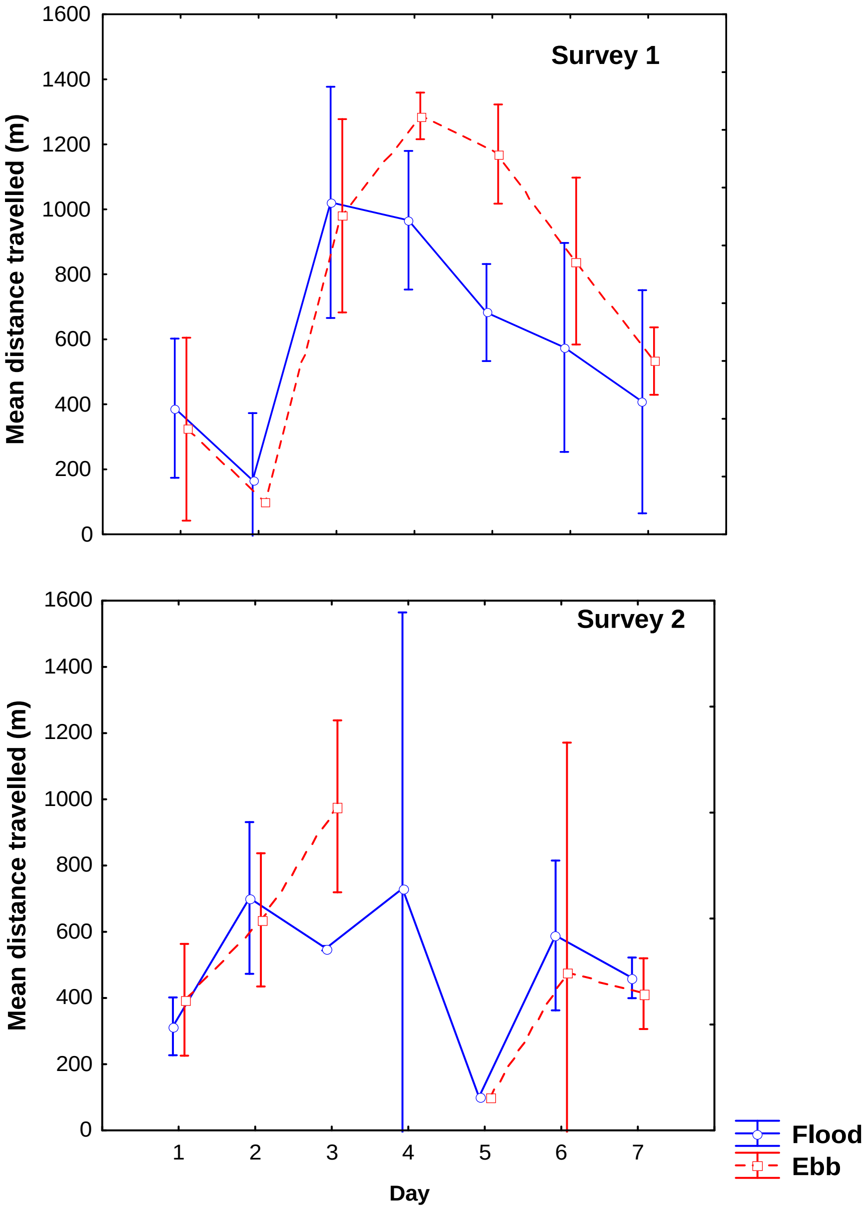

Figure 3.3 Mean distance travelled (m) by the light trap per 30 minute drift, per day in survey one and survey two, in the mouth region of the Kowie Estuary. No GPS data obtained for day four of the ebb tide, due to cloud cover. Error bars indicate 95 % confidence intervals.

3.3.2 Species composition

A total of 553 larval fish were caught during the study period representing nine families and 26 different taxa. Blenniidae contributed 43 % to the total larval fish catch, followed by Clupeidae (32 %) and Clinidae which contributed 17 %. The two dominant species were *Omobranchus woodii* (231 individuals; 42 %) and *Sardinops sagax* (172 individuals; 31 %) (Table 3.3). CPUE per 30 minute deployment was considerably lower compared to total larval fish number recorded in the estuary. Total CPUE over the entire study period consisted of 20 larval fish recorded per 30 minute deployment. A CPUE of 9 was recorded on the ebb tide and a CPUE of 11 larvae was recorded on the flood tide.

Estuarine resident larvae, that breed in estuaries (Ia) dominated the catches in the Kowie Estuary (47 %). Marine stragglers (III) followed, contributing 36 % to the total catch over the study period. Estuarine dependent larvae that may originate from both the estuarine and marine environment (Ib) contributed 11 % toward the total catch. Catadromous species (V) contributed 4 % toward the total catch, with the remaining category IIa, IIb, IIc and IV contributing between 0 and 1 % to the overall larval fish CPUE.

Postflexion larvae dominated the catches, contributing 95.6 % toward the overall catch. Preflexion and flexion (3.9 %) larvae were recorded in insignificant numbers.

Table 3.3 Species composition, overall catch, catch per tide, mean CPUE, body length, developmental stage (dev. stage) and estuarine association (E.A) for all fish caught in the Kowie Estuary over the study period. Pr = Pre flexion, F = flexion, Po = post flexion, Ia = estuarine residents, breeding only in estuaries, Ib = estuarine and marine spawners, IIa = euryhaline marine species, breed in ocean, juveniles dependent on estuaries for nursery grounds, IIc = euryhaline marine species, breed in ocean, juveniles found in estuaries but more abundant in sea, III = Marine stragglers, not dependent on estuaries, V = catadromous species

Family	**Species**	**Total catch**	**Ebb catch**	**Flood catch**	**Mean CPUE**	**Mean ebb CPUE**	**Mean flood CPUE**	**Body length (mm)**		**Dev. stage**	**E.A**
								Mean	**Range**		
	Estuary	**553**	**254**	**299**	**20**	**9**	**11**				
Blenniidae	Blenny 1	1	1	0	0	0	0	10.2	10.2 - 10.2	Po	?
	Blenny 2	3	3	3	0	0	0	13.01	9.1 - 18.55	F, Po	?
	Unidentified Blenny 3	8	2	6	0	0	0	9.1	8.5 - 9.1	F, Po	?
	Omobranchus woodii	231	65	166	8	2	6	16.8	10.5 - 27.8	Po	Ia
Clinidae	*Cirrhibarbis capensis*	23	10	13	0	0	0	26.9	21.1 - 31.9	Po	Ib
	Clinus cottoides	8	5	3	0	0	0	18.4	12.7 - 25.9	Po	Ib
	Clinus superciliosus	26	15	11	1	1	0	20	17.4 - 23.8	Po	Ib
	Clinid 1	1	0	1	0	0	0	15.16	15.16 - 15.16	Po	?
	Clinid 2	6	0	6	0	0	0	20	18.0 - 21.0	Po	?
	Clinid 3	2	0	2	0	0	0	17.6	17.0 - 18.2	Po	?
	Clinid 4	3	2	1	0	0	0	18.4	20.5 - 20. 5	Po	?
	Clinid 5	1	0	1	0	0	0	18.6	17.9 - 19.5	Po	?
	Clinid 6	2	1	1	0	0	0	16.5	16.5 - 16.5	Po	?
	Clinid 7	19	9	10	0	0	0	23.7	17.6 - 28.0	Po	?
Clupeidae	*Etrumeus whiteheadi*	3	1	2	0	0	0	14.2	5.1 - 23.6	F, Po	III
	Gilchristella aestuaria	1	1	0	0	0	0	9.8	9.8 - 9.8	Po	Ia
	Sardinops sagax	172	131	41	6	5	1	28.7	18.8 - 36.2	Po	III
Gobiesocidae	*Eckloniaichthys scylliorhiniceps*	1	0	1	0	0	0	4.3	4.3 - 4.3	Pr	III
Monodactylidae	*Monodactylus falciformis*	3	0	3	0	0	0	6.0	6.0 - 6.0	Po	IIa
Mugilidae	*Mugil cephalus*	4	0	4	0	0	0	21.2	9.5 - 28.4	Po	V
	Myxus capensis	17	0	17	1	0	1	11.7	5.2 - 13.7	Po	V

Table 3.3 cont. Species composition, overall catch, catch per tide, mean CPUE, body length, developmental stage (dev. stage) and estuarine association (E.A) for all fish caught in the Kowie Estuary over the study period. Pr = Pre flexion, F = flexion, Po = post flexion, Ia = estuarine residents, breeding only in estuaries, Ib = estuarine and marine spawners, IIa = euryhaline marine species, breed in ocean, juveniles dependent on estuaries for nursery grounds, IIc = euryhaline marine species, breed in ocean, juveniles found in estuaries but more abundant in sea, III = Marine stragglers, not dependent on estuaries, V = catadromous species

Family	**Species**	**Total catch**	**Ebb catch**	**Flood catch**	**Mean CPUE**	**Mean ebb CPUE**	**Mean flood CPUE**	**Body length (mm)**		**Dev. stage**	**E.A**
								Mean	**Range**		
Scorpididae	*Neoscorpis lithophilus*	3	1	2	0	0	0	12.2	11.7 - 12.6	**Po**	IIc
Sillaginidae	Sillago sp.	8	5	3	0	0	0	9.1	5.9 - 10.0	F, Po	?
Sparidae	*Diplodus capensis*	2	0	2	0	0	0	9.4	9.1 - 9.6	Po	IIc
	Rhabdosargus holubi	2	1	1	0	0	0	10.6	9.9 - 11.1	Po	IIa
	Sarpa salpa	1	1	0	0	0	0	16.3	16.3 - 16.3	Po	IIc

3.3.3 Catch variability

Catch per unit effort (CPUE) per 30 minutes was recorded to be higher during survey two (September) compared to survey one (August). No significant difference in CPUE occurred between the ebb and flood tide for both survey one (H = 0.91; *P* = 0.34) and two (F = 0.03; *P* = 0.86). However, overall CPUE was higher on the flood tide (Figure 3.4).

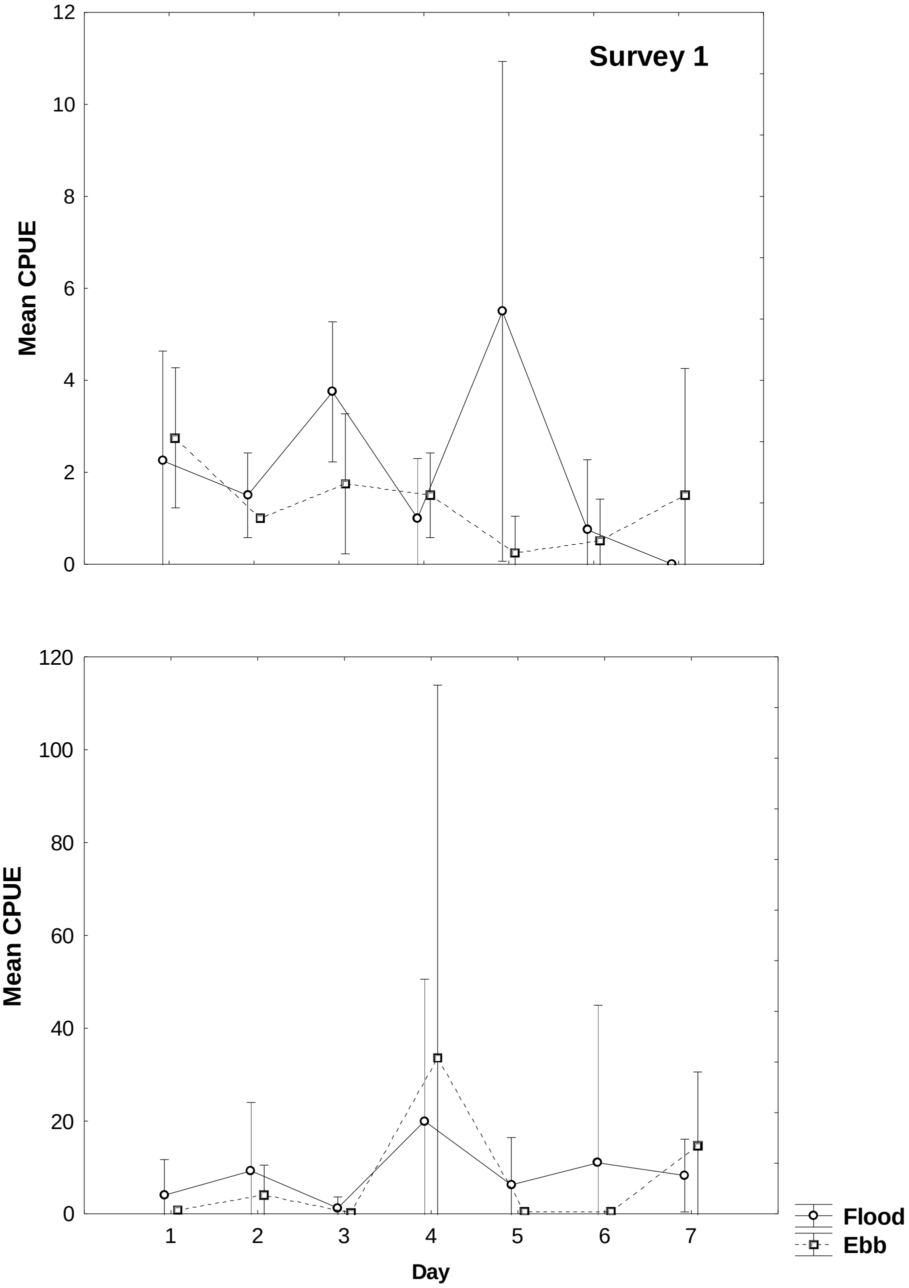

Figure 3.4 Mean CPUE of larval fish on the flood and ebb tide in the Kowie Estuary, for both survey one and two.

