FINAL REPORT

DIVERSITY AND PRODUCTIVITY OF BIOTIC COMMUNITIES IN RELATION TO FRESHWATER INPUTS IN THREE EASTERN CAPE ESTUARIES

by

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EXECUTIVE SUMMARY

The average rainfall in South Africa (500 mm) is well below the world's average of 860 mm. Of this, only a small part (ca 9 %) is converted into runoff, which is by way the most important water source in the country (DWA. 1986). As a result, water is one of South Africa's scarcest commodities. and therefore receives considerable attention concerning its uses by various interest groups. Over half of the available water is exploited by the agricı 'tural sector, and the remaining part is divided amongst the industry and mining, urban and domestic use, as well as the environment (DWAF, 1997). The environment is estimated to use as big a proportion of water as the sector of industry and mining (between 15 and 20 % of the total), and is stated to include recreational and ecotourism uses, which are acknowledged to be a growing sector with an additional high quality demand (DWAF, 1997). The current political situation, which allows for the upliftment of the big proportion of inherently disadvantaged people, will increase the percentage of water used in the urban and domestic sector, due to increasing numbers of households being given access to quality water. The 'White paper on a national water policy for South Africa' (DWAF, 1997) states an integration of environmental, economic and developmental goals, rather than competition between these interest groups, and generally acknowledges the importance of maintaining the "ecological integrity of South Africa's water resources" and in consequence a healthy environment for South Africa's population. Furthermore, it is stated that "The Bill of Rights also gives all South Africans .... the right to have the environment protected for the benefit of present and future generations", which amongst other points allows for rivers, dams and wetlands to be included in the management of water in South Africa, which are recognized as 'legitimate' water users.

With all these constraints and demands on the country's water resources, 289 estuaries along the South African coast (Reddering and Rust, 1990) are in addition dependent on certain amounts of freshwater inflow via their rivers for their ecological functioning. Estuaries are in need of sufficient water levels in their rivers for a variety of reasons. Firstly, freshwater inflow at the tidal head of an estuary creates a salinity gradient along the longitudinal axes of estuaries. Secondly, if freshwater inflow is not sustained, hypersalinities at the head of estuaries are likely to occur. In general, South African estuaries are flood dominated and mostly the lower reaches are effected by the accumulation of marine sand. If floods fail to occur, no scouring effect will be generated, the estuary silts up, and the estuarine mouth may close eventually. Numerous estuaries have been impacted through increased water abstraction (e.g. Kromme, Kariega, Seekoei, Orange), which has its effect in a decrease of the number and strength of floods, as well as the frequency of occurrence of mouth closures. And lastly, rivers in general carry higher concentrations of nutrients compared to seawater (e.g. Aston, 1980; Funicelli, 1984). Reduced freshwater inflow therefore deprives the estuary of sufficient nutrient input to sustain a certain level of phytoplankton production.

Different habitats are created along the length of the estuary due to the presence of a longitudinal salinity gradient, created and maintained by freshwater and seawater mixing, and, a variety of plant and animal species have become adapted to this variable aquatic environment Hypersalinities can be detrimental for the estuarine flora and fauna, mainly through difficultie of coping with osmotic stress as well as unfavourable breeding conditions in these areas. Mouth closure of an estuary inhibits all movement between the sea and the estuary, which is a vital feature for many species spending part of their life cycles in both environments. Nutrient input and phytoplankton production are an indication of the amount of freshwater the individual estuary is receiving. Other biota are equally effected by this feature, and in this study it was hypothesized, that estuaries with a disrupted freshwater inflow sustain a lower biomass, productivity and species diversity of estuarine biota compared to estuaries with adequate freshwater input.

Three estuaries were under study during this project, namely the Kromme, Swartkops and Sundays estuaries, which are situated along the Eastern Cape coast. Those three estuaries were chosen for the investigation of freshwater inflow on various abiotic and biotic parameters, since they differ in the amount of freshwater they receive from their rivers. Mouth closures do not occur in any of the three estuaries, neither on a temporary nor on a permanent basis. The Sundays estuary has a continuous freshwater inflow, despite two major impoundments, the Van Ryneveld Pass dam and the Darlington dam, in its catchment area. Both dams are situated in the upper half of the river, and water is supplemented via the Orange/Fish/Sundays transfer scheme. The Kromme estuary, on the other hand, is deprived of freshwater. The Kromrivier and Impofu dam in its catchment area have a combined storage capacity of over 130 % of the mean annu l runoff. The Impofu is situated only 4 km from the tidal head of the estuary. As a result, the Kromme estuary only receives freshwater if both are full and in addition heavy rains lead to an overflow at both dams. During drier periods therefore, the estuary is freshwater starved. The Swartkops estuary claims an intermediate position in terms of freshwater inflow between the Sundays and Kromme estuaries. The only major impoundment on the Swartkops river, the Groendal dam, is not believed to significantly reduce freshwater flow to the estuary.

These three estuaries with different river flow regimes were studied on a comparative basis. Set objectives were to:

1. assess the freshwater inflow volumes and the resulting salinity regime (Chapter 3)
2. quantify the volume of freshwater necessary to create and maintain a salinity gradient along the longitudinal axis (Chapter 3)
3. investigate the nutrient status and the phytoplankton biomass in relation to freshwater inflow (Chapter 4)
4. establish links between freshwater inflow into the individual estuaries and the biomass, productivity and species diversity of their estuarine biota (Chapter 5)

During the study period, the rate of freshwater inflow was measured to be lowest in the Kromme estuary. The general freshwater inflow pattern ranged from very low to completely absent, and only once was a high flow of over 8 $m^3 \cdot sec^{-1}$ measured at the Impofu dam 4 km from the tidal head of the estuary. Freshwater inflow into the Sundays estuary was continuos and the least variable of the three estuaries, whereas the Swartkops estuary takes an intermediate position between the two former systems. The longitudinal salinity gradient in the three estuaries was a direct reflection of the freshwater inflow pattern. During the study period, the gradient from mouth to the head in the Kromme estuary was only about 5 ppt (from 35 to 30 ppt), in the Swartkops estuary salinities dropped in the upper reaches to a mean value of 15 ppt, whereas in the Sundays estuary salinities were at a mean of ca 10 ppt in the upper reaches.

The Mike 11 hydrodynamic model was applied to define the freshwater volumes needed to create and maintain a longitudinal salinity gradient in the Kromme and Swartkops estuary. In the Kromme estuary, 2×10^6 m^3 per annum are allocated to the estuary, which is considered to compensate for the evaporative losses of the estuary. Various freshwater inflow scenarios with said amount were conducted by EMATEK (CSIR), Stellenbosch, to create a longitudinal salinity gradient in the Kromme estuary. Results from this study showed, that a freshwater inflow of 0.5 $m^3 \cdot sec^{-1}$ for a period of 1 month would be necessary to create a gradient, which would amount to a total of 2.6×10^6 m^3. One major release from the Impofu dam of 2×10^6 m^3 would serve the same purpose. To maintain the longitudinal gradient, a frequent release of smaller amounts would be necessary. Judging from the existing freshwater inflow pattern in the Swartkops estuary, comparatively smaller amounts of additional freshwater would be necessary to create and maintain a longitudinal salinity gradient throughout.

All three estuaries were investigated for their concentrations of various nutrients, which included phosphate, nitrate, nitrite, ammonia and total particulate nitrogen. Nutrient concentrations in all three estuaries were a direct reflection of the freshwater input into the systems. The overall lowest annual nutrient input was measured for the Kromme estuary (0.22 tons P-PO_4 p.a., 6.6 tons of dissolved inorganic nitrogen p.a.). A higher input of all dissolved inorganic nitrogen compounds (22.9 tons p.a.) as well as very high phosphate input (6.5 tons P-PO_4 p.a.) was measured in the Swartkops system. Pollution originating mainly in the Uitenhage area is responsible for these high phosphate loads. The Sundays estuary receives higher amounts of phosphates (1.8 tons P-PO_4 p.a.) than the Kromme estuary, but concentrations are not nearly as high as in the Swartkops estuary. Nitrogen was abundantly supplied to the Sundays estuary (92.9 tons p.a.) and mainly in the form of nitrate.

The Kromme, Swartkops and Sundays rivers were in most cases the major nutrient suppliers to their estuaries. Once the Kromme river reaches its estuary, it contributes to an elevation of all measured nutrients not only in the upper reaches, but throughout the whole estuary. Regarding nutrient concentrations in the estuary, rather smaller and more frequent releases than one or two major releases of the allocated amount of water (2 x 10^6 m^3 p.a.) from the Impofu dam would be favourable to replenish the nutrient pool in the estuary. The Geelhoutboom was found not to be a vital nutrient contributor to the Kromme estuary, since concentrations remained low during low flow conditions. The Swartkops river was the main source of phosphate to its estuary. On the other hand, nitrogen compounds were in addition supplied by the Motherwell canal as well as the Chatty river. The only runoff point source to the Sundays estuary was its river, which was the main source of nitrate. Ammonia seems to be generated in the upper reaches of the Sundays estuary. Phosphate concentrations are small, and are thought to be regenerated on a large scale within the estuary to meet the demands of phytoplankton production.

Atomic N:P ratios in both the Kromme and Sundays estuaries (63:1 and 166:1 respectively) highlight the shortage of phosphate for phytoplankton production. In the Swartkops estuary, the N:P ratio was calculated at 6:1, indicating a shortage of nitrogen. A reflection of the N:P ratios in the river water was apparent throughout their estuaries.

Statistical analysis showed a bigger similarity in terms of nutrients as well as chlorophyll-a concentrations in the lower reaches of the three estuaries, whereas differences became more obvious towards the upper reaches and the river water. These findings are, similar to longitudinal salinity gradients, a direct reflection of the amount of freshwater input into the three systems.

Phytoplankton chlorophyll-a concentrations are in turn a reflection of the availability of nutrients. Overall lowest chl-a concentrations were measured in the Kromme estuary, although an increase was apparent once the river below the Impofu dam commenced flowing and transported nutrients into the estuary. In the Swartkops estuary, the region with the highest biomass of chlorophyll-a were the upper reaches (ca 9 $\mu \cdot l^{-1}$). Both the middle and upper reaches supported high chlorophyll-a concentrations in the Sundays estuary (ca 23 and 22 $\mu \cdot l^{-1}$ respectively).

Other biota in the estuary were influenced by freshwater inflow patterns either in a direct cause and effect relationship or in an indirect way. In general, those biota belonging to the pelagic food chain conform to the former, and those in the benthic food chain to the latter, with the exception of benthic microalgae.

In all three estuaries, the zooplankton standing stock was found to follow the pattern of phytoplankton abundance, namely low in the Kromme, higher in the Swartkops and highest in the Sundays estuaries. In addition, zooplanktivorous fish were distributed accordingly. Freshwater inflow therefore not only determines the nutrient concentrations in the estuaries, but in addition all of the biota deriving sustenance from food sources fueled directly by nutrient input. Piscivores, which included the pelagic predators, were found to exhibit highest biomass and productivity in the Sundays estuary. Both components were found to be lowest in the Swartkops estuary, which can only partly be attributed to angling pressure on certain targeted species. In terms of species diversity, the small planktonic communities in the Kromme estuary show reduced numbers of species preferring low salinities.

Taking the benthic communities into consideration, it was only the benthic microalgae which were directly influenced by freshwater inputs and nutrient concentrations. Regarding other benthic communities, biomass was higher in the Kromme estuary, lowest in the Sundays estuary, and intermediate in the Swartkops estuary. Both saltmarsh and submerged macrophyte communities showed highest biomass and productivity ($mg \cdot m^{-2}$ of areal cover) in the Kromme estuary. The species composition, on the other hand, had shifted from brackish to marine communities. In the Sundays estuary submerged macrophytes only cover a small area, whereas no data are available regarding saltmarsh macrophytes. In the Swartkops estuary a lower biomass and productivity for submerged macrophytes and saltmarsh plants was measured compared to the Kromme estuary.