3.3.4 Larval exchange

Larval exchange during survey one (Figure 3.5) did not exhibit clear trends in exchange of species belonging to estuarine dependence categories. However, *Myxus capensis*, a catadromous mugilid was present on flood tides. In September, the marine spawned *Sardinops sagax*, dominated the ebb tide, whilst *Omobranchus woodii*, the estuarine resident, dominated the flood tide catches (Figure 3.6). Collectively (survey one and two) on the flood tide, catches were dominated by category Ia larvae (47 %). Marine stragglers (III) made up 36 % of the catch on the ebb tide, followed by category Ib (11 %).

Some species were tide specific or present in different numbers on the ebb or flood tides (Figure 3.5, 3.6). Euryhaline marine species (category II) such as *Monodactylus falciformis*, *Rhabdosargus holubi*, *Neoscorpis lithophilus*, and *Diplodus capensis* were recorded only on the flood tides, or appeared more dominantly on the flood tides during both surveys. However, *Sarpa salpa*, also a euryhaline marine species was recorded on the ebb tide and not at all on the floods (Figure 3.5). Positively identified category I estuarine species were predominantly recorded on the ebb tide, except for *Omobranchus woodii*, which was recorded predominantly on the flood tide (Figure 3.6).

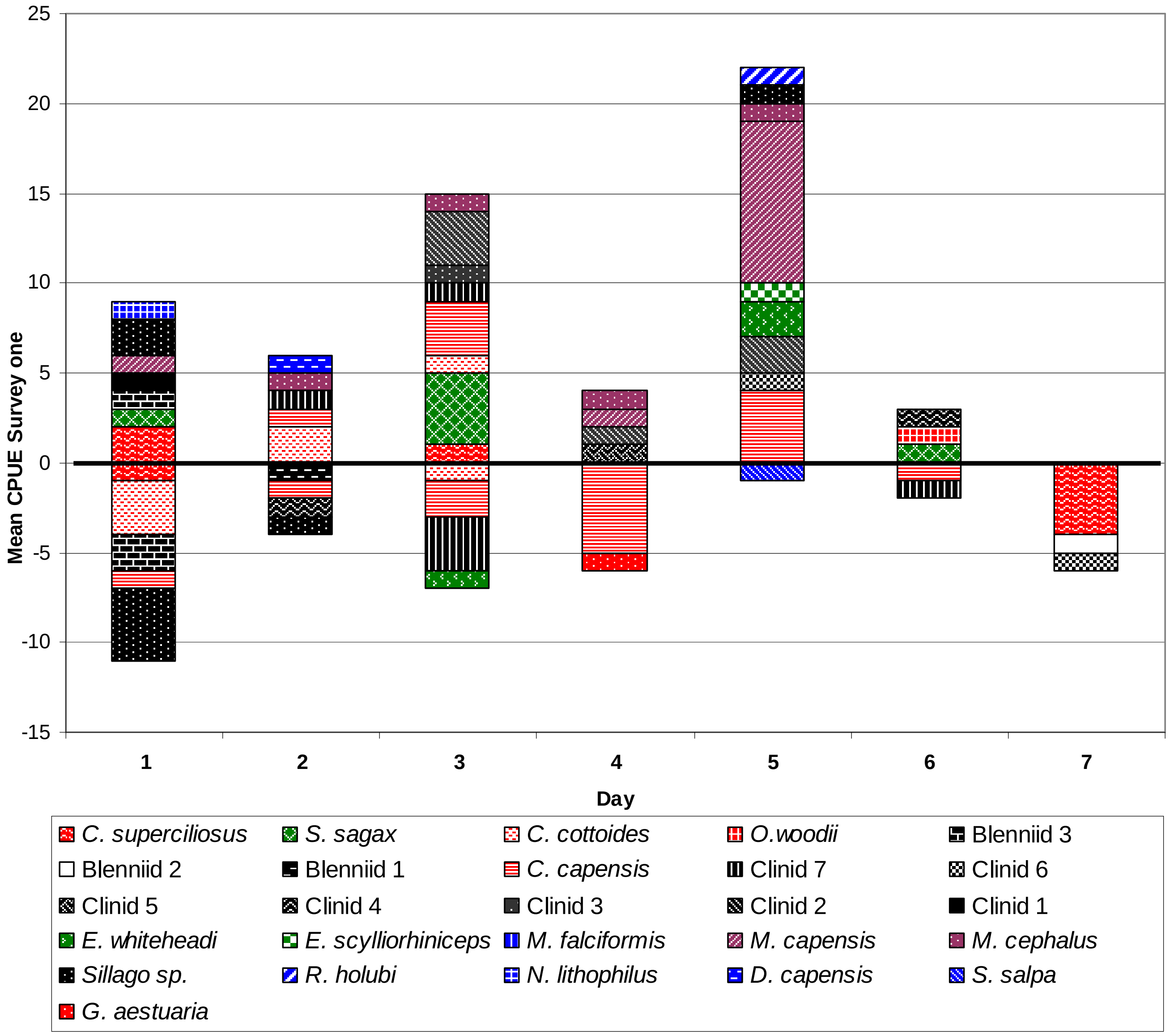

Figure 3.5 Larval fish exchange in the mouth region of the Kowie Estuary, using mean CPUE per tide for seven days in survey one. Red = estuary spawned, residents, Blue = estuarine dependent marine species, Green = marine stragglers, purple catadromous species, black & white = unknown. Flood tides indicated as positive values, ebb indicated as negative values.

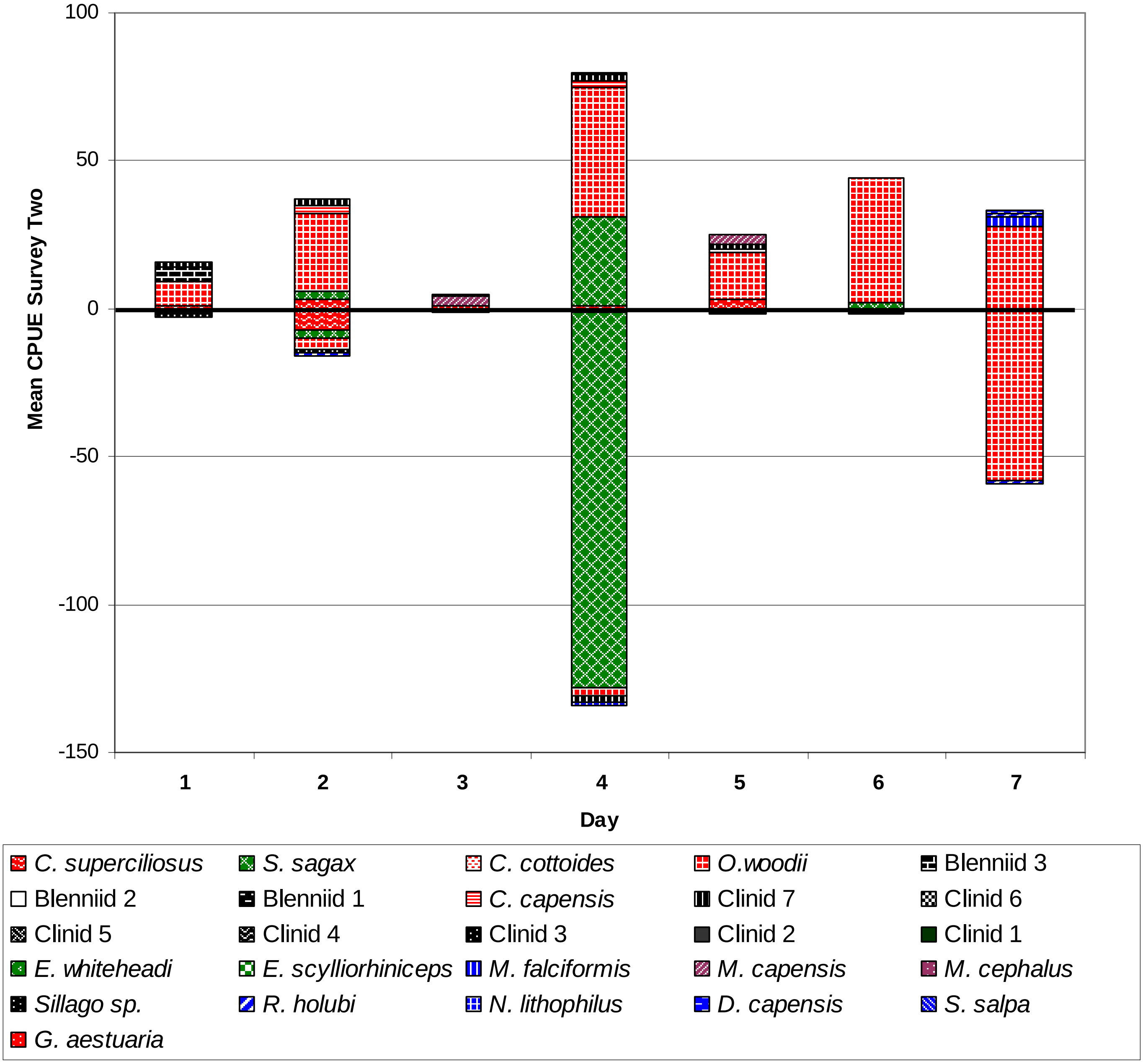

Figure 3.6 Larval fish exchange in the mouth region of the Kowie Estuary, using mean CPUE per tide for seven days in survey two. Red = estuary spawned, residents, Blue = estuarine dependent marine species, Green = marine stragglers, purple catadromous species, black & white = unknown. Flood tides indicated as positive values, ebb indicated as negative values.

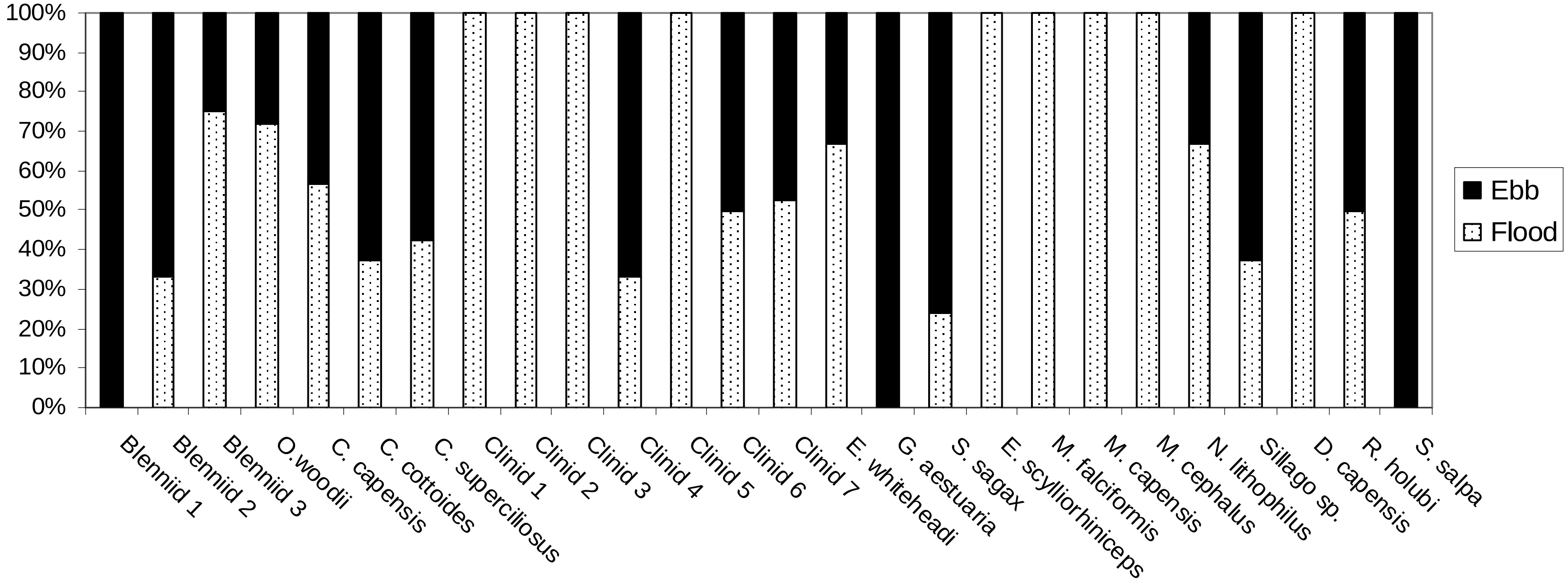

Figure 3.7 Overall percent contribution of all species to the ebb and flood tides catches throughout the entire sampling periods in the mouth of the Kowie Estuary using drifting light traps.

3.3.5 Community analysis

SIMPER determines the similarity between clusters formed in the Bray-Curtis Similarity Matrix (Figure 3.8). A good discriminating species, which may contribute toward habitat dissimilarity, typically has a low SD. Therefore, referring to Table 3.5 below, *Cirrhibarbis capensis* and *Clinus cottoides* are primarily responsible for the dissimilarity between tides. Species richness (*d*) and diversity (*H'*) was highest on the flood tide in survey one. Lowest species richness (*d*) and diversity (*H'*) occurred on the ebb tide in September (survey two) (Table 3.4).

Table 3.4 Species richness (*d*) and diversity (*H'*) for the flood and ebb tide in the Kowie Estuary in August (survey 1) and September 2008 (survey 2).

	Total species (S)	**Total individuals (N)**	**Species richness (d)**	**Species diversity (H')**
Survey 1				
Flood	21	59	4.91	2.68
Ebb	13	37	3.32	2.22
Survey 2				
Flood	13	240	2.19	1.19
Ebb	9	217	1.49	1.04

Results from ANOSIM (R = 0.027) indicate that similarities between and within the ebb and flood tide groups were similar. SIMPER results indicate that within tide heterogeneity is fairly low (Table 3.5).

Table 3.5 Community analysis (ANOSIM and SIMPER) of survey one and two in the Kowie Estuary. SD = standard deviation

	Flood			**Ebb**		
ANOSIM	R = 0.027					
	Species	% contribution	SD	Species	% contribution	SD
SIMPER	*O.woodii*	50.8	0.45	Clinid 7	24.84	0.18
	S.sagax	13	0.25	*C. capensis*	23.88	0.18
	Clinid 7	8.22	0.2	*O. woodii*	16.33	0.18
	C. superciliosus	7.85	0.2	*C. superciliosus*	14.12	0.18
	M. capensis	7.06	0.17	*S. sagax*	8.7	0.12
	C. capensis	6.96	0.2	*C. cottoides*	6.07	0.11

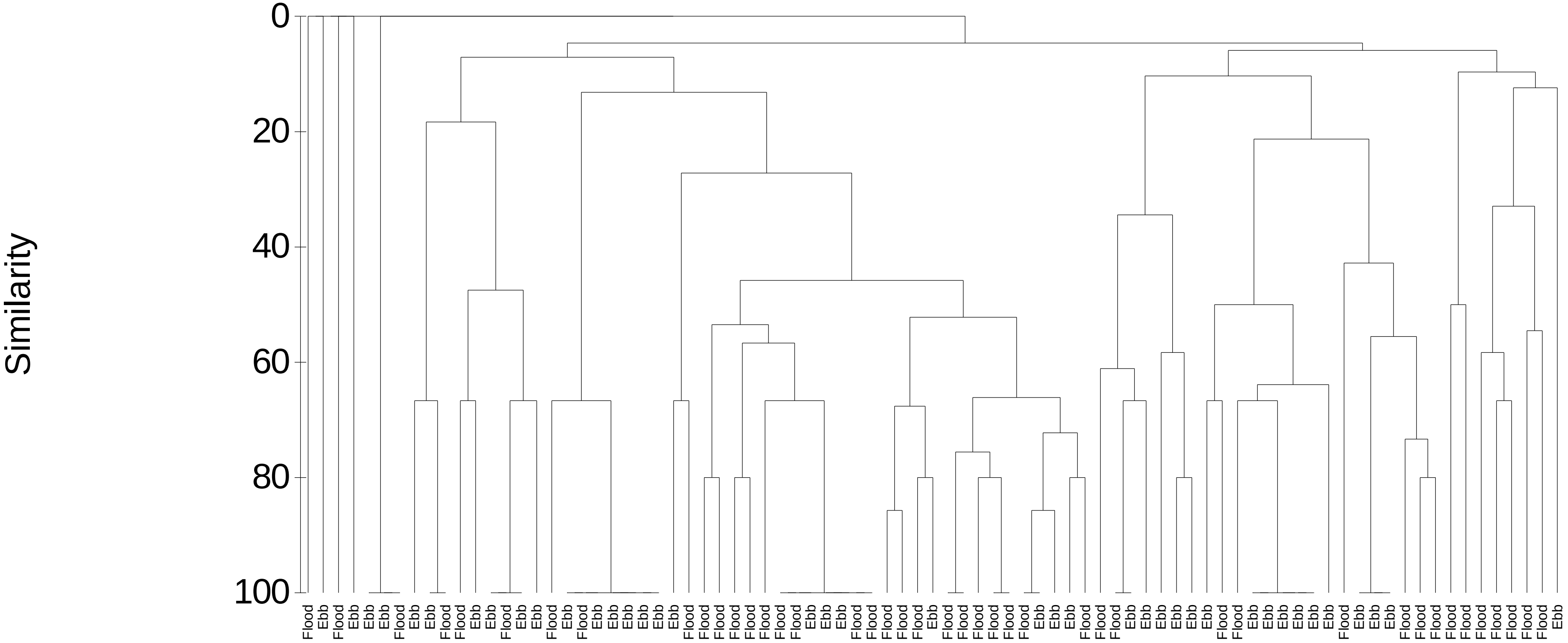

Figure 3.8 Bray Curtis similarity matrix generated based on species presence or absence for survey one and two in the Kowie Estuary, indicating groupings on the flood and ebb tide in August and September 2008.

3.3.6 Comparison of light trap catches with towed net studies in similar estuaries

The dominant species recorded in the current study were compared to the top five species caught in the same estuary, using towed nets. *Omobranchus woodii* dominated the tidal exchange light trap study; however in the towed net study in the same estuary, catches were dominated by *Gilchristella aestuaria*. Although sampling occurred in the same estuary, species dominance varied. When comparing the dominant five species recorded in other tidal exchange studies in the region (Beckley 1985; Swartkops Estuary); (Whitfield 1989; Swartvlei Estuary); (Strydom & Wooldridge 2005; Gamtoos Estuary), similar species are repeatedly recorded within these studies, but not similar to those of the present study (Table 3.6). The dominant species recorded in all three of these tidal exchange papers is *Caffrogobius gilchristi*.

Table 3.6 Comparison of the percentage contribution of dominant six species toward tidal exchange investigations using towed nets and light trap catches, in the Kowie Estuary, as well as Swartkops, Swartvlei and Gamtoos.

		This study	Swartkops- Beckley (1985)	Swartvlei - Whitfield (1989)	Gamtoos - Strydom & Wooldridge (2005)	Kowie Estuary Mouth (Chapter 2)
	Gear type	**Light traps**	**Towed net**	**Towed net**	**Towed net**	**Towed net**
	Total number of larvae recorded	**553**	**6623**		**1529**	**1497**
	Total number of species recorded	**26**		**15**	**20**	**38**
Family	**Species**					
Atherinidae	*Atherina breviceps*	-	-	-	1.8	-
Blenniidae	*Omobranchus woodii*	42	-	8.4	-	-
	Parablennius cornatus	-	9	-	-	-
	Blenniid 1	-	-	-	-	14.0
Clinidae	*Clinus superciliosus*	5	-	-	-	-
Clupeidae	*Gilchristella aestuaria*	4	-	-	-	59.0
	Sardinops sagax	31	8	-	-	-
Gobiidae	*Caffrogobius gilchristi*	-	53	31.5	76.7	
	Caffrogobius nudiceps	-	-	-	-	9.0
	Psammogobius knysnaensis	-	-	27.4	3.6	8.0
Mugilidae	*Liza richardsonii*	-	-	4.5	3.3	-
	Myxus capensis	3	-	-	-	-
Soleidae	*Heteromycteris capensis*	-	5	-	-	-
Sparidae	*Rhabdosargus holubi*		8	-	8.2	-
	Spondyliosoma emarginatum	-	-	15.9	-	-
Syngnathidae	*Syngnathus temminckii*	-	-	-	-	1.9
Other		**15**	**17**	**12.3**	**6.4**	**8.1**

3.4 Discussion

Significant differences in salinity and temperature between the ebb and flood tide were not evident over the study period. The lower reaches of the Kowie Estuary are marine dominated and thus differences in salinity typically do not occur. Significant differences in turbidity did occur and was higher on the flood tide (P = 0.004). Turbidity has been found to provide an important cue for recruitment of larval fishes into estuaries (Blaber & Blaber 1980) and the higher turbidity on the flood tide may have been linked to increased recruitment and thus a higher CPUE on the flood tide. Recorded GPS data was used to determine mean distance travelled by the light trap, per tide, per sampling day. The trap moved further on the ebb tide for both surveys, when compared to the flood tide. This may be due to the channelling effect caused by the artificial lower reaches and mouth in the Kowie Estuary. Past studies investigating the effects of artificial channelling on estuarine systems have indicated that flow velocities are considerably higher under artificial conditions, (Young & Potter, 2003a, b), however difference in water velocity on the ebb and flood tide under artificial channel conditions were not explored.

A total of 553 larval fish were recorded during the study, representing 26 species in nine fish families. Of the 26 different species, 15 were positively identified to species level; the remaining 11 species were identified to family level. The family Blenniidae dominated the catches (43 %), followed by Clupeidae (32 %), Clinidae (17 %) and Mugilidae (4 %). In terms of species dominance, *Omobranchus woodii* contributed 42 % towards the total catch, followed by the Clupeid, *Sardinops sagax* (31 %). A study using moored light traps by Strydom (2003) found a similar trend where the family Blenniidae (45 %) dominated the trap catches in the temperate, permanently open Swartkops Estuary. Other families recorded in the Swartkops light trap study included Atherinidae (22.4 %), Mugilidae (22.4 %), Gobiidae (9.8 %) and Clupeidae (6 %). Those species collected in the Swartkops light trap study were similar to the Kowie catches with the same dominant species appearing in both estuaries (Strydom 2003). In the same study, in terms of species and family number, a total of 12 families and 28 different species were represented in the Swartkops light trap study, similar to the Kowie light trap composition (Strydom 2003). Permanently open estuaries have higher species diversity and most often range from between 21 to 37 different species (Strydom *et al*. 2003), therefore it appears that both light trap studies, reflect species and family numbers expected in a permanently open estuary.

High catches of the Blenniid, *Omobranchus woodii* are often recorded in permanently open temperate estuaries in southern Africa (Strydom *et al.* 2003), however other typical species expected in southern African estuaries, evident in past towed net catches, such as the Gobiids, *Caffrogobius gilchristi* and *Psammogobius knysnaensis* were not recorded in the Kowie Estuary light trap study, and contributed 1 % or less to the Swartkops light trap study (Strydom 2003). This is because these species only occur in estuaries at the preflexion larval phase and thus would not be reflected in light trap catches, as light traps sample postflexion and presettlement larvae more effectively and towed nets sample preflexion larval fish more effectively (Doherty 1987; Choat *et al*. 1993). Therefore, gear selectivity for specific species and developmental stages is evident with all different gear types.