The invertebrate macrozoobenthos seemed to favour the extensive macrophyte beds in the Kromme estuary. Especially suspension feeders and detritivores showed the highest biomass and productivity in the Kromme estuary. In this case, the habitat structure and food availability seems to gain in importance to the macrozoobenthos compared to a particular salinity regime in the estuary.

Similarly is the behaviour of the benthic feeding fish. In both the Kromme and Sundays estuary were mullet stocks found to be high, although the food resources are of a different nature in the two systems (detritus vs benthic microalgae). In the Kromme estuary, other benthic feeding fish profit from a higher detritus production and highe · macrozoobenthic standing stocks as a food source, as well as shelter provided by the extensive macrophyte beds.

Overall, the Kromme estuary with its decreasing phytoplankton biomass but encroaching macrophyte beds has shifted towards a detritus based system. The lack of freshwater inflow is responsible for such a shift, since a salinity gradient, nutrient input and floods fail to occur on a regular basis and thus the habitat became more stable. Macrophytes therefore could encroach, build new habitats for the macrozoobenthos as well as benthic feeding fish, and produce high amounts of detritus. Despite negative effects on the pelagic components of the biota, positive effects on certain biota in the Kromme estuary were noted. It must be kept in mind, that these developments were observed in a timespan of ca 5 to 10 years after the Impofu dam was built, but no conclusions can be drawn as yet for the future years. However, the species diversity of certain planktonic communities is already on the decline. The pelagic food chain in the Sunday estuary is prominent, and if freshwater inflow into the estuary is sustained at the present level, no shift in energy flow pathways is expected. The Swartkops estuary shows features of both the Kromme and Sundays estuaries, incorporating both a prominent pelagic as well as benthic food chain. Similarly, if present freshwater inflow patterns are sustained, habitats and biotic communities within the estuary should be sustained at present patterns.

The main concerns regarding the three estuaries are that of the reduced fres water inflow into the Kromme estuary, that of pollution in the Swartkops estuary, and that of a probable increased freshwater abstraction in the future regarding the Sundays estuary. In the case of the Kromme estuary, the present pattern of freshwater inflow could turn the estuary in a marine lagoon, that is if tidal action at the estaurine mouth can sustain a permanent connection to the sea. From a salinity, but especially a sediment point of view, releases of greater volumes of water from the Impofu dam will be most efficient in establishing a salinity gradient on the one hand, and scour accumulated sediments on the other. Regarding nutrients, a frequent freshwater inflow at the head of the estuary is desirable to sustain phytoplankton and benthic microalgal production, both an important food source for various other biota. Nutrients, especially phosphate, are of major concern in the Swartkops estuary. Pollution from the Uitenhage area enables excessive plant growth in the lower Swartkops river. These inputs at the tidal head as well as the high nitrogen loads from the various point sources along the estuary are not only additional nutrient inputs to favour microalgae growth, but their sources (i.e. sewage, industrial waste, etc.) can equally be a health hazard to people using this popular recreation area.

Results of this study give an indication of the influence, both detrimental and beneficial, of freshwater on estaurine biota. The often encountered resilience of est aries to environmental perturbations is an important feature when estuaries are to cope with natural fluctuations, but can not cope in the case of a continuous deterioration of certain features which maintain estuaries as an intact ecosystem. The management of estuaries nowadays concentrates mainly on features such as floods and mouth closure, whereas the amount of freshwater flowing into an estuary as a determinant of the structure and biology of estuarine biota has so far escaped wider attention for management purposes. This study highlights the importance of freshwater inflow on three systems with a permanent connection to the sea, and differences were apparent from all aspects investigated.

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CHAPTER 1

INTRODUCTION

The availability of water is increasingly recognised as one of the main control factors to global population growth and development. In order to meet water demands, the water supply schemes already in existence are likely to undergo further development in the future and considerable attention will be paid to interbasin water transfers (Balchin, 1991). South Africa is one of the numerous countries which are facing a problem in providing water for agriculture, industry and its fast growing population. The average rainfall in South Africa is about 500 mm per annum, which is distinctly lower than the world's average of 860 mm, and in most areas of the country evaporation exceeds rainfall. The eastern and southern coastline receive the major part of the rainfall, whereas an arid or semi-arid climate is found in the interior and western parts of South Africa. 65% of the country receives less than 500 mm of rain annually and 21 % less than 200 mm (DWA, 1986).

Since South Africa's ground water resources are meagre, most of the freshwater for the populations requirements is supplied by surface run-off (Middleton et al., 1981; DWA, 1986). Only 9 % of the total rainfall is discharged by rivers, where the average annual run-off of all South African rivers is estimated at 53500×10^6 m^3. Due to the high variability in river flow combined with high evaporation, only 62 % or 33000×10^6 m^3 of the mean annual run-off can be exploited. To account for this variability in river flow, major dams in South Africa have a storage capacity of about 50 % of the mean annual run-off (DWA, 1986). Furthermore, drought conditions are no rarity, where the hydrological cycle spans for about 18 years in most of South Africa, nine years of poor and nine years of good rainfalls (Tyson, 1986). A 10 - 12 year oscillation is confined to the region of the southern Cape coast (Tyson, 1986). The inland water resources in the country are already developed, which leaves the east and south coast for further exploitation, an area where the major water resources of South Africa lie. This part of the country generates about 85 % of the nation's total run-off (Middleton and Lorentz, 1988).

It is also on this stretch of the South African coast, where most of the estuaries have developed. Since an estuary is dependent on a riverine influence for its functioning, 289 estuaries (Reddering and Rust, 1990) nowadays have to compete for freshwater with South Africa's population. Estuaries are dependent on freshwater inflow for its physico-chemical environment, i.e. salinity gradients, flooding as well as material input into estuaries, properties, which in turn influence the biota in the estuary (Kennedy, 1984; Whitfield and Wooldridge. 1994; Allanson and Read, 1995).

These ecosystems are in a state of a dynamic equilibrium and characterised by various successionary trends in terms of the biotic organisation in the estuary (Whitfield and Bruton, 1989). The magnitude and regularity of freshwater inflow plays a vital role in leading the ecosystem from a less to a more mature system. and equally in resetting the whole system to an earlier state, which is induced by the events of floods. The increased water abstraction from the rivers is therefore likely to critically affect the whole estuarine system. South Africa ı estuaries are in general flood dominated and consequently the problem of sediment accumulation in the estuary arises. The development of extensive flood tide deltas and of sand barriers, which close the estuaries off from the sea on a either permanent or temporary basis, are a feature of all estuaries on the South African coast. Floods are vital to scour sediments out to sea and secure a connection therewith (Reddering, 1988), which is important in terms of material input from the sea and a vital feature in the lifestyle of organisms utilising both the estuary and the ocean during parts of their lifecycles (Wooldridge, in press).

It is not only the timing and regularity of flood events, which are altered by the restriction of freshwater flow to the estuary, but also the salinity gradients (including the occurrence of hypersalinities) and the availability of riverine material replenishing the estuarine nutrient pool. The effects of a reduction in freshwater inflow on the biota in the estuary are thought to be manifold, and one of the detrimental consequences is considered to be a distinct decrease of diversity, biomass and productivity. In this study it was aimed to quantify these effects in three systems with varying freshwater input. The Kromme, Swartkops and Sundays estuaries are have a permanent connection to the sea, but differ markedly in the amount of freshwater they receive. Data on freshwater inflow, salinity gradients, nutrient inputs at the tidal head and on nutrient concentrations and phytoplankton biomass in the estuary were collected in all three estuaries, results of which are presented in Chapter 3 and 4 respectively. The diversity, biomass and productivity of the various biot: in the three estuaries were quantified for the purpose of interestuarine comparisons using various published and unpublished data (seeChapter 5).

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CHAPTER 2

DESCRIPTION OF STUDY AREAS

2.1 The Kromme estuary

The Kromme estuary is situated approximately 15 km west of Humansdorp (3408'S; 2451'E) (Bickerton and Pierce, 1988) (Fig. 2.1). The 95 km long Kromme river originates in the Tsitsikamma mountains and drains a catchment area of 936 km^2 (Reddering and Esterhuysen, 1983), which is partly vegetated by fynbos and natural forest whereas the remaining part is mainly farmland utilised for stock raising and grain cultivation (Baird et al., 1992). Rainfall in the Kromme river basin occurs throughout the year. Peaks in spring and autumn are prevalent, and the lowest rainfalls are measured in January and February (Bickerton and Pierce, 1988). The mean annual precipitation varies from 700 to 1200 mm, which results in a mean annual runoff of approximately 105.5×10^6 m^3 (Table 2.1). Since the river runs through high relief, rocky slopes and sparsely vegetated areas, the runoff is high (Reddering and Esterhuysen, 1983). Nevertheless, only a small proportion of the runoff reaches the estuary owing to two major obstructions on the Kromme river. The Kromrivier Dam (former Churchill Dam), which was completed in 1943, is situated 50 km upstream from the mouth of the estuary and has a storage capacity of 33.3×10^6 m3. The Impofu Dam (former Charlie Malan or Elandsjagd Dam) was completed in 1982 and is situated 4 km above the tidal head of the estuary (approximately 18 km from the mouth of the estuary), with a storage capacity of 107×10^6 m^3 (Bickerton and Pierce, 1988). Freshwater inflow into the estuary has decreased markedly since the construction of the Impofu dam. A release policy, which provides for 2×10^6 m^3 per annum (EMATEK (CSIR), 1994), was proposed to account for the evaporative loss of the estuary (Jezewski and Roberts, 1986).

Rapids mark the tidal head of the 14 km long Kromme estuary. Its major tributary is the Geelhoutboom which enters the estuary approximately 7 km from the mouth (Fig. 2.2). In addition, there are numerous small rivers entering along the entire length of the Kromme estuary, of which the Sand river, which joins the estuary 1.3 km from the mouth and drains part of a by-pass dunefield, is the most prominent (Fig. 2.2) (Bickerton and Pierce, 1988).

Emphasising the estuary's status as a popular recreation area are the development of the Marina Glades, near the mouth, and holiday shacks further upstream. The land around the estuary is used for farming which is practised only on a limited scale on the estuarine banks itself (Reddering and Esterhuysen, 1983; Bickerton and Pierce, 1988). From a scientific point of view, the system is well known, with numerous studies conducted on various physico-chemical, biological and ecological aspects during the past 15 years.

Table 2.1: Ca chment characteristics of the Kromme, Swartkops and Sundays estuaries. (*Sources: Reddering and Esterhuysen, 1981a; Reddering and Esterhuysen, 1981b; Reddering and Esterhuysen, 1983; Bickerton and Pierce, 1988).

	Kromme		**Swartkops**	**Sundays**	
Catchment area*	936 km^2		1360 km^2	20729 km^2	
MAP*	700 - 1200 mm		640 mm	323 mm	
MAR*	105 x 10^6 m^3		84 x 10^6 m^3	186 x 10^6 m^3	
Dams	Kromrivier (Churchill)	Impofu (C. Malan)	Groendal	Van Ryneveld Pass	Darlington (Lake Mentz)
Capacity*	33.3 x 10^6 m^3	107 x 10^6 m^3	12 x 10^6 m^3	53 x 10^6 m^3	206 x 10^6 m^3
Capacity as % MAR	32 %	101 %	14 %	29 %	111 %
	combined: 133 %			combined: 140 %	
Km from tidal	35 km	4 km	35 km	Graff-Reinet	Middle regions of Sundays river

2.2 Swartkops estuary

The location of the Swartkops estuary is approximately 15 km north of the Port Elizabeth harbour (3352' S and 2538' E) (Baird et al., 1986) (Fig. 2.1). Both the Swartkops and its biggest tributary, the Elands river, originate in the Groot Winterhoek mountains and meander for 155 km to the estuary (Reddering and Esterhyusen, 1981a). Their course takes them mainly through forested area and some land along the Elands river is in agricultural use (Baird et al., 1986; MacKay, 1993). The total catchment area of both rivers adds up to approximately 1360 km^2, where rainfall occurs during all seasons with slight peaks in autumn and spring. The mean annual rainfall is calculated at 636 mm with a range from 1000 mm in the Groot Winterhoek mountains and 500 mm east of Uitenhage resulting in a mean annual runoff of 84.2 x 10^6 m^3 (Table 2.1) (Reddering and Esterhuysen, 1981a). There are no dams on the Elands river, although its two tributaries, the Sand and Bulk river are both impounded. The only major obstruction on the Swartkops River is the Groendal Dam, which holds back a sixth of the total runoff of the Swartkops river basin and reduces floods by only 5%. (Baird et al., 1986).