More larval fish were recorded on the flood tide compared to the ebb tide for both surveys. Higher flood tide catches of larval fishes in artificial channels in Australia were observed by Young and Potter 2003a, b. Higher larval fish richness (*d*) and diversity (*H'*) occurred on the flood tide for both surveys indicating a larval credit for the estuary in terms of influx. CPUE was lower in the first survey, and larval exchange trends were not clear. However, for survey two (September), postflexion stage *Omobranchus woodii* dominated the larval fish catches on the flood tide, whilst *Sardinops sagax* dominated the ebb catches. Collectively, throughout the sample period, the same trend was evident. *O. woodii* is an estuarine dependent species, breeding only in the estuarine environment (Ia) whereas *S. sagax* is a marine spawned species, with no dependence on estuaries (III) (Whitfield 1998). Catches of these larvae on these specific tides were unexpected. However, Strydom & Wooldridge (2005) found in isolated incidences that some estuarine dependent marine species were present on the ebb tide in a tidal exchange study in the same region. Additionally, Beckley (1985) also found *S. sagax* on night ebb tides. Beckley (1985) suggested that these larvae may have been swept in on the previous flood tide, and retained in the estuary until the following ebb. Beckley (1985) also noted significant effluxes of *O. woodii* on the outgoing tide. However, Trnski (2001), suggests that larvae originating from estuarine spawned eggs, such as *O. woodii*, are generally more prevalent on the ebb tide, whereas larvae with a marine spawned decent, are typically more abundant on flood tides (Beckley 1985; Whitfield 1989; Strydom & Wooldridge 2005). This appears logical for species destined for nursery habitat but does not take into account those larvae either passively trapped in tidal flux or those utilizing the water body for feeding purposes, as estuarine waters are rich in copepod prey as was found in Chapter 4. The results of the current Kowie Estuary study are somewhat different to past tidal exchange studies and typical hypotheses (Beckley 1985; Whitfield 1989; Trnski 2001; Strydom & Wooldridge 2005). This difference may be as a result of two distinguishing factors in the Kowie Estuary study. Firstly, light trap sampling selectivity may influence composition of catches compared to previous towed net findings and secondly, the lack of marginal water in the mouth and lower reaches due to artificial banks in the Kowie Estuary preclude adequate maintenance within the estuary post recruitment into the system.

Strydom & Wooldridge (2005) investigated tidal exchange in the Gamtoos Estuary, a permanently open, warm temperate estuary in the region with a natural entrance. The difference between the two studies is that conventional WP2 plankton nets were used to sample in the Gamtoos Estuary, as opposed to light traps, which were used in this study. Family and species numbers were similar in the Kowie (26 species; nine families) and Gamtoos (20 species; 12 families) and typical of permanently open systems (Strydom *et al*. 2003); however species and family dominance are vastly different. The Gamtoos study was dominated by the family Gobiidae (80 %), whereas the Kowie Estuary light trap study was dominated by Blenniidae (43 %) followed by Clupeidae (32 %). These different rank findings may be as a result of the sampling selectivity exhibited by light traps. Furthermore, in comparison to the Kowie Estuary towed net study (Chapter 2), 23 families and 38 different species were recorded, with dominance of Gobiids and Blenniids.

The success of light traps as a sampling method depends on the ability of the larvae to observe the light and react to it (Doherty 1987; Hickford & Schiel 1999; Beckley and Naidoo 2003; Marchetti *et al.* 2004). Therefore, those species that do not display a photopositive response towards the trap will be excluded from the catch. From the results of this and other studies, it appears that Blenniid and Clupeid larvae, specifically *Omobranchus woodii* and *Sardinops sagax*, appear to be more photopositive than other species typically recorded in permanently open temperate estuaries. Strydom (2003) used a stationary light trap to sample an estuarine creek in the Swartkops Estuary. Catches from the Swartkops light trap study were also dominated by Blenniid larvae (45 %) as well as Mugilidae (11.6 %) and Clupeidae (6 %), all species that were well represented in the Kowie Estuary light trap study, but not so much in the Gamtoos Estuary where plankton nets were used. Adding to the fact that light traps may show selectivity toward photopositive species, when the larval fish assemblage of the Kowie Estuary was investigated using WP2 plankton nets, Blenniidae did not dominate the catches and only contributed 5.9 % toward the total catch in the estuary. This evidence further supports the assumption that light traps sample specific larvae and exclude others.

Sampling selectivity, however, is not solely confined to light traps. Other sampling devices also show species, size and development stage selectively. A well known weakness associated with towed-net sampling is detection and avoidance of the net by larger, more agile larvae and hence the inefficient sampling of such sized larvae (Thorrold 1992; Choat *et al.* 1993; Trnski 2001). However, it has repeatedly been established that light traps are more successful, yet biased, toward capturing and retaining larger size larvae than plankton nets (Thorrold 1992; Choat *et al.* 1993; Hickford & Schiel 1999; Meekan *et al.* 2001). Postflexion stage larvae dominated the catches in the present study (95.6 %) and thus the majority of the recorded larvae were potential settlers. This characteristic of light traps may be a partial reason for the atypical larval exchange result compared to past tidal exchange investigations where euryhaline marine larvae typically dominate the flood tide, whilst estuarine species are typically more predominant on the ebb tide (Beckley 1985; Strydom & Wooldridge 2005). *Omobranchus woodii* was more dominant on the flood tide, and thus may have been returning to the estuary, after being swept out as preflexion or flexion larvae and was now at the stage ready to settle out of the planktonic mass within the estuary. On the other hand, *S. sagax*, which was more prevalent on the ebb tide and could have been returning to the marine environment from earlier entry into the system on the flood tide. Strydom & Wooldridge (2005) also found in isolated incidences that estuarine dependent larvae were also present on the ebb tide, although not significantly. It was also noted during sampling that fish larvae were seen actively swimming against currents in the mouth of the Kowie Estuary, possibly displaying rheotaxis in order to prevent being displaced by the oncoming tide.

It appears, that in the Kowie Estuary, a combination of gear type, which may exhibit selectivity and the habitat alteration in the mouth of this estuary, has resulted in uncharacteristic tidal exchange results. Numerous studies, including the present one, have found that it is often best to combine various sampling strategies to create a more accurate description of the larval assemblage and exchange and thus minimize individual gear selectivity (Doherty 1987; Choat *et al.* 1993; Hickford & Schiel 1999; Strydom 2003). Rehabilitations in the mouth region of this estuary or the recreation of suitable larval fish habitat may be required in order for this estuary to better reflect similar estuaries in the region and provide a better functioning nursery area, allowing larval fish to better exploit important functions such as tidal exchange.

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CHAPTER 4

PLANKTON DYNAMICS ASSOCIATED WITH THE CONVERGENCE ZONE OF A SHEAR FRONT IN THE PERMANENTLY OPEN KOWIE ESTUARY, SOUTH AFRICA

4.1 Introduction

Plankton patchiness in the marine environment has been found to come about primarily due to an interaction between biological properties of organisms and physical conditions of the water column and adjacent environment (Dustan & Pickney 1989; Govoni *et al.* 1989). Circulation patterns within the water column and the extent of mixing all play an important role in plankton accumulation (Dustan & Pinckney 1989; Eggleston *et al.* 1998). These aggregations occur at the meeting points of different water types where salinity and pressure gradients are created resulting in the formation of a front (Dustan & Pinckney 1989; Eggleston *et al.* 1998; Warner *et al.* 2003). In tidal estuarine systems, density gradients are common, resulting from the meeting of marine salt water and fresh river water (Dustan & Pinckney 1989). The fronts may limit flow across these different water types thus resulting in possible accumulation, transportation and down welling of planktonic organisms along the front (Eggleston *et al.* 1998).

Estuarine frontal systems are most often distinguished by visible changes in water colour accompanied by floating debris, foam lines and increased biological activity (Largier 1993; Ferrier & Anderson 1997; Eggleston *et al.* 1998; Duck & Wewetzer 2001). These fronts have been defined by Largier (1993) as ‘a region characterized by an anomalous local maximum in the horizontal gradient of some water property’, such as temperature or salinity (Duck & Wewetzer 2001). Alternatively, fronts can be described as interfaces where ‘water masses converge, separate or move laterally from one another (Duck & Wewetzer 2001). In a review of fronts in estuaries, O’Donnell (1993) identified three primary types of estuarine surface fronts. These are namely plume or tidal intrusion fronts, tidal mixing fronts and shear fronts, however frontal characteristics of different types of fronts can often overlap (O'Donnell 1993).

In South Africa, research on the effects that frontal convergence has on ecological properties, through changes in the physical environment and biological aggregations within estuaries is limited. Furthermore, an understanding of these irregular systems and the role that they play in plankton accumulation and transport is critical to fisheries species and plankton feeder's worldwide (Eggleston *et al.* 1998). The present study focused on shear fronts that occur regularly in the Kowie Estuary. Shear fronts, also known as axial convergence fronts, are formed during the flood tide where the incoming water velocity is reduced due to friction created with the estuary bed (Ferrier & Anderson 1997; Duck & Wewetzer 2001). Less dense fresh water from the contributing river system or water of a higher temperature is forced above the more dense, cooler incoming sea water (Schumann *et al.* 1999). Two circulation cells are set up with down welling occurring in the centre (Schumann *et al.* 1999). Such fronts are clearly distinguished by the bands of foam along the front line (Ferrier & Anderson 1997) and occur in the centre of the channel in well mixed or partially mixed estuaries. Ultimately all types of estuarine fronts are created in response to some aspect of the ebb and flood tidal regime (O'Donnell 1993; Grimes & Kingsford 1996; Ferrier & Anderson 1997; Duck & Wewetzer 2001) and have been found to be far more spatially and temporally variable than that of the well researched oceanic frontal systems (Dustan & Pinckney 1989; O'Donnell 1993).

Although our understanding of these systems is limited, the general consensus is that fronts must, in some way play a role in larval recruitment, transportation and plankton accumulation (O'Donnell 1993). Grimes & Kingsford (1996) found that the processes and oceanography involved in fronts affect both pelagic and benthic larvae as well as juveniles and adults that reside in the open ocean or recruit into estuaries. As the surface waters at the front meet, passive planktonic organisms accumulate with the moving waters and those organisms that are not buoyant will move downward at the convergence zone (Grimes & Kingsford 1996). The combination of frontal systems acting as transport mechanisms for recruitment into nursery grounds and the abundance of food that the frontal systems potentially hold, through plankton accumulations, make them important, yet under researched processes, affecting plankton organism and ultimately larger specimens feeding off plankton (Grimes & Kingsford 1996; Ferrier & Anderson 1997). However, information on the role and importance of frontal systems is limited, with some studies suggesting that frontal systems might not have higher concentrations of plankton than surrounding water (Dustan & Pinckney 1993). These contradictions evident in the literature further suggest that more research is required focusing on estuarine frontal systems and their potentially important function on plankton dynamics as patch food sources, particularly for ichthyoplankton. Access to food patches allows fish larvae benefits of rapid growth and thus a reduced pelagic larval duration (Searcy & Sponaugle 2000; Bergenius *et al*. 2005).

In this study, it was hypothesized that more plankton will accumulate in the shear fronts that form in the mouth of the Kowie Estuary and this could have feeding implications for ichthyoplankton. In this chapter, plankton refers to ichthyoplankton, zooplankton and phytoplankton. Species composition of zooplankton and ichthyoplankton would also differ in and out of the convergence zone, with predacious species more abundant in the convergence zones of the front in order to exploit the ephemeral food patches. Ultimately, ichthyoplankton use of such food resources will depend on the costs and benefits of such potential food patches.

4.2 Methods

4.2.1 Study site

Ichthyoplankton, zooplankton and phytoplankton samples were collected from the permanently open Kowie Estuary (33°36’11”S; 26°54’10”E) situated in Port Alfred on the Eastern Cape coast of South Africa (Figure 4.1). The climate in this region is classified as warm temperate, with mean annual rainfall occurring during summer (Whitfield 2000). The lower reaches of the estuary are heavily impacted by anthropogenic activities (Whitfield 2000) including the construction of the marina, which has altered the natural water flow in the estuary and characterizes the lower reaches with steep, walled artificial channels. The river is approximately 70 km long, with an average depth of 2.75 m, the summer water temperatures range from 21 °C to 29 °C and winter temperatures range from 11 °C to 16 ° (Hill & Allanson 1971).

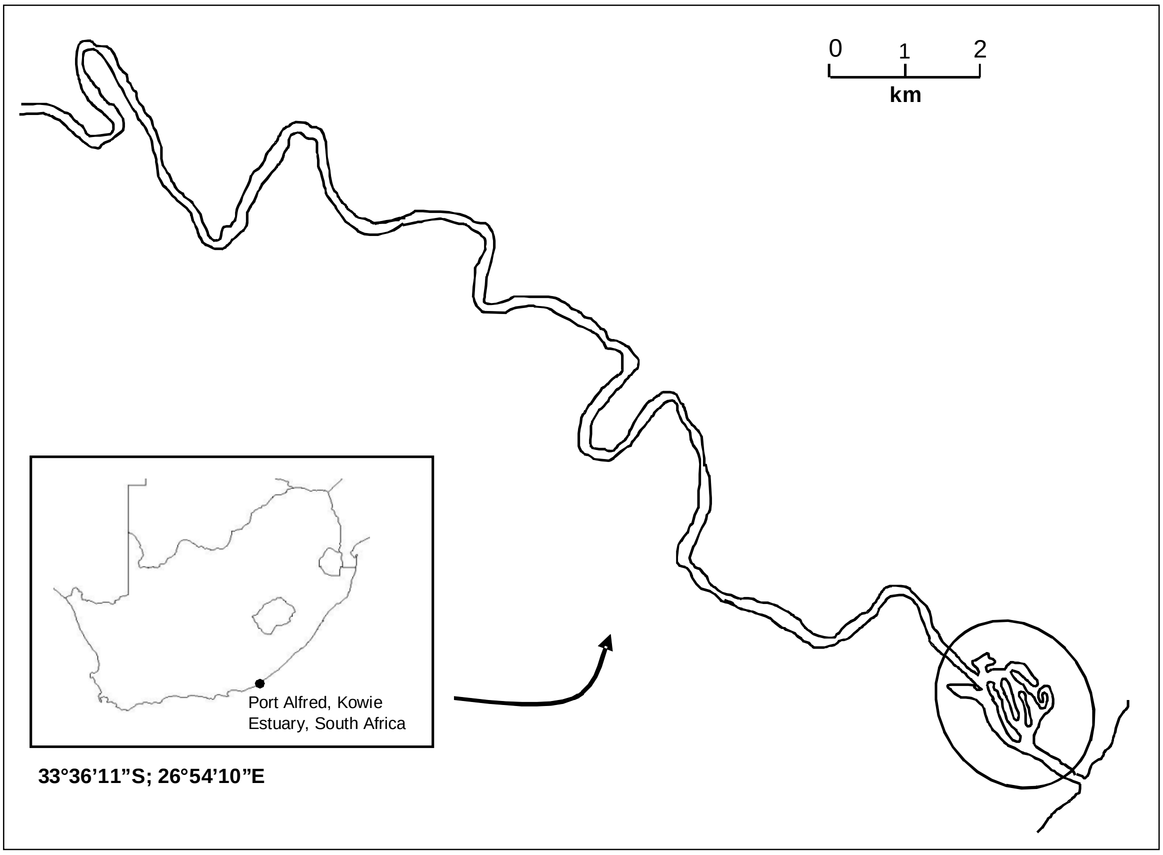

Figure 4.1 Geographical position of the Kowie Estuary, South Africa. Convergence zones confined to the lower reaches of the estuary, near the mouth.

4.2.2 Field sampling and plankton identification

Sampling of frontal systems took place in summer 2008 in the mouth of the Kowie Estuary. All sampling was conducted in daylight, and fronts were sampled until the frontal system disintegrated, which prevented further sampling. Samples were collected simultaneously at the surface in the convergence zone (A) and immediately out of this zone (B) within the shear front (Figure 4.2). A total of five different fronts were sampled during the study period and the number of samples collected within each different front ranged from 3 to 11, depending on the duration of the front.

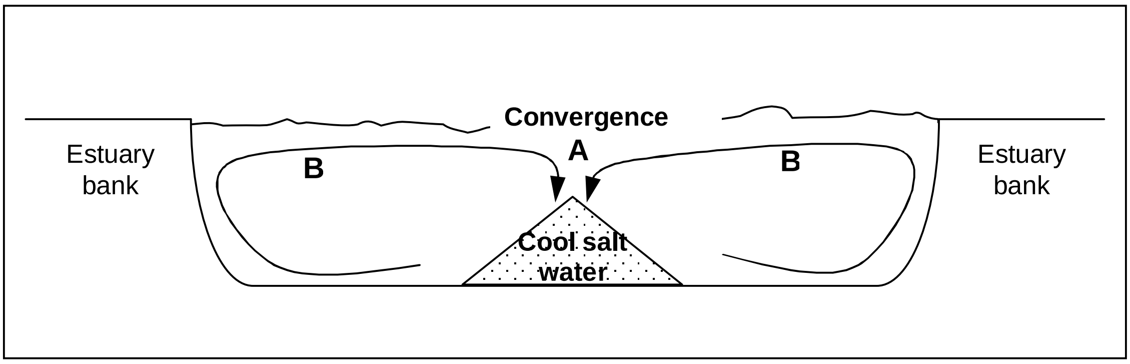

Figure 4.2 A cross section diagram indicating the development of a shear front circulation pattern. A = Convergence zone; B = out of convergence, salt water = intrudes at the estuary bottom, which is more saline and colder than existing estuarine water (Adapted from Schumann *et al.* 1999).

Samples were collected using two WP2 plankton nets (570 mm mouth diameter and 0.2 mm mesh aperture), which were lowered simultaneously from a single hulled boat (Strydom *et al.* 2002; Pattrick *et al.* 2007). Each WP2 net was fitted with a Kahlsico 005 WA 130 flow meter. One net was towed in the convergence zone, indicated by a foam line and this net represented the in front sample, the second net was towed simultaneously out of the zone. Three minute tows were conducted in and out of the convergence zone on the surface of the water column and towing speed ranged between one and two knots (Strydom *et al.* 2002; Pattrick *et al.* 2007). The WP2 plankton nets were emptied after each tow and samples were preserved in 10 % formalin on site. Temperature (°C), total dissolved solid (TDS), salinity, pH, dissolved oxygen (mg/l and %) and chl-a were measured in and out of the front for every tow conducted using a YSI water quality meter. Additionally, surface water samples were collected on every tow using 1ℓ sample bottles, in and out of the front. The water samples were then gravity filtered using plastic Millipore filter towers with Whatman filter papers. The filter papers were labelled and stored below 0 °C for later phytoplankton and chlorophyll-*a* (chl-*a*) analyses. Chlorophyll was extracted in the laboratory by placing the filters into a glass vial with 10 ml of 95 % ethanol, these vials were then stored over night at one to two °C. The contents of the vials where then filtered and two drops of 0.1 N HCL was added to the vials and the light absorbance at 665 nm of the supernatant was read using a spectrophotometer (Bate *et al*. 2002). The chl-*a* was then determined according to Nusch (1980). Phytoplankton was stored on site in Lugols.

In the laboratory the larval fish and zooplankton was removed from the plankton mass, identified and counted. Sub sampling was used to count zooplankton. All larvae were identified to the lowest possible taxon in accordance with Smith & Heemstra (1986); Neira *et al.* (1998), Leis & Carson-Ewart (2000). Zooplankton was identified down to order and sub class levels only. Larval fish density was calculated using a calibration value of each flow meter used, following the formula:

$$\boldsymbol{D = (N/V) * 100\ \mathrm{m}^3}$$

Where D is the larval fish density per m^3; N is the number of larvae recorded in a specific tow and V is the volume of water filtered by the WP2 plankton nets in a specific tow. Zooplankton density was calculated using the following formula:

$$\boldsymbol{D = (N * F) / V}$$

Where D is the zooplankton density per m^3; N is the number if zooplankton recorded in a specific tow and F the fraction, which is determined by dividing the entire sample volume of a specific tow by the sub sample ml (* 3). Phytoplankton were identified into groups by an expert at Nelson Mandela Metropolitan University (NMMU).

4.2.3 Data analysis

All data was tested for normality and homogeneity of variance using STATISTCA 8. Zooplankton and ichthyoplankton counts were converted to density values using equations indicated above. Density values were used to determine whether differences occurred in and out of the convergence zone. Multiple linear regression was run on the top five contributing larval fish species in the study, as well as all zooplankton and phytoplankton groups, in order to determine which environmental variables had a significant relationship with density. A significance level of $P = 0.05$ was used, unless otherwise stated.

Community analysis was conducted using PRIMER 5 software. ANOSIM and SIMPER was used to determine the differences and similarities between groups and species comprising these groups for all plankton communities. Bray-Curtis similarity matrices and multi-dimensional scaling plots (MDS) were generated for ichthyoplankton, zooplankton and phytoplankton.

4.3 Results

4.3.1 Environmental variability

Water quality parameters were compared in and out of the convergence zone of the shear front in the Kowie Estuary. Salinity, temperature (°C) pH, TDS, dissolved O_2 (Oxygen) $_($%), dissolved O_2 (mg/l) showed no significant difference ($P > 0.05$) between water masses in and out of the convergence zone. However, chl-*a* was found to be significantly higher in the convergence zone (F = 6.62; $P < 0.05$).

4.3.2 Ichthyoplankton variability

A total of 18 different larval fish species, representing 12 different families were recorded in the fronts study. All specimens were positively identified to species level except one. *Ecklonіaichthys scylliorhiniceps* (Gobiesocidae) dominated the ichthyoplankton catches in the fronts (38.3 %), followed by gobiid, *Caffrogobius nudiceps* (31.6 %) (Table 4.1).

Larval fish density (all species included) was not significantly different (F = 0.55; P = 0.46) between water masses sampled. No significant differences in individual species densities were found for any species in and out of the front ($P > 0.05$) (Figure 4.3 A).
Multiple linear regression was run on the top five contributing ichthyoplankton species recorded in the study. Temperature and dissolved O_2 (mg/l; %) were found to have a significant relationship with total larval fish density. TDS and pH showed a significant relationship with *Ecklonіaichthys scylliorhiniceps* and *Caffrogobius nudiceps*. Temperature and dissolved O2 (mg/l; %) showed a significant relationship with *Psammogobius knysnaensis*. Salinity and pH showed a significant relationship with unidentified Blenniid. *Caffrogobius gilchristi* densities had no significant relationship with environmental variables in the Kowie Estuary (Table 4.2).

4.3.3 Zooplankton variability

The study focused predominantly on two main classes of zooplankton, being Malacostracea (Isopoda, Amphipoda and Decapoda) and Maxillopoda (Copepoda) and broad categories of subclass and order were identified and did not go to species level. Chaetognatha and medusa (Cnidaria) were also counted. Copepoda completely dominated the overall zooplankton catch in the area of the convergence zone (97.47 %). Overall zooplankton density was different between convergence and non-convergence zone water, but not significantly, ($F = 0.86$; $P = 0.36$) (Table 4.1). No significant difference was found in zooplankton density by group in and out of the convergence zone for all taxa, except for megalopa (Decapoda) which was found to be significantly higher in the convergence zone compared to out of this zone ($P < 0.01$) (Figure 4.3 B). Active predators, such as Amphipoda, Zoea, Megalopa, Isopoda and Mysidacea were more abundant in the convergence zone. Passive predators and ichthyoplankton predators were predominantly found out of the convergence zone, these include Copepoda, Decapoda, Chaetognath and medusa. Salinity and pH showed a significant relationship with total zooplankton density and copepod density ($P < 0.05$). Decapoda density was found to have a significant relationship with TDS ($P < 0.05$) (Table 4.2).

4.3.3 Phytoplankton variability

Phytoplankton community structure was compared in and out of the convergence zone. Phytoplankton community comparisons included flagellates, diatoms, dinoflagellates, chlorophytes, cyanophytes, coccolithophorids, euglena and silicoflagellates. However, no significant differences were observed in phytoplankton counts in and out of the convergence zone. The majority of the groups had higher counts out of the convergence zone, except for coccolithophorids and silicoflagellates, which were higher, but not significantly so, in the convergence zone (Table 4.1). Mean chlorophyll-a was found to be very low, 2.1963 μg^{-1} in the convergence zone and 1.7819 μg^{-1} out of the front. Multiple linear regression reveal that salinity has a significant relationship with flagellate, diatoms and dinoflagellate densities in the Kowie Estuary ($P = 0.05$) (Table 4.2).