A causeway, 16.4 km from the mouth at Perseverance, marks the upper limit of the estuary. About 0.5 km upstream of the Swartkops village the Chatty river, its biggest tributary, enters the estuary (Baird et al., 1986). There are numerous industrial activities along the estuary such as salt pans, clay mining, a power station, sewage treatment works and the Markman industrial area. Two villages, Swartkops and Redhouse are situated on the southern bank. On the northern bank the residential area of Amsterdamhoek is located near the mouth and is spreading along Tippers Creek (Fig. 2.2). Further upstream a nature reserve is bordering the estuary. The Swartkops valley is densely urbanised. Agricultural activity is limited, whereas the estuary is a popular recreation area (Baird et al., 1986).

The earliest studies on the Swartkops estuary were carried out as far back as 1916 by Fitz Simons and the estuary is well known due to many studies over the past thirty years (e.g. see Baird et al., 1987).

2.3 Sundays estuary

The Sundays river originates north of Graaff-Reinet (3343'S, 2525'E) (Fig. 2.1). The catchment area of the 310 km long river extends for 20729 km^2, with sheep farming and citrus cultivation in some areas as the main agricultural activity. In the northern region of the drainage basin summer rainfall prevails (ca. 250 to 500 mm p.a.), whereas in the southern region two peaks occur in autumn and late winter (approximate rainfall: 400 to 1000 mm p.a.). The overall mean annual precipitation is 323 mm, categorising the Sundays River catchment as a semi-arid area, from which the mean annual runoff is 186 x 10^6 m^3 (Table 2.1). Two dams are situated along the river, the Van Ryneveld Pass Dam (at Graaff-Reinet) with a storage capacity of 53 x $10^6 m^3$, and the Darlington Dam (former Lake Mentz) situated half way up the river. The latter has a storage capacity of 206 x 10^6 m^3 (Reddering and Esterhyusen, 1981b).

The estuary itself is located 30 km north-east of Port Elizabeth (Fig. 2.1). A sudden rise in the riverbed marks the tidal head of the estuary near Barkley bridge (MacKay and Schumann, 1990). The entire length of the estuary is estimated between 21 (Reddering and Esterhuysen, 1981b) and 24 km (MacKay and Schumann, 1990). Recreation is the main activity on the estuary and limited farming is practised on the banks of the upper estuary. A caravan park and a number of holiday houses are situated on the banks of the lower part of the estuary (Reddering and Esterhuysen, 1981b).

Research on the estuary has its beginnings in the late seventies (Wooldridge, 1979; Marais, 1976). Subsequent research focused mainly on zooplankton, macroinve. :ebrates, ichthyofauna, phytoplankton as well as sedimentation and hydrology.

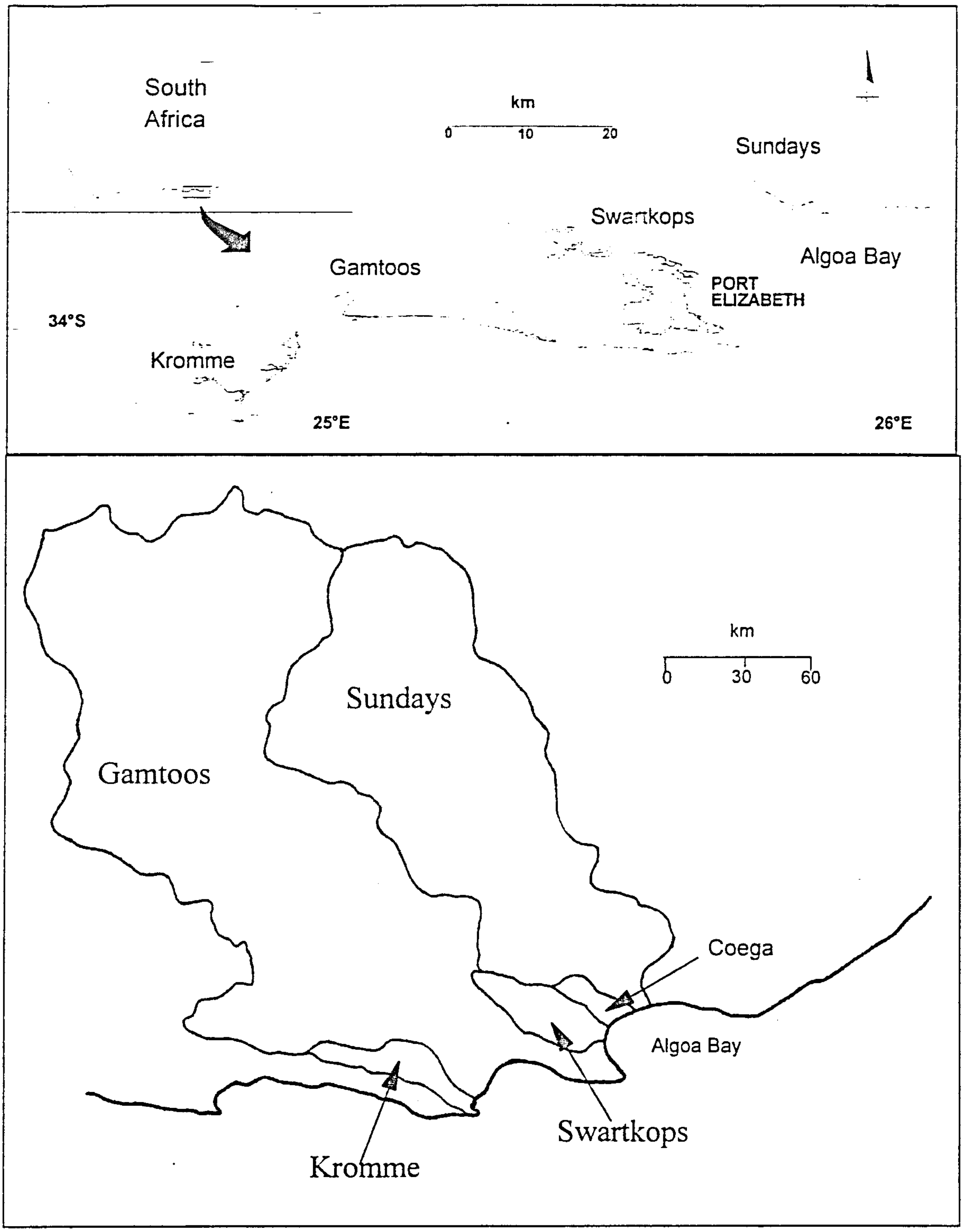

Fig.2.1: Location of estuaries and their catchment areas along the South African coast.

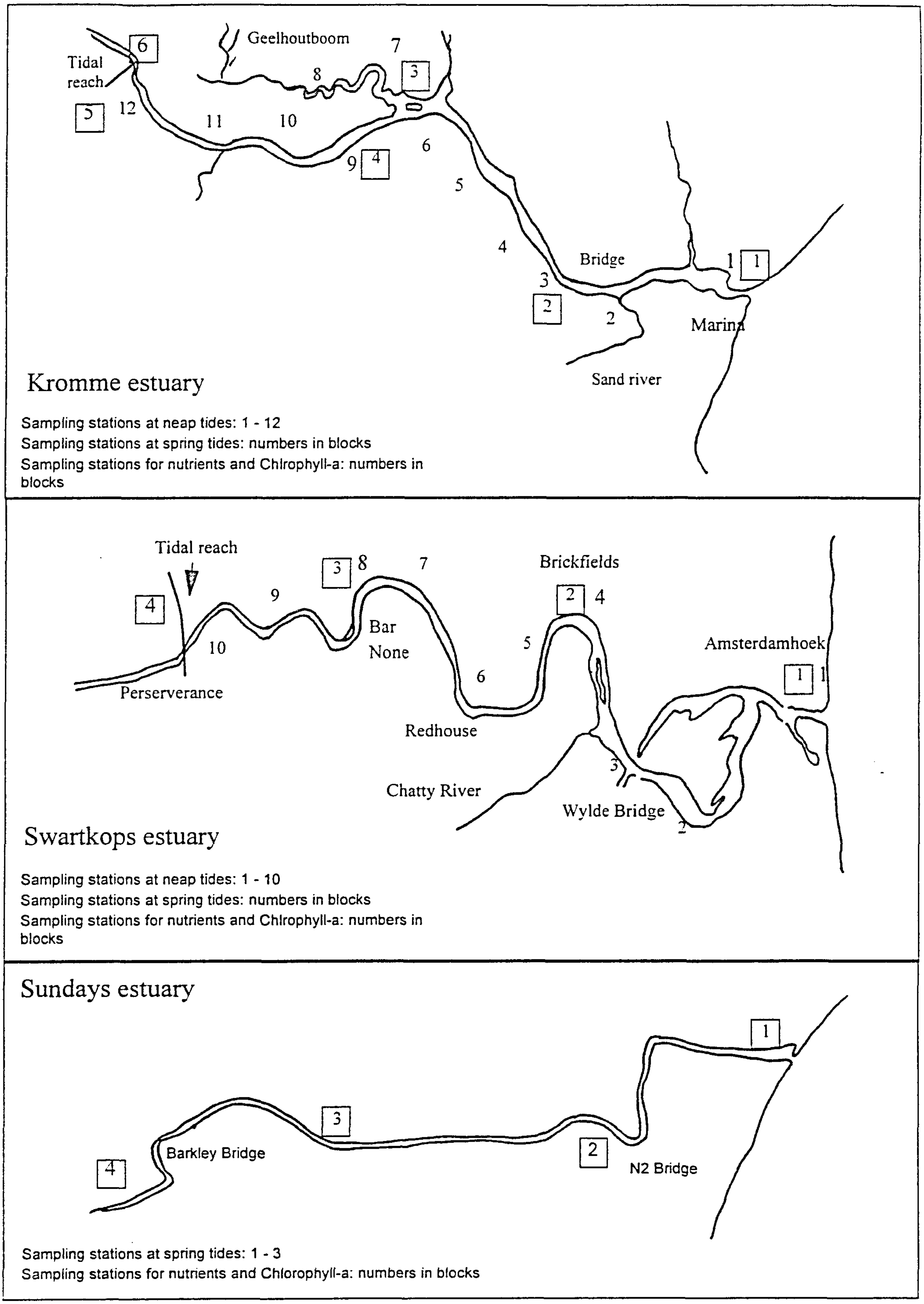

Fig. 2.2: Location of the sampling stations in the Kromme, Swartkops and Sundays estuaries.

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CHAPTER 3

FRESHWATER INPUT AND SALINITY GRADIENTS IN THE KROMME, SWARTKOPS AND SUNDAYS ESTUARIES

3.1 INTRODUCTION

Estuaries are aquatic transition zones between rivers and the sea and one essential criterion of estuaries is the combination of riverine freshwater with seawater (Pritchard, 1967; Odum, 1971; Heydorn, 1979; Day, 1980). Under natural conditions, the magnitude of the mixing processes between the two water bodies is subject to the cyclic nature of rainfall and drought, a cycle which is emphasised in arid countries such as South Africa. Alterations to these natural fluctuations are often intensified by man induced modifications, which essentially interfere in the catchment area through the construction of impoundments and other obstructions to river flow, as well as through the abstraction and transfer of river water. Being the last freshwater user at the very end of the river, an estuary will inevitably reflect the collective effects of all the changes brought about in its catchment area, of which the most threatening is a reduction in river flow.