Table 4.1 Species composition in and out of the convergence zone in the Kowie Estuary, for ichthyoplankton, zooplankton and phytoplankton (no. 100m^{-3}).

		% Contr.	Total	In	Out
ICHTHYOPLANKTON (Count)					
Family	**Species**		**849**	**436**	**413**
Atherinidae	*Atherina breviceps*	2.8	24	13	11
Blenniidae	*Omobranchus woodii*	1.2	10	3	7
	Blenniid 1	4.1	35	21	14
Clinidae	*Clinus cottoides*	0.5	4	3	1
Clupeidae	*Etrumeus whiteheadi*	0.5	4	1	3
Gobiidae	*Caffrogobius nudiceps*	31.6	268	124	144
	Caffrogobius gilchristi	3.9	33	17	16
	Psammogobius knysnaensis	8.1	69	31	38
Gobiesocidae	*Eckloniaichthys scylliorhiniceps*	38.3	325	185	140
Monodactylus	*Monodactylus falciformis*	1.4	12	4	8
Mugilidae	*Liza richardsonii*	0.1	1	1	0
Mugilidae	*Myxus capensis*	0.4	3	3	0
Soleidae	*Solea turbynei*	0.2	2	1	1
	Heteromycteris capensis	1.1	9	3	6
Sparidae	*Diplodus capensis*	0.5	4	3	1
	Rhabdosargus holubi	1.8	15	8	7
Tetraodontidae	*Amblyrhynchotes honckenii*	0.1	1	1	0
	Unidentified One	3.5	30	14	16
ZOOPLANKTON (No. 100m^{-3})			**127741**	**46544**	**81197**
Amphipoda		0.48	609	579	30
Brachyura	Megalopa	1.45	1851	1847	4
	Zoea	0.23	293	221	72
Copepoda		97.47	124509	43604	80905
Decpoda (prawn)	*Upogebia*	0.17	221	56	165
Isopoda		0.17	214	207	7
Mysidacea		0.02	22	15	7
Chaetognath		0.02	22	15	7
Medusa		0	0	0	0
PHYTOPLANKTON (No. 100m^{-3})			**16991**	**8464**	**8493**
Chl-a		0.94	159	88	71
Flagellates		46.37	7878	4146	3732
Diatoms		51.37	8729	4167	4562
Dinoflagellates		0.74	125	49	76
Chlorophytes		0.09	16	0	16
Cyanophytes		0.04	6	3	3
Coccolithophorids		340.34	58		24
Euglena		0.11	18	9	9
Silicoflagellates		0	2	2	0

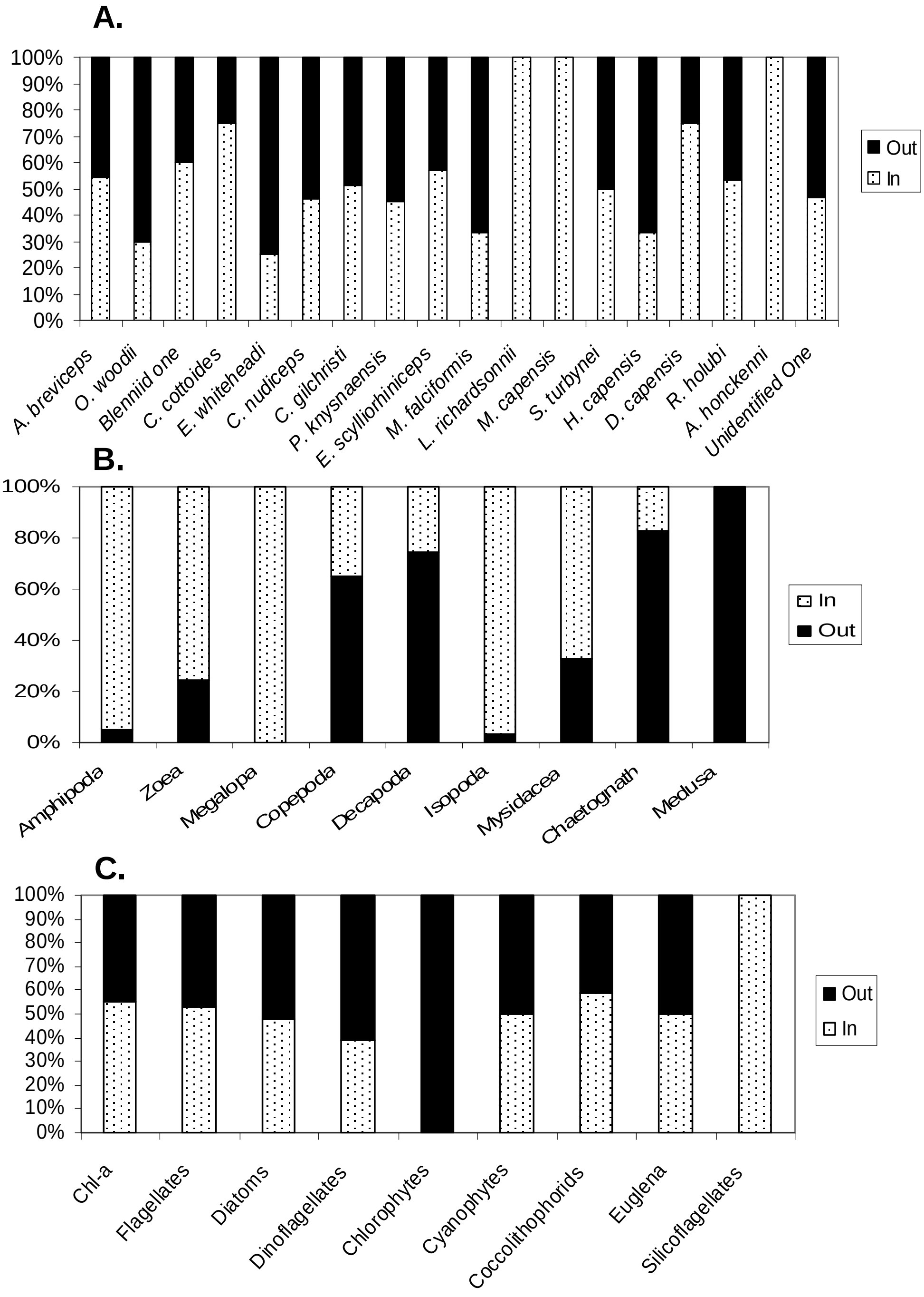

Figure 4.3 Individual ichthyoplankton (A), zooplankton (B) and phytoplankton (C) species and group contribution in and out of the convergence zone in the presence of a frontal system in the Kowie Estuary.

Table 4.2 Multiple linear regression statistics for the relationship between ichthyoplankton, zooplankton and phytoplankton density and environmental variables (Salinity, temperature, pH, TDS, dissolved O_2 mg/l, dissolved O_2 %, chl-a) in the Kowie Estuary.

Ichthyoplankton species	**r^2**	**r**	**F**	**Significant variable**
Total ichthyoplankton	0.20	0.45	2.53	Te, dis O2 (mg/l, %)
Eckloniaichthys scylliorhiniceps	0.66	0.81	19.71	TDS, pH
Caffrogobius nudiceps	0.57	0.76	13.72	TDS, pH
Psammogobius knysnaensis	0.20	0.45	2.60	Te, dis O2 (mg/l, %)
Blenniid one	0.25	0.50	3.34	Sal, pH
Caffrogobius gilchristi	0.17	0.42	2.15	-
Zooplankton order / subclass				
Total zooplankton	0.32	0.57	4.89	Sal, pH
Amphipoda	0.05	0.22	0.54	-
Zoea	0.08	0.28	0.86	-
Megalopa	0.08	0.27	0.83	-
Copepoda	0.32	0.56	4.81	Sal, pH
Decapoda	0.15	0.39	1.80	TDS
Isopoda	0.05	0.23	0.58	-
Mysidacea	0.04	0.21	0.47	-
Chaetognath	0.19	0.44	2.44	-
Medusa	0.11	0.33	1.29	-
Phytoplankton group				
Flagellates	0.28	0.53	3.95	Sal
Diatoms	0.35	0.59	5.51	Sal
Dinoflagellates	0.23	0.48	3.12	Sal
Chlorophytes	0.03	0.18	0.34	-
Cyanophytes	0.09	0.31	1.06	-
Coccolithophorids	0.21	0.45	2.65	-
Euglena	0.21	0.46	2.72	-
Silicoflagellates	0.04	0.20	0.45	-

4.3.4 Community analysis

A community analysis approach was used to further investigate the relationships between plankton communities in and out of the convergence zone in the Kowie Estuary (Table 4.3). *Eckloniaichthys scylliorhiniceps* dominated the ichthyoplankton catches in and out of the convergence zone. However, a clear swop of rank in and out of the zone for the most contributing species occurred. Blenniid one was a dominant species in the convergence, whilst *Caffrogobius nudiceps* dominated out of the convergence.

Furthermore *Atherina breviceps* was found to make a significant contribution only out of the convergence zone. Significant differences in SIMPER results did not occur for zooplankton and phytoplankton.

Table 4.3 Community analysis results for all plankton communities recorded in and out of the convergence zone associated with shear fronts in the Kowie Estuary.

	In convergence zone			**Out convergence zone**		
ANOSIM	**Ichthyoplankton**			R = - 0.01		
	Species	% contribution	SD	Species	% contribution	SD
SIMPER	*E. scylliorhiniceps*	47.57	0.48	*E. scylliorhiniceps*	40.64	0.43
	Blenniid one	19.34	0.28	*C. nudiceps*	17.15	0.3
	P. knysnaensis	11.43	0.3	*P .knysnaensis*	15.91	0.29
	C. gilchristi	7.09	0.21	*C. gilchristi*	6.79	0.21
	C. nudiceps	6.7	0.2	*A. breviceps*	5.1	0.14
				Blenniid one	4.72	0.18
ANOSIM	**Zooplankton**			R = 0.021		
	Species	% contribution	SD	Species	% contribution	SD
SIMPER	Copepoda	95.18	0.85	Copepoda	94.3	0.78
ANOSIM	**Phytoplankton**			R = - 0.008		
	Species	% contribution	SD	Species	% contribution	SD
SIMPER	Flagellates	61.53	3.32	Flagellates	55.91	2.94
	Diatoms	37.93	2.06	Diatoms	43.46	1.8

Clusters in the Bray-Curtis similarity matrix for ichthyoplankton density were interpreted using Analysis of Similarities (ANOSIM). A global R statistic of - 0.011 was revealed for ichthyoplankton (Table 4.3). This indicates that similarities between and within groups are on average the same. The values for in and out of the convergence zone determined by SIMPER are low and thus within site heterogeneity is quite high (Figure 4.4 A).

Results from ANOSIM reveal a global R value of 0.021 for zooplankton

(Table 4.3). This indicates that similarities between and within groups in the sample are on average the same. SIMPER results reveal a global R statistic of -0.008, indicating that similarities between and within groups are on average quite similar.

Table 4.4 SIMPER values In and Out of the convergence zone for ichthyoplankton, zooplankton and phytoplankton.

	In	**Out**
Ichthyoplankton	13.69	11.68
Zooplankton	23.08	21.13
Phytoplankton	72.82	69.17

A multi-dimensional scaling plot (MDS) for ichthyoplankton was generated. A stress value of 0.14 indicating in and out frontal systems community groupings (Figure 4.5 A). A MDS for zooplankton community groupings in and out of the convergence zone was generated. Stress of 0.17 (Figure 4.5 B).

A MDS was generated for phytoplankton community groups in and out the convergence zone, with a stress of 0.11. The smaller the stress the better the reproduced matrix fits the observed one. Therefore, phytoplankton groupings in and out of the convergence zones are not clearly evident (Figure 4.5 C).

4.3.5 Species richness and diversity

Species richness was higher in the convergence zone associated with the frontal zone for phytoplankton and ichthyoplankton. For zooplankton, species richness was lower in the convergence zone. However, species diversity was all higher out of the front. Species diversity was higher out of the front for ichthyoplankton and zooplankton.

Table 4.5 Species richness and diversity in and out of the convergence zone in the Kowie Estuary.

	Species richness (*d*)		**Species diversity (*H'*)**	
	In	**Out**	**In**	**Out**
Ichthyoplankton	**2.65**	2.03	1.46	**1.78**
Zooplankton	0.65	0.71	0.31	**3.40**
Phytoplankton	0.72	0.71	0.78	0.77

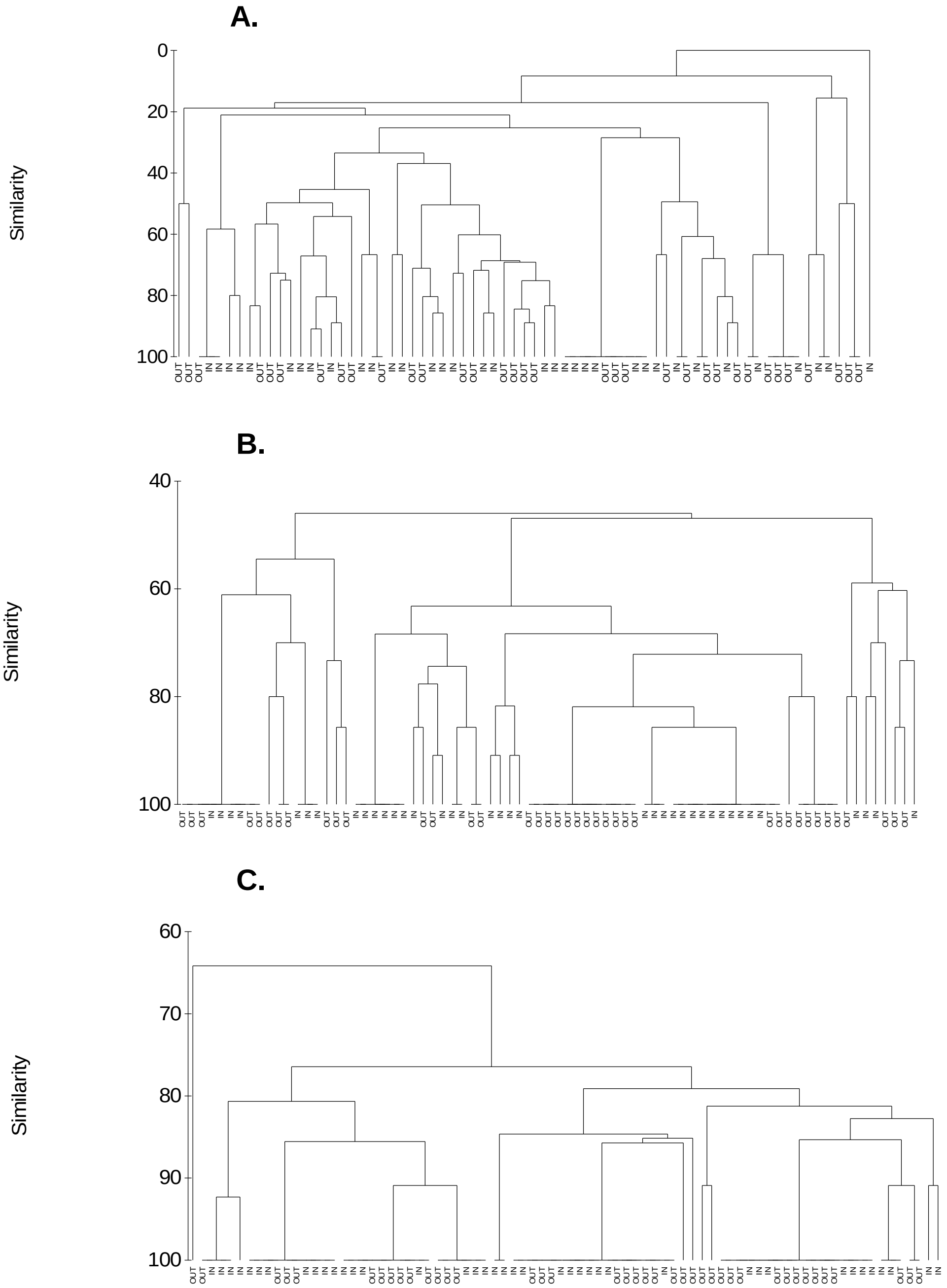

Figure 4.4 Bray-Curtis similarity dendrogram indicting percentage similarity of ichthyoplankton (A), zooplankton (B) and phytoplankton (C) samples in and out of the convergence zones associated with shear fronts in the Kowie Estuary.

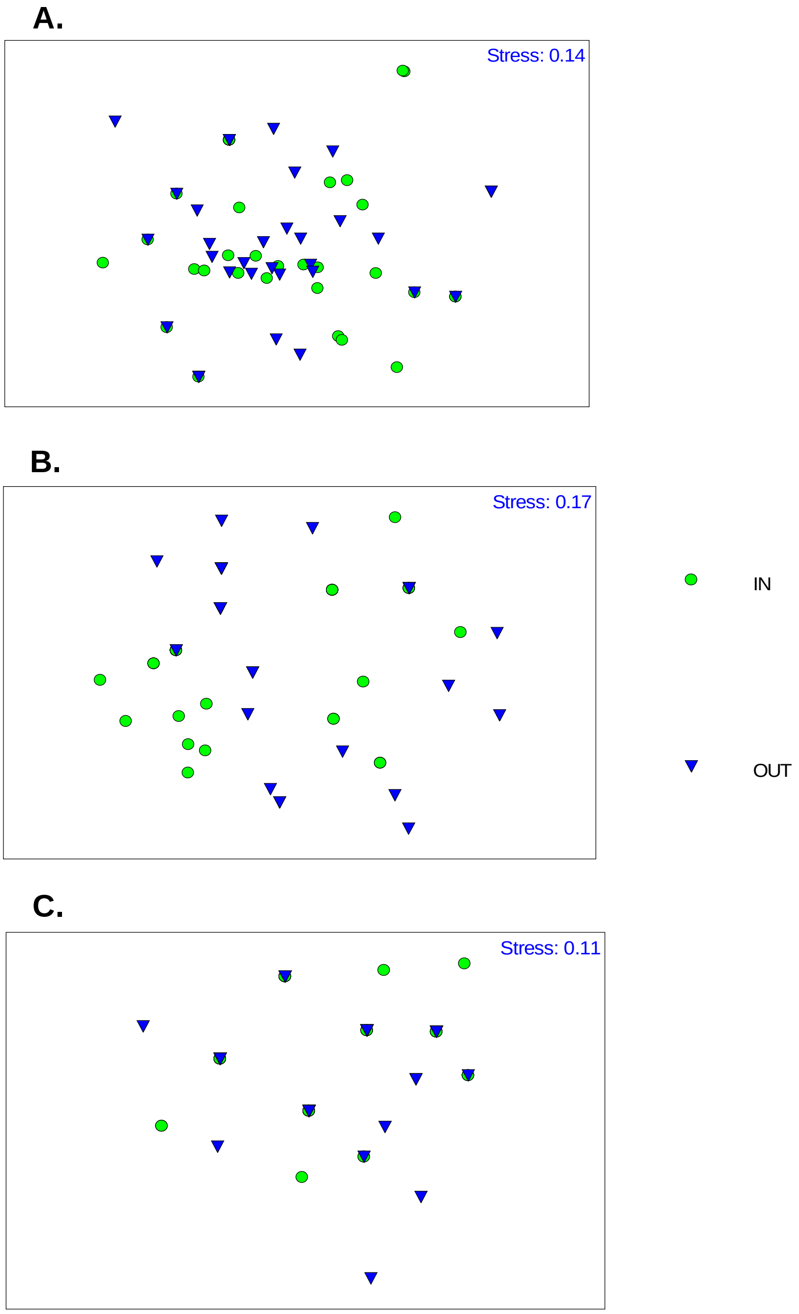

Figure 4.5 Multi dimensional scaling plot (MDS) for ichthyoplankton (A), zooplankton B) and phytoplankton (C) groups in and out of the convergence zone associated with shear fronts in the Kowie Estuary.

4. 4 Discussion

Physical characteristics both in and out of the convergence zone of shear fronts in the Kowie Estuary were similar. A study of the physical differences between in and out of estuarine front (Dustan & Pinckney 1990) showed that density and turbidity differences were evident between the different water masses. In this study, although not significant, higher TDS values were recorded in the front. Additionally mean temperature, although not statistically significant, was also higher in the convergence zone. Chlorophyll-a (chl-*a*) was significantly higher in the convergence zone, although mean chl-*a* in and out the convergence zone was exceptionally low in the Kowie Estuary when compared to similar estuaries in the region (Adams *et al*. 1999). The low chl-*a* recorded may be as a result of the high salinity in the mouth of the Kowie, where the sampling took place. Furthermore, when freshwater input is low and salinity is high, nutrient loading is limited, so in turn phytoplankton peaks, measured by chl-*a*, do not occur as readily (Adams *et al*. 1999). Other warm temperate systems in the area, such as the Sundays Estuary, which has a higher freshwater input and increased nutrient loading, typically has chl-*a* concentrations occurring around 29 µg l^{-1}, with the increased nutrient inputs allowing for phytoplankton blooms (Adams *et al*. 1999).

Ecklonaichthys scylliorhiniceps (38.3 %) dominated the ichthyoplankton catches in and out of the convergence zone in the Kowie Estuary, followed by *Caffrogobius nudiceps* (31.6 %) which was dominant out of the convergences and Blenniid one, which was dominant in the convergence zone. Overall ichthyoplankton density was higher out of the convergence zone, although this was not statistically significant. Of all 18 species recorded, 16 were found both in and out of the convergence zone in similar densities and only *Liza richardsonii*, *Amblyrhynchotes honckenii* and *Myxus capensis* were found only in the front. No clear, trends in density or species composition emerged in this study.

Overall zooplankton density was found to be higher out of the front, but not significantly. Crab larvae, megalopa, were the only zooplankton group to be significantly higher in the frontal region. A study of frontal systems by Clancy and Epifanio (1989) similarly found that blue crab larval density was significantly higher in the front. Salinity and pH was found to have a significant relationship on total zooplankton density in the study, as well as copepoda, whilst TDS showed a significant relationship with decapoda. However, none of these parameters were significantly different in and out of the front, and therefore cannot account for possible changes in zooplankton or ichthyoplankton densities between the different water regions.

In terms of phytoplankton community structure, only silicoflagellates and coccolithophorid concentrations were higher in the frontal system, the remaining recorded phytoplankton community groupings were higher, but not significantly, out of the fronts, or showed no large differences in concentrations in and out of the convergence zone. Furthermore, salinity was found to have a significant relationship with flagellates, diatoms and dinoflagellates.

Previous studies investigating the role of estuarine fronts in plankton accumulations have found that dinoflagellates were frequently found in high concentrations in the frontal regions (Tyler *et al.* 1982; Martin & White 1988). Dustan and Pinckney (1990) investigated tidal fronts in Charleston Harbour, South Carolina, and similarly found no significant plankton accumulations occurring in the frontal region. Previously recorded plankton accumulations have typically been associated with large estuarine fronts, ranging from 10 to 50 km in length. Such fronts would therefore, typically display maximum convergence and down welling, resulting in plankton accumulation (Dustan & Pinckney 1990). Shear fronts in the Kowie Estuary, as well as those sampled by Dustan & Pinckney (1990) are small fronts, with a length ranging between 1 to 2 km. It may be that in such fronts, optimal functioning, convergence and downwelling is limited and thus plankton accumulations may be irregular or short lived.

The importance of frontal systems in estuaries is currently still unclear (O’Donnell 1993). However, it is thought that these circulation systems must result in the accumulation of phytoplankton and zooplankton resulting in a feeding spot for plankton predators and other higher trophic levels (Dustan & Pinckney 1990; Largier 1993; O’Donnell 1993).

Estuarine frontal systems are characterized by much shorter time scales and smaller physical forces and functioning, compared to the larger scale oceanic and large estuarine fronts (Largier 1993). Due to the reduced size and decreased temporal scales of these fronts, it is not always expected that plankton can readily take advantage of the fronts when they occur (Pinckney & Dustan 1990; Largier 1993) due to their limited ability to respond quickly enough before the fronts dissipate. However there have been studies showing that plankton accumulations occur within estuarine frontal regions and thus plankton predators have the ability to congregate when the opportunity presents itself (Clancy & Epifanio 1989). However, Mugilids, an important estuary dependent group of fishes, were only recorded in the convergence zone. Higher numbers of isopods in the convergence zone would however preclude the mobile ichthyoplankton from making full use of good food patches as a result of predation pressure from the isopods. Evidence of increased activity in the presence of fronts in the Kowie Estuary during data collection was witnessed, including diving birds and high concentrations of fish larvae and zooplankton in the region of the fronts. No analytically clear trends occurred in the current study to suggest that frontal systems in the Kowie Estuary are regions of increased overall productivity and plankton accumulation; however species specific trends appear to exist.