The immediate effect of reduced freshwater discharge to the estuary is indicated by a less pronounced longitudinal salinity gradient. In cases of excessive abstraction of river water, hypersalinities can be measured in the upper reaches of the estuary, especially during periods of elevated evaporation, causing the salinity gradient to be reversed. Such phenomena have been documented for a number of estuaries along the South African coast, e.g. the Seekoei (Whitfield and Bruton, 1989), Kromme (Baird et al., 1992) and Kariega estuaries (Hodgson, 1987) on the Eastern Cape coast, or the St. Lucia estuary (Boltt, 1974) on the coast of Natal. Unavoidable consequences of diminished riverine influence are changes in the chemical (e.g. salinity, oxygen, pH, nutrient concentrations) and physical (e.g. temperature, turbidity, sediment accumulation) properties of the estuary. The different habitats which are initially created by the physical and chemical parameters along the estuary are exploited and inhabited by certain floral and faunal assemblages, which are physiologically adapted to cope with the short and long term natural fluctuations typical of estuaries. But the structure and productivity of the estuarine biotic communities could be affected, if environmental conditions are artificially altered and the marine influence increases (Heydorn, 1979; Hart and Allanson, 1984; Day et al., 1986; Reddering, 1988; Michaelis, 1990). Since the maintenance of a longitudinal salinity gradient is one of the most characteristic features of an estuary, this chapter will assess the salinity structures of the Kromme. Swartkops and Sundays estuaries. It is aimed to quantify the freshwater inflow necessary to respectively create and maintain a longitudinal salinity gradient throughout these estuaries.

3.2 MATERIALS AND METHODS

3.2.1 Literature Survey

The purpose of the literature survey was to obtain an overview on the salinity and temperature structure, and possible temporal changes thereof, in each of the Kromme, Swartkops and Sundays estuaries. The information was extracted from McLachlan (1972), Hecht (1973), McCallum (1974), Marais (1976), Melville-Smith (1978), Wooldridge (1979), Hanekom (1982), Marais (1982), Wooldridge and Bailey (1982), Marais (1983), Hilmer (1984), Beckley (1985), Pereyra-Lago (1986), Emmerson and Erasmus (1987), Jerling (1988), MacKay (1988), de Wet (1988), Emmerson (1989), Cloete (1990), Harrison and Whitfield (1990), Hilmer (1990), Hanekom and Baird (1992), Jerling (1993), MacKay (1993), Newman (1993), Daniel (1994), Hilmer (unpub. data), Jerling and Wooldridge (unpub. data), Pereyra-Lago (unpub. data) and Slinger (unpub. data).

3.2.2 Sampling strategy

Salinity and temperature measurements were taken in the Kromme, Swartkops and Sundays estuaries between April 1993 and June 1994 on bimonthly sampling trips at spring low tides. These data were collected in conjunction with water samples, subsequently to be analysed for nutrients. Since the purpose of the latter study was to investigate the riverine influence on the estuary, spring low tides were chosen for the gathering of the relevant data. Additional monthly measurements at neap tides, which were fundamental for the calibration of the Mike 11 hydrodynamic simulation model (see 3.2.3), were taken in the Kromme and Swartkops estuaries. The sampling period for neap tides in the Kromme estuary extended from November 1993 to March 1994 and from July to October 1994, and for the Swartkops estuary from F:bruary to October 1994. Overall, there were eight sampling occasions at spring tides for all three estuaries, and additional nine at neap tides in the case of the Kromme and Swartkops estuaries. At each sampling station (Fig. 2.2), a CTDS Valeport Ser. 600 was used to measure salinity and temperature at depth intervals of 0.5 m from surface to bottom.

Freshwater inputs were quantified after every completed sampling session in the Swartkops and Sundays estuaries. Since a causeway was built upstream of the Swartkops estuary, the waterflow through several pipes underneath the causeway was measured using a OTT C20 Mini-current meter.

In the Sundays estuary a crossectional area was measured at Barkley Bridge (Fig. 2.2). Due to slow waterflow and difficulties of streamlining the Mini-current meter in turbid waters, current velocities were measured using a PVC bottle filled with enough water to allow the bottle to drift just below the surface. The drifting bottle was timed three times over a distance of three meters, and the average velocity calculated. Freshwater inflow into the Kromme estuary was chosen to be equal to the volume of water leaving the Impofu dam, since it is situated only 4 km above the tidal head of the estuary and therefore the only real source of freshwater at the tidal head. The information on waterflow from the Impofu dam was provided by the Department of Water Affairs in Pretoria. Due to the inaccessibility of the upstream border of the Geelhoutboom estuary, the freshwater input could not be quantified at this location.

3.2.3 Mike 11 Modelling System

To assess the freshwater requirements of the Kromme and Swartkops estuaries in terms of creating and maintaining a longitudinal salinity gradient, the Mike 11 Modelling System, a hydrodynamic simulation model, was applied in co-operation with EMATEK (CSIR) in Stellenbosch. No hydrodynamic simulations were carried out for the Sundays estuary, mainly due to the lack of survey data for model calibration (e.g. crossectional profiles) for this particular estuary.

The modelling system consists of two components:
A - a hydrodynamic model which simulates water movements in an estuary and
B - a transport-dispersion module which simulates the dispersive processes within the estuary.
Both parts consider effects of tidal variation, river flow at the tidal head, density differences along the axis of the estuary as well as evaporation and precipitation. Calibration is achieved by adjusting the bottom shear stress term in the hydrodynamic model and a dispersion coefficient in the transport-dispersion module, until model output results (i.e. computed salinity results) are in agreement with measurements taken in the f eld. The Mike 11 Modelling System is then used to simulate salinity gradients in the estuary resulting from a specified amount of freshwater input at the head of the estuary. Vertical stratification cannot be considered in this model due to its one-dimensional character, but a salinity gradient along the longitudinal axis of the estuary can be computed (EMATEK (CSIR), 1994).

Due to a lack of continuous freshwater inflow data into the Swartkops estuary (freshwater inflow was only measured on sampling occasions, whereas data for the Impofu dam at the Kromme river are available on a daily basis), the model could not be calibrated. Nevertheless, an adjustment was performed leading to an agreement of model results with the actual measurements taken in the estuary during the sampling period.

3.3 RESULTS

3.3.1 Freshwater inflow:

Two datasets were available to serve the purpose of direct comparisons between the Kromme, Swartkops and Sundays estuaries. Firstly, a dataset obtained for all three estuaries during a sampling period cha acterised by spring tides, and secondly a set of data obtained during a neap tide sampling period. Only the Kromme and Swartkops estuaries were sampled during the neap tides (see 3.2.2).

The freshwater inflow measured during the sampling period at spring tides differed to a great extent between the three estuaries (Fig. 3.1). The lowest and most irregular input of freshwater was found to be into the Kromme estuary (a mean flow rate of 1.16 $m^3 \cdot sec^{-1}$; SD = 3.07), whereas the highest as well as the least variable into the Sundays estuary (mean = 2.74 $m^3 \cdot sec^{-1}$; SD = 1.03). The Swartkops estuary takes a intermediate position with a mean value of 1.52 $m^3 \cdot sec^{-1}$ (SD = 2.14). High discharge of freshwater occurred on one occasion in both the Kromme (8.75 $m^3 \cdot sec^{-1}$ in June 1993) and the Swartkops estuary (6.44 $m^3 \cdot sec^{-1}$ in October 1993). If those peak values are not taken into account, the average freshwater inflow drops to 0.07 $m^3 \cdot sec^{-1}$ (SD = 0.14) for the Kromme and to 0.82 $m^3 \cdot sec^{-1}$ (SD = 0.86) for the Swartkops estuary (Fig. 3.1).

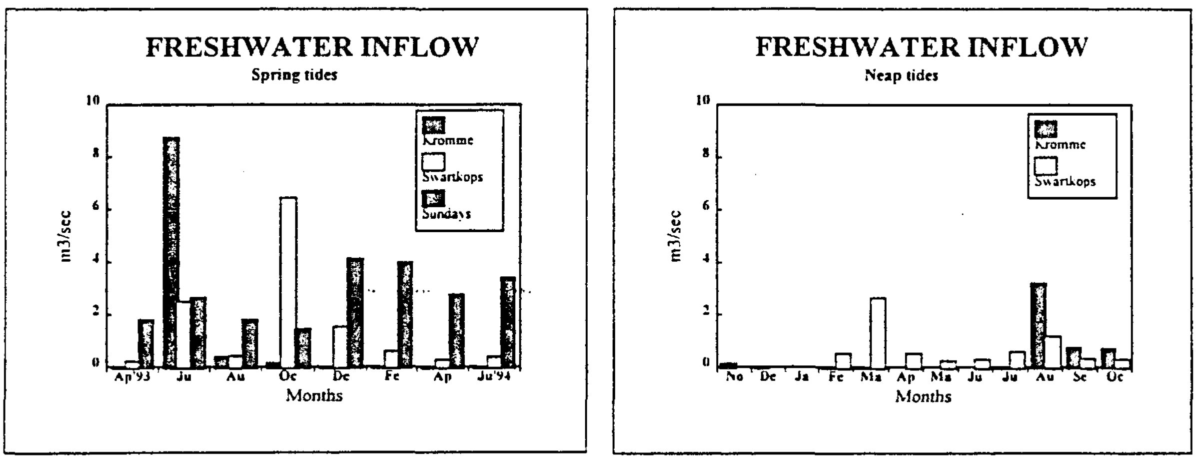


Fig. 3.1: Freshwater inflow into the Kromme, Swartkops and Sundays estuaries during spring and neap tide sampling periods (see Materials and Methods: 3.2.2.).

Freshwater inflow during neap tides (Fig. 3.1) was again lower in the Kromme ($x = 0.59$ $m^3 \cdot sec^{-1}$; SD = 1.10) than in the Swartkops estuary ($x = 0.71$ $m^3 \cdot sec^{-1}$; SD = 0.78). Similarly, if peak flow values are not taken into consideration, which were 3.21 $m^3 \cdot sec^{-1}$ for the Kromme (in August 1994) and 2.64 $m^3 \cdot sec^{-1}$ for the Swartkops (in March 1994), average freshwater inflow drops to 0.22 $m^3 \cdot sec^{-1}$ (SD = 0.33) and to 0.44 $m^3 \cdot sec^{-1}$ (SD = 0.31) respectively (Fig. 3.1).

3.3.2 Salinity structure

3.3.2.1 Longitudinal salinity gradients:

Salinity data which were obtained from the literature are represented in Table 3.1 and illustrated in Fig. 3.2. For further reference, the lower, middle and upper reaches for all three estuaries were defined by dividing their length into three more or less equal parts. Furthermore, before calculating means (±SD), salinity data for each station in each estuary were depth averaged. The same procedure was applied for the datapoints in Figs. 3.2, 3.3, 3.4, 3.5 and 3.6.

Salinities along the longitudinal axis of the three estuaries were found to be the highest throughout in the Kromme estuary, which range from 32.8 ppt in the lower reaches to 31.1 ppt in the upper reaches (Table 3.1). In the Sundays estuary salinities were lowest in comparison to the Kromme and Swartkops estuary (range: 27.6 - 5.3 ppt). Mean salinity values in the Swartkops estuary reflect an intermediate position between the Kromme and Sundays estuaries, although salinities differ to a lesser extent from those in the Kromme estuary as compared to those in the Sundays estuary (Table 3.1). The difference between mean winter and summer salinities is small, changing between 1 and 3 ppt for the lower, middle and upper reaches in all three estuaries. In the Kromme and Swartkops estuaries, the salinity is slightly higher in summer than in winter, whereas the opposite is true for the Sundays estuary (Table 3.1). No temporal changes of the salinity regime were apparent throughout the years. The 'conventional' salinity gradients of each individual estuary only seem to be disrupted during the extreme events of floods (Fig. 3.2).

Table 3.1: Mean (±SD; n) salinities (in ppt) for the Kromme, Swartkops and Sundays estuaries, calculated from data available in the literature.

	Lower reaches	Middle reaches	Upper reaches
Kromme	32.8 (4.4; 313)	31.6 (6.1; 374)	31.1 (6.3; 131)
Geelhoutboom	31.0 (7.3; 148)		
Swartkops	32.0 (5.8; 303)	26.0 (9.5; 272)	20.4 (11.6;52)
Sundays	27.6 (4.6; 149)	16.2 (5.6; 305)	5.3 (4.3; 131)

	Lower reaches		Middle reaches		Upper reaches	
	summer	winter	summer	winter	summer	winter
Kromme	33.6 (2.5; 153)	32.0 (5.6; 160)	32.5 (4.9; 186)	30.8 (7.0; 187)	32.0 (5.2; 82)	30.2 (7.2; 79)
Geelhoutboom	31.8 (5.5; 77)	30.1 (8.8; 71)				
Swartkops	32.7 (3.2; 144)	31.2 (7.3; 159)	27.7 (8.5; 128)	24.5 (10.0; 144)	21.5 (12.4;125)	19.3 (10.6; 127)
Sundays	26.8 (4.6; 126)	28.3 (4.4; 123)	14.6 (5.8; 158)	17.9 (5.0; 147)	3.8 (2.5; 6.4)	6.7 (5.1; 67)

To enlighten the role of the Geelhoutboom as a freshwater contributor to the Kromme estuary, comparisons were made between salinities measured in the lower reaches of the Geelhoutboom estuary and at one station in the middle reaches of the Kromme estuary, which is situated just above their confluence. Overall, the mean salinity in the Geelhoutboom was only 0.6 ppt lower than the mean for the middle reaches of the Kromme estuary (Table 3.1; Fig. 3.3). Because of this similarity, it was furthermore intended to demonstrate the lack of discrepancy in the salinities between the lower reaches of the Geelhoutboom and the middle reaches of the Kromme estuary by statistical means. Measurements used for this purpose were consecutively taken at the two stations at or just before spring low tides (Jerling, unpub. data; Pereyra-Lago, unpub. data; present study). The result of a Wilcoxon paired-sample test ($P = 0.912$; $a = 0.05$) showed no statistical significant difference between the two reaches of the two estuaries.

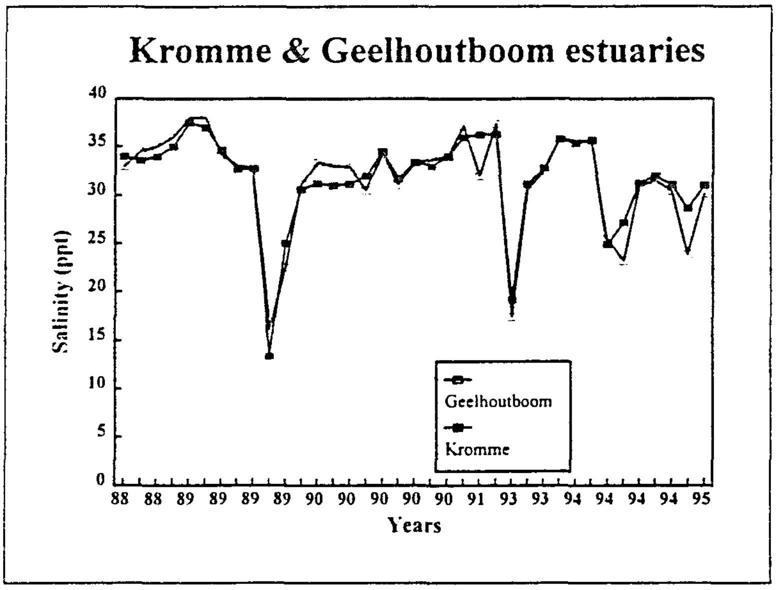


Fig. 3.3: Salinity measurements taken in the lower reaches of the Geelhoutboom estuary and in the Kromme estuary at one station above their confluence.

During the present study, salinities measured during both spring and neap tides were again highest in the Kromme estuary and lowest in the Sundays estuary with the Swartkops occupying an intermediate position (Table 3.2; Fig. 3.4, 3.5). Compared to the overall picture obtained via the literature survey, salinity gradients along the longitudinal axis of the Kromme and Swartkops estuary were more pronounced during the present study, where gradients of between 29.7 and 26.7 ppt were measured in the Kromme estuary and between 33.2 and 16.8 ppt in the Swartkops estuary (Table 3.2). In the Sundays estuary, however, salinities measured during this study only dropped to 11.3 ppt in the upper reaches, compared to 5.3 ppt resulting from the literature survey (Table 3.1, 3.2). The most frequently observed salinities for the Kromme estuary in this study were overall lower during the neap than spring tide sampling (Table 3.3), although salinities seldom dropped below 25 ppt in the upper reaches. In the Swartkops estuary the most frequently observed salinities were similar during spring and neap tides, which ranged from 30 to 35 ppt in the lower to 15 to 25 ppt in the upper reaches. For the Sundays estuary, which was only sampled at spring tides, 25 to 30 ppt were the most frequently observed salinities in the lower reaches, whereas in the upper reaches two prominent groups (0 to 5 ppt and around 20 ppt) became evident.

Table 3.2: Salinities (mean ±SD; n) during spring (A) and neap (B) tides during the present study for the Kromme, Swartkops and Sundays estuaries.

	Lower reaches	Middle reaches	Upper reaches
	mean (±SD; n)	mean (±SD; n)	mean (±SD; n)
A Kromme	29.7 (9.4; 16)	29.3 (8.9; 8)	26.7 (12.6; 8)
Geelhoutboom	26.2 (12.5; 7)		
Swartkops	33.2 (3.0; 8)	22.8 (8.2; 8)	16.8 (11.1; 8)
Sundays	27.3 (4.1; 8)	19.9 (6.4; 8)	11.3 (10.0; 8)
B Kromme	30.8 (6.3; 32)	29.3 (7.4; 32)	27.5 (7.0; 16)
Geelhoutboom	26.8 (9.5; 14)		
Swartkops	33.6 (2.1; 30)	26.0 (4.7; 40)	17.9 (6.3; 30)

	Lower reaches		Middle reaches		Upper reaches	
	summer	winter	summer	winter	summer	winter
	mean (±SD; n)	mean (±SD; n)	mean (±SD; n)	mean (±SD; n)	mean (±SD; n)	mean (±SD; n)
A Kromme	30.5 (5.9; 6)	29.1 (11.3; 10)	28.5 (8.4; 3)	29.7 (10.2; 5)	28.6 (6.3;3)	25.6 (15.9;5)
Geelhoutboom	27.8 (9.3; 3)	25.0 (15.8; 4)				
Swartkops	31.1 (4.5; 3)	34.4 (0.7; 5)	15.5 (8.1; 3)	27.1 (4.8; 5)	5.9 (9.6; 3)	23.4 (4.9; 5)
Sundays	24.0 (3.8; 3)	29.3 (3.0; 5)	13.6 (4.8; 3)	23.7 (3.7; 5)	1.1 (0.7; 3)	17.4 (7.1; 5)
B Kromme	33.3 (2.7; 20)	26.6 (8.3; 12)	32.6 (3.5; 20)	23.8 (9.1; 12)	30.7 (4.6; 10)	22.2 (7.3; 6)
Geelhoutboom	30.8 (4.4; 9)	19.8 (12.6; 5)				
Swartkops	33.9 (1.4; 9)	33.5 (2.4; 21)	24.8 (4.5; 12)	26.5 (4.7; 28)	13.7 (6.3; 9)	19.8 (6.2; 21)

Table 3.3: Most frequently observed salinity ranges during spring (A) and neap (B) tides during the present study for the Kromme, Swartkops and Sundays estuaries.

		Lower reaches	Middle reaches	Upper reaches
A	Kromme	30 - 35 ppt	30 - 35 ppt	30 - 36 ppt
	Geelhoutboom	30 - 36 ppt		
	Swartkops	30 - 35 ppt	20 - 25 ppt	15 - 25 ppt
	Sundays	25 - 30 ppt	20 - 30 ppt	0 - 5 ppt / 20 ppt
B	Kromme	30 - 35 ppt	25 - 35 ppt	25 - 36 ppt
	Geelhoutboom	25 - 36 ppt		
	Swartkops	30 - 35 ppt	25 - 30 ppt	15 - 25 ppt

Being in line with the results of the literature survey, no difference between the most frequently observed salinity ranges in the Geelhoutboom and in the middle reaches of the Kromme estuary were observed during the present study (Table 3.2, 3.3). Salinities at the confluence of both the Geelhoutboom and Sand river (situated 7.5 and 1.3 km from the mouth respectively) with the Kromme estuary, were only lower in June 1993 and August 1994 (Fig. 3.4, 3.5). These represented periods of high rainfall, during which additional freshwater inflow at the head of the Kromme estuary was evident, caused by overtopping of the Impofu dam.

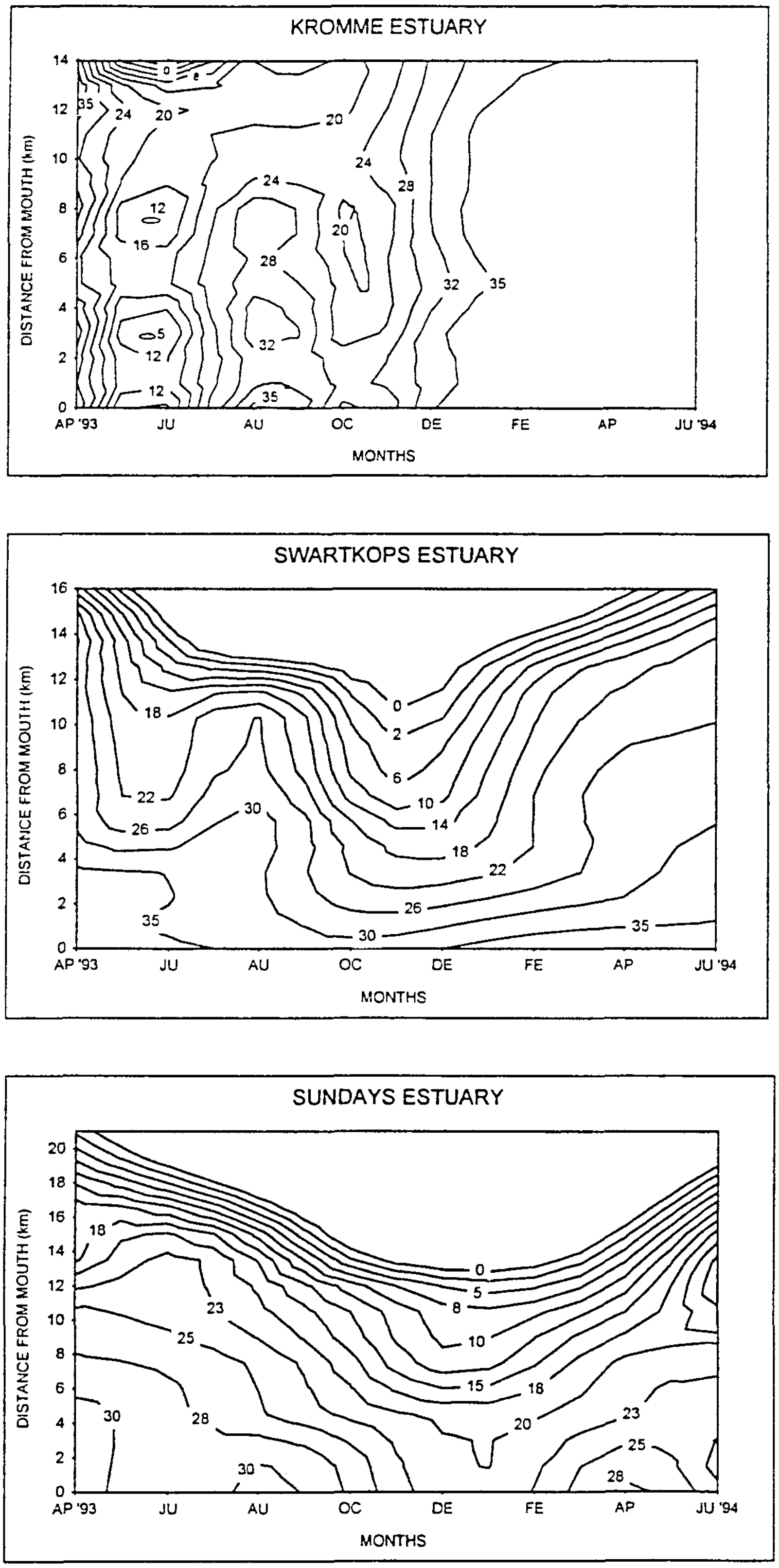
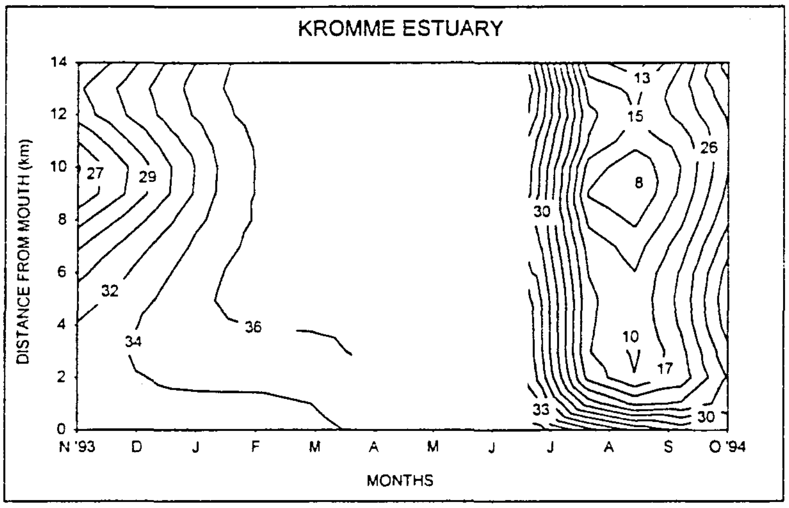


Fig. 3.4: Contour graphs for salinities (in ppt) during spring tides in the Kromme, Swartkops and Sundays estuaries.