4.5 Acknowledgements

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CHAPTER 5

SYNTHESIS AND CONCLUSION

5.1 Synthesis

Numerous marine and estuarine fish utilize estuaries as nursery areas (Blaber & Blaber 1980). Larvae originating from marine spawned eggs need to successfully locate and enter estuaries and avoid further displacement (Beckley 1985; Whitfield 1989). Larval fish spawned in the ocean, particularly estuarine dependent marine fish, will begin to recruit toward nursery areas during the larval phase (Miskiewicz 1986; Whitfield 1994a). These estuarine and marine larvae have been noted to alter their behaviour and position in the water column in order to aid the recruitment process (Watt-Pringle & Strydom 2003). Estuarine dependent larvae accumulate in surf zones in proximity to estuarine nursery areas (Boehlert & Mundy 1988). Once accumulated in the surf zones adjacent to nursery areas, larvae will use tidal and along shore currents to enter into the estuary (Beckley 1985; Boehlert and Mundy 1988; Strydom & d'Hotman 2005).

Tidal currents in permanently open estuaries play an important role in the transport of larvae between the marine and estuarine environment (Beckley 1985; Whitfield 1989). Larvae of marine descent need to exploit flood tides in order to enter into the nursery environment, whilst estuarine spawned, resident larvae need to ensure that they avoid ebb tide displacement from the estuary (Beckley 1985; Trnski 2001). Past tidal exchange investigations have found that there is a dominance of marine species on the flood tide and estuarine species under going a marine developmental phase on the ebb (Beckley 1985; Whitfield 1989; Trnski 2001; Strydom & Wooldridge 2005). However, tidal exchange using light traps in the Kowie Estuary was found to deviate from the past towed net studies. Collectively, the results showed that marine stragglers (III), specifically *Sardinops sagax*, dominated catches on the ebb tide and estuarine dependents (Ia), in particular *Omobranchus woodii*, dominated the flood tide catches. Although isolated incidences of such trends found in the Kowie Estuary, have been reported in previous studies, the common trend of marine stragglers dominating flood tides and estuarine residents undergoing an obligatory marine phase dominating ebb tides did not occur. It is postulated that such species found in the current study were lost from the nursery on the previous tide and are returning to the nursery areas using the following tide (Strydom & Wooldridge 2005). However, species collected in the light trap study were mostly postflexion larvae and thus are capable swimmers; it is therefore unlikely that these larvae would become displaced from the estuary easily (Strydom & Wooldridge 2005).

Tidal exchange in the Kowie Estuary was investigated using drifting light traps. Light traps function by exploiting the positive response to light that many species of larval fish display (Doherty 1987; Hickford & Schiel 1999; Beckley & Naidoo 2003; Marchetti *et al*. 2004). Therefore, those species that do not display a photo positive response, will be excluded from a light trap sample and results from previous studies with different gear types may not be comparable. It has repeatedly been established that all gear types exhibit size and species selectivity and thus it has been suggested that combining different techniques may be a way to more accurately estimate actual larval composition (Doherty 1987; Choat *et al*. 1993; Hickford & Schiel 1999; Strydom 2003). The utilization of a drifting light trap is beneficial as previous investigations have indicated that a moored trap may be difficult for larvae to enter as the current pushes past the trap, however the drifting trap allows for easy entry as larvae move with the current (Thorrold 1992; Strydom 2003). However, a follow up study to Thorrold (1992) indicated that catches of larval fish were lower when utilizing a drifting light trap and that a stationary trap was more effective, with higher capture rates (Meekan *et al*. 2001). It is evident that more research on this sampling technique is required.

The larval fish composition sampled in the Kowie Estuary comprised a total of 11 125 larval fish, representing 23 fish families and 38 taxa. These results are characteristic of such estuaries. Permanently open estuaries typically have a higher species diversity and abundance when compared to temporarily open/closed systems (Strydom *et al*. 2003). The family Gobiidae dominated catches in the Kowie Estuary, followed by Blenniidae.

Dominance of Gobiid larvae in permanently open estuaries is typical of the temperate region of South Africa (Strydom *et al.* 2003). *Gilchristella aestuaria* (Clupeidae) contributed almost half of the species catch. The dominance of *G. aestuaria* in temperate South African estuaries is also a common trend found in numerous past studies (Strydom *et al*. 2002; Pattrick *et al*. 2007; Montoya-Maya & Strydom 2009). Peaks in *G. aestuaria* densities occurred during summer months and was likely to be in response to rainfall giving rise to increased freshwater and nutrient input and reduced salinities (Strydom *et al*. 2002). Peaks in *G. aestuaria* in other permanently open estuaries, have commonly been found during such periods of low salinity (Strydom *et al*. 2002; Pattrick *et al*. 2007), which triggers spawning for this species. This highlights the importance of freshwater input for such species and their spawning events. The abstraction of water through impoundments may negatively influence the spawning of *G. aestuaria* and other such species that may rely on such a cue (Strydom & Whitfield 2000).

The composition of the Kowie Estuary revealed an overwhelming dominance of estuarine resident species, followed by a small contribution by marine species dependent on estuaries. Catches in permanently open estuaries are typically dominated by estuarine resident species (Strydom *et al.* 2003 (Eastern Cape); Pattrick *et al.* 2007 (KwaZulu Natal); Montoya-Maya and Strydom 2009 (Western Cape). The permanently open mouth allows for easy access of marine species to enter the estuary using tidal currents; however a number of estuary dependent marine species in the Kowie Estuary were not as high when compared to similar estuaries in the region.

Once successfully in the estuary, larval fish will actively locate favourable areas within the estuary; this is largely driven by predator avoidance and the need for access to refuge and food patches. On entry, larvae must move to the estuary margins in order to avoid being displaced from the estuary via tidal currents (Beckley 1985; Whitfield 1989; Strydom & Wooldridge 2005). Marginal, shallow water habitats in estuaries are therefore very important in order for larvae to avoid being swept from the nursery area and avoid being exposed to increased predation in deeper waters (Beckley 1985; Whitfield 1989; Strydom 2003). Additionally, access to food patches within the nursery environment is important in order to reduce time spent in the vulnerable pelagic larval phase (Govoni *et al*. 1985; Strydom *et al*. 2003).

Salinity zones in estuaries play important roles in distribution and density of larval fish in temperate South African estuaries (Strydom *et al*. 2003). There are six salinity zones that may occur in the estuarine environment occurring in response to salinity changes that occur along the length of the estuary (Strydom *et al*. 2003). The mesohaline zone was found to be the region of highest larval fish density in the Kowie Estuary. This has similarly been found in other studies by Strydom *et al*. (2003); Pattrick *et al*. (2007); and Montoya-Maya *et al*. (2009). Increased densities associated with the mesohaline zones occur due to this salinity zone being typically associated with the river-estuary interface (REI). The REI zone is a region of high productivity, where fresh and saline water meet. This frontal region results in the accumulation of particulate matter and hence a feeding patch is created (Wooldridge & Bailey 1982; Snow *et al*. 2000; Strydom *et al*. 2003).

Estuaries are known for their highly productive nature and this is evidenced through the large abundance of fish, invertebrates and birds (Lubke 1998). Often this productivity is governed by physical processes that occur in the estuary on various temporal and spatial scales (Lubke 1998). An example of such a process would be estuarine frontal systems. The freshwater and/or the warmer estuarine water from the estuarine system and the saline water from the ocean will meet, and typically the less dense, warmer water will flow above the denser, cooler ocean water, resulting in density gradients occurring and a water circulation pattern developing (Schumann & Slinger 1999). Previous studies on both oceanic and large scale estuarine fronts have hypothesized that these regions, due to circulation patterns, may result in the accumulation of plankton and thus the development of a feeding patch for organisms (Largier 1993; Ferrier & Anderson 1997; Eggleston *et al*. 1998; Duck & Wewetzer 2001). Access by larval fish and other planktonic organisms to good food patches may play critical roles in enhancing development and therefore reducing time spent in the vulnerable planktonic stage (Searcy & Sponaugle 2000; Bergenius *et al*. 2005). Shear fronts, which are a regular occurrence in the Kowie Estuary, are hypothesized to play some role in plankton accumulation and feeding in the estuary. Understanding the predator-prey relationships between ichthyoplankton and zooplankton in the frontal zone is important in understanding the role of small scale fronts in estuaries. Shear fronts were studied using towed nets in the mouth region of the Kowie Estuary. It was found that Mugilids, an important estuary dependent group of fishes were only recorded in the convergence zone of the shear front. Additionally active fish larvae predators, such as isopods were more numerous in the convergence zone, which may result in predation pressure on smaller larvae in the convergence zone. Mysid shrimps and more passive predators such as chaetognaths and jelly fish (medusa) were more abundant out of the convergence zone. Further investigations into plankton accumulations in the presence and absence of the convergence zone of shear fronts as well as the presence and absence of shear fronts is required to completely understand plankton accumulation and response in the region of frontal systems.

The Kowie Estuary is highly impacted by anthropogenic activities and the lower reaches are characterized by a marina development comprised of artificial channels with steep stone-packed walls. The effect that artificial channelling has on larval fish composition, developmental stage and abundance is not well understood. Young & Potter (2003a, b) have found that artificial channelling results in reduced species diversity and richness. In the present study, a comparison of larval fishes in the lower reaches and marina of the Kowie Estuary revealed some unexpected trends. A notable absence of postflexion larvae occurred in areas that were artificially walled and marine stragglers and marine dependents, which commonly occur in the lower reaches (Whitfield 1994a; Strydom *et al*. 2003), were almost absent. The absence of postflexion larvae may be indicative of the undesirable habitat created by the walled lower reaches resulting in a lack of shallow, marginal water habitat. This lack of marginal water in the lower reaches of the Kowie Estuary has two impacts. Firstly, due to the lack of shallow margins, larvae are more easily swept out of the estuary on strong ebb tide currents (Strydom 2003; Strydom & Wooldridge 2005). It has been found that estuaries with intact natural habitat are more heterogeneous, with an increase in species numbers and diversity (Whitfield 1999; Strydom *et al*. 2003; Young & Potter 2003a, b). Comparing species numbers and diversity in the lower artificial channels of the Kowie Estuary, with lower reaches in other similar estuaries, it appears that the Kowie Estuary has lower species numbers and diversity (Whitfield 1994b; Strydom *et al*. 2003). Secondly, a lack of a shallow, marginal water habitat results in increased predation. This phenomenon is termed ‘deep water predation’, with an increase in water depth resulting in an increase in predator size and thus an increase in predation pressure (Manderson *et al*. 2004).

5. 2 Conclusion

Investigations focusing on plankton, especially in South Africa, have become an important part of estuarine research, however many species and many estuaries are still incompletely studied or unstudied. Almost 70 % of South African estuaries have been rated as having poor or no scientific information (Whitfield 2000). The South African coastline is rugged and thus, estuaries and bays that provide nursery and feeding areas are particularly important for larval and juvenile fishes. Estuaries also provide important links between the ocean and the fresh water river systems (Beckley 1983). Additionally, because the completion of the larval and juvenile phase of some commercially and recreationally important fish species takes place in estuaries, they play an important part in fisheries and ecology. It is imperative to better understand the dynamics of this fragile fish life history stage in conjunction with the plankton environment and estuarine processes influencing these interactions.

Estuarine degradation is high and adequate conservation effort of these areas is lacking. Marina developments, such as that on the Kowie Estuary, alter natural water flow and remove important marginal habitat (Young & Potter 2003a, b). The Kowie Estuary marina development has resulted in a complete loss of shallow, marginal habitat and the creation of a harsh nursery environment in the lower reaches. Key marine species that are commonly found in the lower reaches of other permanently open estuary were almost completely absent in the Kowie Estuary. This finding should provide impetus for rehabilitation within the marina and better ecological considerations for similar developments in the future. Slopes of retaining walls within marinas should be low, and conservation of patches of original wetland and vegetated areas should be a priority in construction. Necessary coastal and marina development should consider the importance of access to marginal water habitats for young fish and the impending impacts of altering natural water courses through development.

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