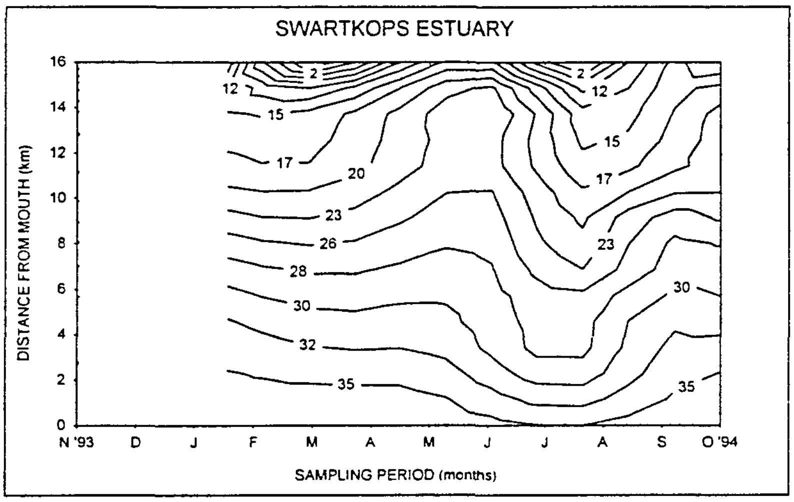
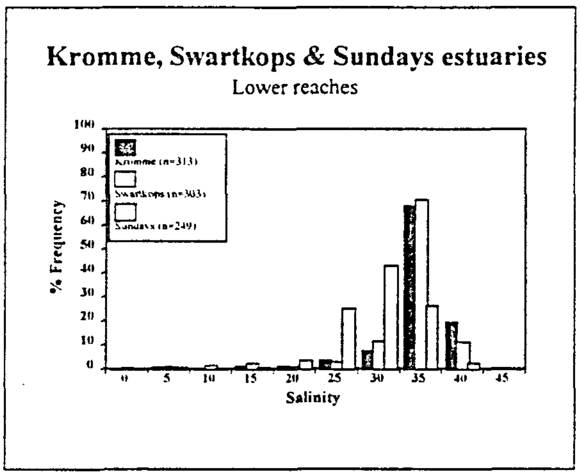
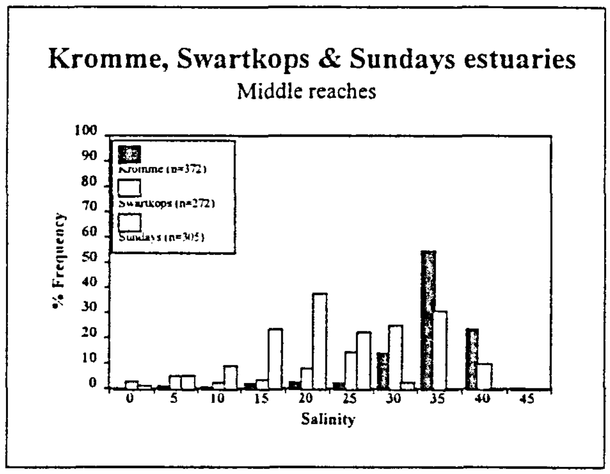


Fig. 3.5: Contour graphs for salinities (in ppt) measured during neap tides in the Kromme and Swartkops estuaries.

The distribution of specific salinity measurements along the longitudinal axes of the Kromme, Swartkops and Sundays estuaries is presented as percent frequency of occurrence in Fig. 3.6. It is evident that all three estuaries have approximately the same salinity structure in the lower reaches and only differ from one another to some degree towards the upper reaches. In the lower reaches salinities between 30 and 35 ppt prevailed in the Kromme and Swartkops estuaries (around about 70 % of all observations), whereas in the Sundays estuary salinities below 30 ppt were frequently observed. In the middle reaches, ca 80 % of all measurements ranged between 30 and 40 ppt in the Kromme estuary. On the other hand, the Swartkops and Sundays estuaries showed lower salinities in their middle sections, which were to 70 % between 20 and 35 ppt in the Swartkops and to 83 % between 10 and 25 ppt in the Sundays estuary. Moving towards the tidal head, differences between the three estuaries became even more pronounced. In the upper reaches of the Kromme estuary, over 80 % of the salinities were in the range of between 25 to 40 ppt. Salinities measured in the Swartkops estuary showed a fairly uniform distribution from 0 to 40 ppt, although salinities between 20 and 35 ppt were more frequently observed. Results for the upper reaches of the Sundays estuary deviated distinctly from the Kromme and Swartkops estuaries, in that the most frequently observed salinities ranged from 0 to 5 ppt (to 63 %). Highlighting the extreme discrepancies between the Kromme and Sundays estuaries even more is the fact that in the upper reaches of the Sundays estu ry no single measurement was ever above 30 ppt (n = 131), whereas in the Kromme estuary salinities below 20 ppt were only measured on 7 out of 161 occasions (Fig. 3.6).





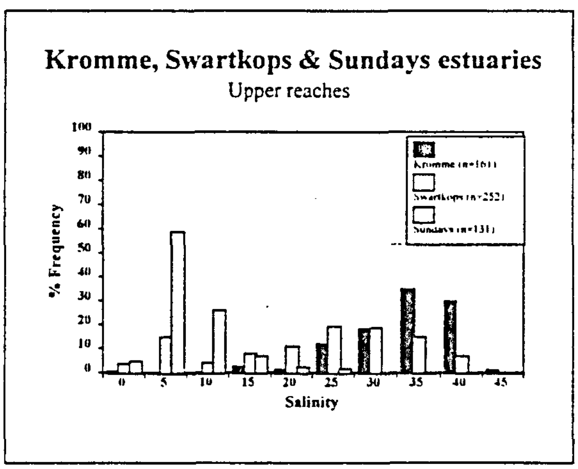


Fig. 3.6: All available salinity measurements (literature survey and data from present study) for the lower, middle and upper reaches of the Kromme, Swartkops and Sundays estuaries, expressed as % frequency of occurrence.

3.3.2.2 Vertical salinity gradients:

Since the amount of freshwater input into the estuary determines the extent to which the water column will be stratified, the salinity stratification in the upper reaches of the Kromme, Swartkops and Sundays estuaries were compared. The data chosen for this purpose were collected at sampling stations nearest to the tidal head of the respective estuary, which was within 1.5 km from the tidal head of the Kromme, 2.5 km of the Swartkops and 3 km of the Sundays estuary. It is apparent, that in those particular reaches of the Kromme estuary salinities were usually high (Fig. 3.7). Low surface salinities were seldom encountered and most measurements were above 25 ppt throughout the watercolumn (Fig. 3.7), reflecting a lack of freshwater input into the system. The Sundays estuary on the other hand showed low salinities throughout the watercolumn, where most measurements were below 20 ppt. In the Swartkops estuary, freshwater input is more frequent than in the Kromme estuary, but high salinity water seems to penetrate far upstream, which is reflected in the uniform appearance of a wide salinity range (0 -35 ppt) throughout the entire water column in the upper reaches of the Swartkops estuary (Fig. 3.7).

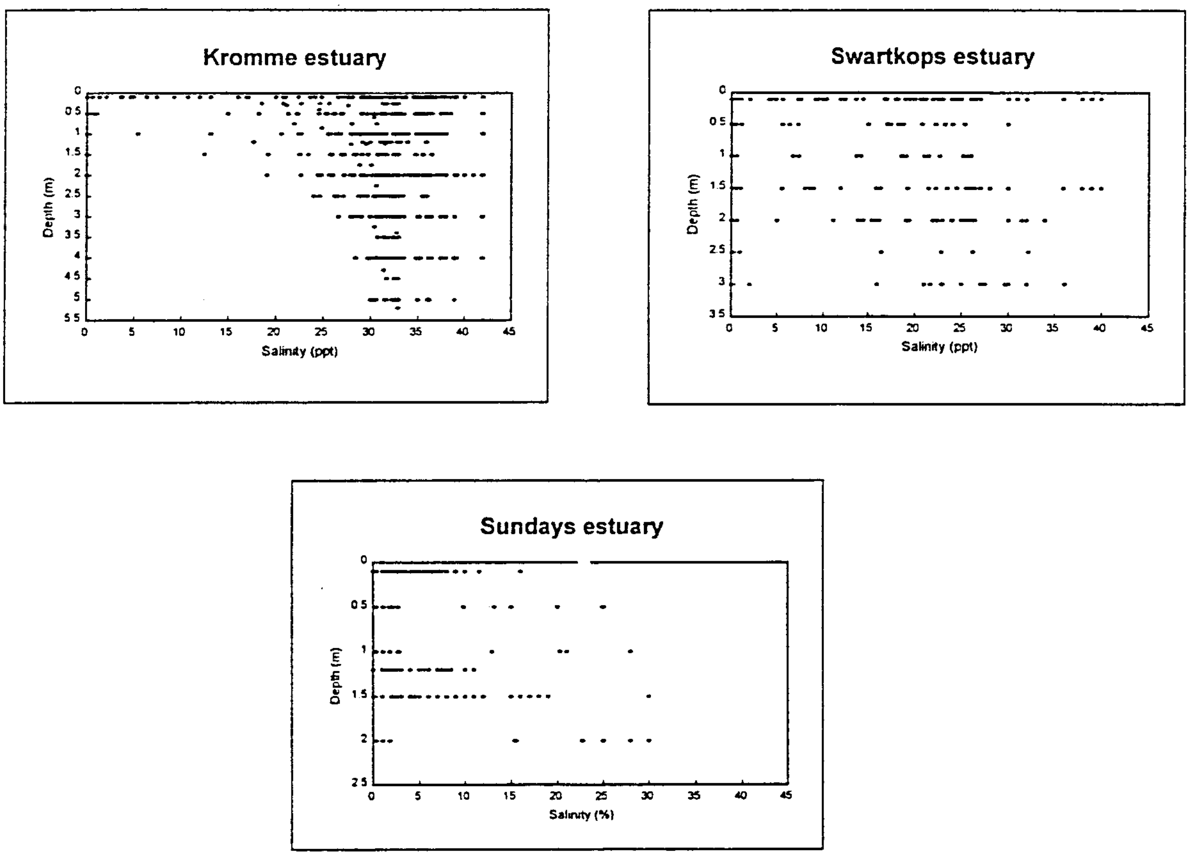


Fig. 3.7: Salinity stratification at the tidal head of the Kromme, Swartkops and Sundays estuaries.

The percent frequency of occurrence of a particular salinity value (Fig. 3.8) reflects the trend discussed above (Fig. 3.7). Low salinities (0 - 10 ppt) were dominant in the Sundays estuary, whereas high salinities (above 20 ppt) are dominant at the tidal head of the Kromme estuary. A comparatively uniform distribution of salinity values was apparent throughout the watercolumn in the Swartkops estuary (Fig. 3.7).

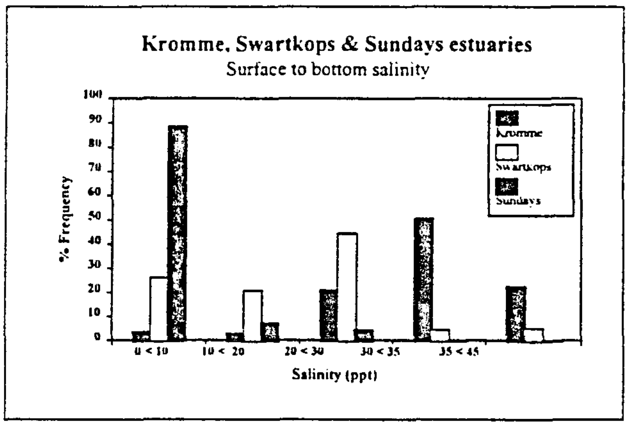


Fig. 3.8: Salinity data for the entire watercolumn at the tidal head of the Kromme, Swartkops and Sundays estuaries, expressed as % frequency of occurrence.

3.3.3 Temperature gradients

Summer and winter temperatures were found to be within a fairly close range in the Kromme, Swartkops and Sundays estuaries (Table 3.4). Winter and summer temperatures varied from 16 - 18°C and 20 - 23°C respectively in all three estuaries. Differences between summer and winter temperatures in the three estuaries were 3.5 to 5°C in the lower reaches, ca 6°C in the middle and between 4.5 and 6.5°C in the upper reaches. In the Kromme and Sundays estuaries summer temperatures increased from mouth to head, whereas in the Swartkops estuary slightly higher temperatures were measured in the middle reaches. In winter the temperatures between the lower, middle and upper reaches of the Kromme and Sundays estuaries were within 0.4°C and 0.2°C respectively, again highlighting the small range of temperature gradients within the estuaries. Highest winter temperatures of all three estuaries (18.7°C) were measured in the lower reaches of the Swartkops estuary.

Table 3.4: Mean (±SD; n) temperatures for the Kromme, Swartkops and Sundays estuaries, calculated from all available salinity data.

	Lower reaches mean (±SD; n)	Middle reaches mean (±SD; n)	Upper reaches mean (±SD; n)
Kromme	18.5 (3.2; 274)	19.1 (4.2; 319)	19.6 (4.6; 139)
Geelhoutboom	19.9 (4.5; 147)		
Swartkops	20.3 (3.3; 243)	20.1 (4.3; 221)	20.0 (3.9; 196)
Sundays	19.4 (3.4; 227)	20.1 (4.1; 296)	20.1 (4.4; 128)

	Lower reaches		Middle reaches		Upper reaches	
	summer	winter	summer	winter	summer	winter
	mean (±SD; n)	mean (±SD; n)	mean (±SD; n)	mean (±SD; n)	mean (±SD; n)	mean (±SD; n)
Kromme	20.8 (2.4; 133)	16.5 (2.3; 141)	22.2 (2.9; 158)	16.1 (2.8; 161)	22.9 (3.3; 69)	16.4 (3.0; 70)
Geelhoutboom	23.2 (2.8; 77)	16.2 (2.9; 70)				
Swartkops	22.2 (2.6; 11.3)	18.7 (3.0; 130)	23.3 (3.0; 105)	17.2 (3.0; 116)	22.3 (3.2; 97)	17.8 (3.1; 99)
Sundays	21.8 (2.3; 118)	16.7 (2.3; 109)	23.1 (2.5; 155)	16.7 (2.7; 141)	23.2 (3.4; 66)	16.9 (2.8; 62)

Temperatures measured during the present study showed similar trends to those discussed above. Identical temperature ranges were measured in winter and summer (ca. 16 - 18°C and 20 - 23°C respectively) (Table 3.5). Differences between the three estuaries were small (ca. 1.5°C), as were the longitudinal gradients along the estuaries (<2°C during spring and neap tides). However, a gradient of 4°C (from 20°C at the mouth to 24°C at the head) was measured in the Kromme estuary at neap tides during summer (Table 3.5).

Table 3.5: Temperatures (mean ±SD; n) during spring (A) and neap (B) tides during the present study for the Kromme, Swartkops and Sundays estuaries.

		Lower reaches		Middle reaches		Upper reaches	
		summer	winter	summer	winter	summer	winter
		mean (±SD; n)	mean (±SD; n)	mean (±SD; n)	mean (±SD; n)	mean (±SD; n)	mean (±SD; n)
A	Kromme	20.1 (3.0; 6)	16.9 (3.1; 10)	22.0 (4.4; 3)	17.6 (3.9; 5)	22.2 (5.0; 3)	17.8 (3.8; 5)
	Geelhoutboom	22.6 (4.0; 3)	16.4 (4.4; 4)				
	Swartkops	21.0 (3.7; 3)	16.8 (3.2; 5)	22.3 (3.4; 3)	17.4 (4.0; 5)	23.0 (3.5; 3)	18.1 (4.0; 5)
	Sundays	21.1 (3.0; 3)	16.4 (3.3; 5)	22.5 (2.5; 3)	17.1 (3.7; 5)	22.8 (2.8; 3)	17.6 (3.8; 5)
B	Kromme	20.1 (2.0; 20)	16.8 (1.9; 12)	22.8 (2.5; 20)	16.8 (2.4; 12)	23.8 (2.6; 10)	16.5 (1.8; 6)
	Geelhoutboom	23.7 (3.0; 9)	16.7 (2.7; 5)				
	Swartkops	21.9 (2.0; 9)	17.4 (1.9; 21)	22.3 (1.6; 12)	15.7 (2.2; 28)	23.7 (1.5; 9)	18.2 (3.4; 21)

		Lower reaches	Middle reaches	Upper reaches
		mean (±SD; n)	mean (±SD; n)	mean (±SD; n)
A	Kromme	18.1 (3.3;16)	19.3 (4.4; 8)	19.5 (4.6; 8)
	Geelhoutboom	19.0 (5.1; 7)		
	Swartkops	18.4 (3.8; 8)	19.3 (4.3; 8)	20.0 (4.4; 8)
	Sundays	18.2 (3.9; 8)	19.1 (4.2; 8)	19.5 (4.2; 8)
B	Kromme	18.9 (2.5; 32)	20.5 (3.8; 32)	21.1 (4.3; 16)
	Geelhoutboom	21.2 (4.4; 14)		
	Swartkops	18.8 (2.8; 30)	17.7 (3.6; 40)	19.8 (3.9; 30)

3.3.4 Mike 11 Modelling System

Different scenarios of freshwater inflow into the Kromme and Swartkops estuaries were tested for their effect on salinity gradients, making use of the hydrodynamic simulation model 'Mike 11'. All freshwater inflow scenarios were simulated over a period of two months. Data for precipitation, evaporation and tidal variation used in the model were the actual data for the timespan of October 1, 1993 to November 30, 1993. From the simulation a 'measurement' was taken every 6 hours, representing the data points in Fig. 3.9 and 3.11. The oscillation in the graphs denotes the tidal variation.

The initial salinities at the start of the simulation in the Kromme estuary, were assumed to be 35 ppt for the lower, middle and upper reaches (Fig. 3.9). Fig. 3.9 A displays the results of the simulation of a continuous freshwater inflow of 0.5 $m^3 \cdot sec^{-1}$ into the Kromme estuary. After the first month, salinities dropped to 33 ppt in the lower, 27 ppt in the middle and 11 ppt in the upper reaches. The longitudinal salinity gradient after two months extended from 31 ppt in the lower to 8 ppt in the upper reaches (Fig. 3.9 A, 3.10 A; Table 3.6). A second simulation with a inflow scenario of 1 $m^3 \cdot sec^{-1}$ was performed for the Kromme estuary. With this particular inflow scenario, a more pronounced salinity gradient was achieved after 1 month. Salinities ranged from 29 ppt in the lower to 3 ppt in the upper reaches (Fig. 3.9 B, 3.10 B; Table 3.6). In the case where freshwater inflow into the Kromme estuary is cut off for two months, salinities in the upper reaches climb to 36.3 ppt after the first month and reach 36.9 ppt after the second month (EMATEK (CSIR), 1994).

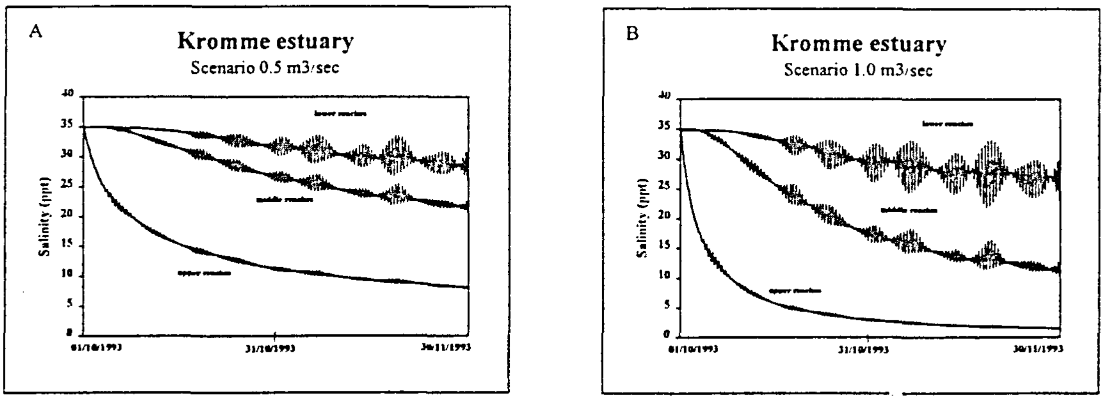


Fig. 3.9: Salinities at the lower, middle and upper reaches of the Kromme estuary as a result of two freshwater inflow scenarios (0.5 $m^3 \cdot sec^{-1}$ (A); 1 $m^3 \cdot sec^{-1}$ (B)) simulated by the Mike 11 hydrodynamic model over a period of 2 months.

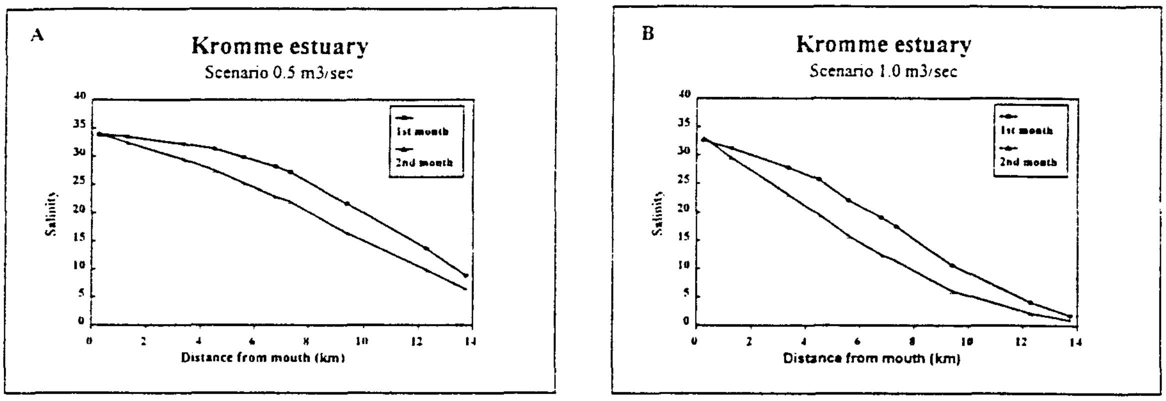


Fig. 3.10: Longitudinal salinity gradients in the Kromme estuary. Datapoints result from the above simulation of 2 different freshwater inflow scenarios (0.5 $m^3 \cdot sec^{-1}$ (A); 1 $m^3 \cdot sec^{-1}$ (B)) using the Mike 11 hydrodynamic model (see Fig. 3.9).

Table 3.6: Various freshwater inflow scenarios and their effect on creating/maintaining a longitudinal salinity gradient in the Kromme estuary. All scenarios were simulated at EMATEK (CSIR) in Stellenbosch. Reference to * scenarios is given in EMATEK (CSIR) 1994, ** scenarios were simulated during the present study.

Freshwater inflow Scenarios	Salinity gradients		Timespan after which salinity gradients are reached following a release from the Impofu Dam
	mouth	*Tidal head*	
1.67 x $10^5 m^3$ per month at a rate of ca. 1.3 m^3/sec for 36 hours *	35 ppt	16 - 20 ppt	Time of release
	35 ppt	25 - 30 ppt	1 week
	35 ppt	30 - 35 ppt	1 month
2 x 10^6 m^3 at a rate of 20 m^3/sec for 28 hours *	33 - 35 ppt	0 ppt	Time of release
	33 - 35 ppt	20 ppt	6 weeks
	35 ppt	30 ppt	3 months
	35 ppt	35 ppt	3½ months
2 x $10^6 m^3$ in the form of two releases (November and May) at a rate of 20 m^3/sec for 14 hours *	34 - 35 ppt	0 ppt	Time of release
	34 - 35 ppt	18 ppt	2 weeks
	35 ppt	27.5 ppt	6 weeks
	35 ppt	30 ppt	8 weeks
	35 ppt	36 ppt	3 months
No freshwater release *	35 ppt	>35 ppt	1 month
	35 ppt	38.5 ppt	3½ months
	35 ppt	35 ppt	8 months
0.5 m^3/sec **	34 ppt	9 ppt	1 month
	34 ppt	6 ppt	2 months
1.0 m^3/sec **	32 ppt	2 ppt	1 month
	31 ppt	1 ppt	2 months

In the Swartkops estuary, the salinities at the start of the simulation were set at 35 ppt in the lower, 33 ppt in the middle and 27 ppt in the upper reaches. The two scenarios simulated for the Swartkops estuary were a continuous freshwater inflow of 0.25 $m^3 \cdot sec^{-1}$ and 0.5 $m^3 \cdot sec^{-1}$ respectively. With both scenarios, lower salinities were achieved in a shorter period of time in the Swartkops estuary, than with a freshwater inflow of 0.5 $m^3 \cdot sec^{-1}$ in the Kromme estuary (Fig. 3.9, 3.10, 3.11, 3.12). Simulating the scenario of 0.5 $m^3 \cdot sec^{-1}$ in the Swartkops estuary, a salinity gradient from 32 ppt in the lower to 1 ppt in the upper reaches is already established after the first month (Fig. 3.11 A, 3.12 A). In the Kromme estuary, however, salinities in the upper reaches did not fall below 11 ppt (Fig. 3.9 A, 3.10 A). After two months of si.nulation in the Swartkops estuary, salinities in the lower, middle and upper reaches dropped to 30 ppt, 9 ppt and 0 ppt respectively (Fig. 3.11 A; 3.12 A). Even a freshwater input of only 0.25 $m^3 \cdot sec^{-1}$ in the Swartkops estuary had a more dramatic effect on salinity gradients than the 0.5 $m^3 \cdot sec^{-1}$ for the Kromme estuary. After the first month of a continuous freshwater input of 0.25 $m^3 \cdot sec^{-1}$, salinities dropped to 23 and 7 ppt in the middle and upper reaches in the Swartkops estuary, as opposed to 27 and 11 ppt in the Kromme estuary (Fig. 3.9, 3.10, 3.11, 3.12).

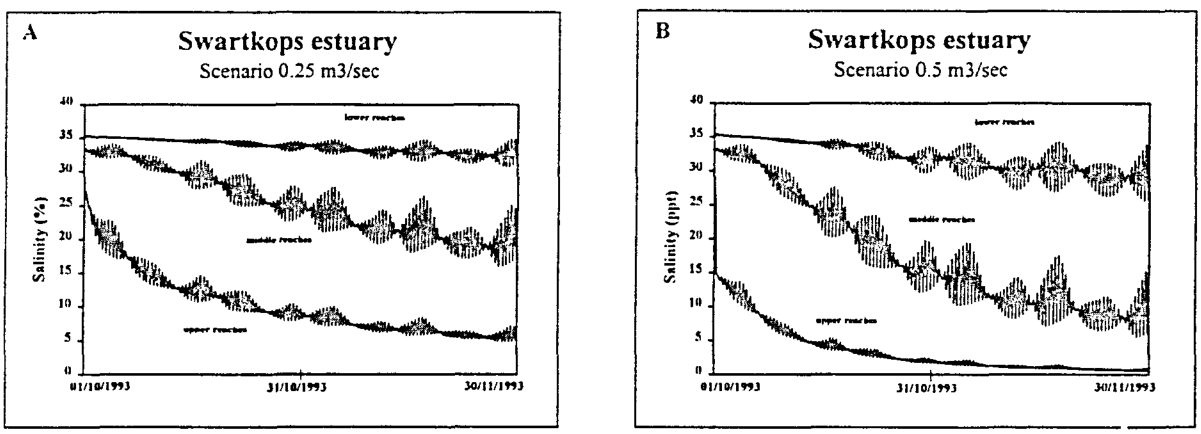


Fig. 3.11: Salinities at the lower, middle and upper reaches of the Swartkops estuary as a result of two freshwater inflow scenarios (0.5 $m^3 \cdot sec^{-1}$ (A); 1 $m^3 \cdot sec^{-1}$ (B)) simulated by the Mike 11 hydrodynamic model over a period of 2 months.

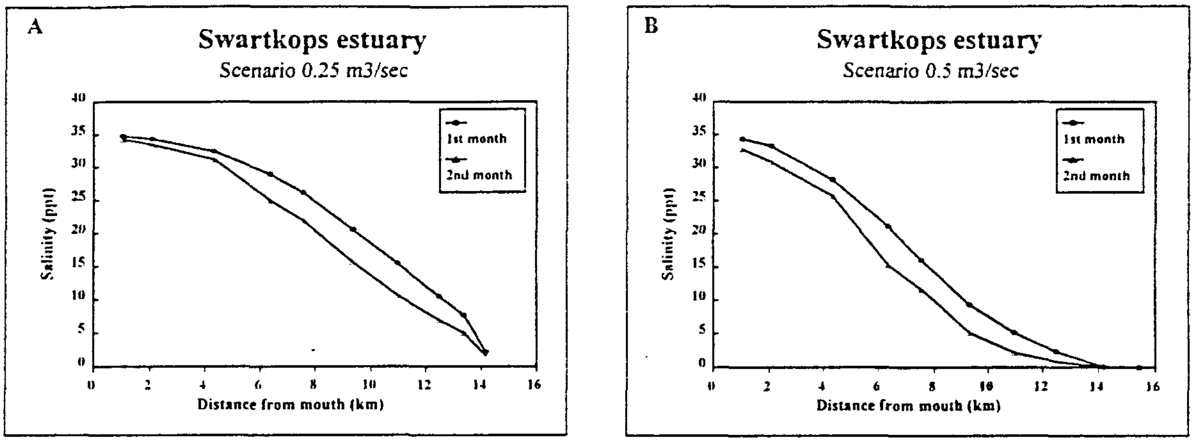


Fig. 3.12: Longitudinal salinity gradients in the Kromme estuary. Datapoints result from the above simulation of 2 different freshwater inflow scenarios (0.5 $m^3 \cdot sec^{-1}$ (A); 1 $m^3 \cdot sec^{-1}$ (B)) using the Mike 11 hydrodynamic model (see Fig. 3.11).

In summary, to create a longitudinal salinity gradient of ca. 35 ppt, a continuous freshwater inflow of 1 $m^3 \cdot sec^{-1}$ must be adhered to for one month in the Kromme estuary. However, freshwater flowing continuously at a rate of 0.5 $m^3 \cdot sec^{-1}$ into the Swartkops estuary would have a similar effect on its longitudinal salinity gradient. A more realistic salinity gradient of ca 25 ppt between the lower and upper reaches in both estuaries is possible to achieve with smaller volumes of water, which represent a freshwater inflow rate of 0.5 $m^3 \cdot sec^{-1}$ for the Kromme and 0.25 $m^3 \cdot sec^{-1}$ for the Swartkops estuary for the duration of one month. To maintain these gradients in both estuaries, an even lower rate of freshwater inflow would suffice. With the particular freshwater inflow scenarios described for the Kromme and Swartkops estuaries, no continuation of the simulations were performed to establish the time period over which the created longitudinal salinity gradient would be sustained. However, additional simulations with different freshwater inflow scenarios in terms of creating and maintaining certain salinity gradients along the longitudinal axis of the Kromme estuary were carried out by EMATEK (CSIR) in Stellenbosch. These results are discussed below (see also 3.4.4, Table 3.6).

3.4 DISCUSSION

3.4.1 Freshwater input

The amount of freshwater inflow into the Kromme, Swartkops and Sundays estuaries is rather a reflection of human activity in their catchment areas (i.e. the construction of various obstructions to river flow such as impoundments) than of natural runoff conditions. The mismanagement of catchments is very well demonstrated in the Kromme estuary. Here, runoff is high (105×10^6 m^3) relative to its catchment area (936 km^2), but due to the high storage capacity of both dams at the river, which amounts to 133 % of the MAR, and the short distance between the dams and the head of the estuary, freshwater input into the latter is negligible. Similarly, the excessive water abstraction in the Sundays river catchment exceeds the mean annual runoff of its catchment area. However, its dams are situated too far upstream to affect freshwater inflow into the estuary dramatically. Furthermore, the water resources of the Sundays river catchment are supplemented by water imports via the Orange/Sundays river scheme into Darlington dam (Roussouw, 1993). For this reason, additional impoundments on the Sundays river did not seem to be of necessity up until this date, although perceptions may change in the future. Contrary to the Kromme and Sundays rivers, the only impoundment on the Swartkops river, the Groendal dam, has a small storage capacity compared to the mean annual runoff (ca 14 %). Therefore, considerable amounts of freshwater cannot be supplied to the estuary through releases from the dam. The role of groundwater flow to the estuary has not yet been established (MacKay, 1993), although it seems to be and interesting feature, since the Swartkops river flows partly or on the whole underground for much of its course (Martin, pers. comm.).

3.4.2 Longitudinal salinity gradients

The extent of the variable freshwater inputs into the Kromme, Swartkops and Sundays estuaries is strongly reflected in the extension of the salinity gradients along their longitudinal axes. The Kromme estuary is an extreme case, which has been characterised as a freshwater starved estuary, following its diminished riverine input (e.g. Marais, 1983; Emmerson and Erasmus, 1987; Adams, et al., 1992 a,b; Jerling and Wooldridge, 1994). Results from field surveys carried out before the construction of the Impofu dam in 1982 showed salinity gradients of ca 20 ppt in winter and ca 12 ppt in summer for the years of 1979 to 1981 (Emmerson and Erasmus, 1987). In contrast, salinities of 35 and 36 ppt were reported in the upper reaches in a study carried out in 1972 (Hecht, 1973). Since the construction of the Impofu dam, however, freshwater only reaches the estuary during periods of high rainfall, which would previously have resulted in floods of various magnitudes. During the past 10 years, hypersalinities in the middle and especially upper reaches were unfortunately no rarity, and the lack of salinity gradients in the Kromme estuary is often reported (e.g. Marais, 1983; Hanekom and Baird, 1984; Newman, 1993). During the present study the average salinity gradient along the longitudinal axis was about 10 ppt, suggesting a period of increased rainfall compared to previous studies. Due to the Impofu dam, mainly smaller than 1 in 30 year floods are dampened in their effect

(Anon, 1991). Furthermore, the scouring potential of floods is reduced to 15 % of the total, which is mainly caused by their infrequent occurrence (Fromme and Badenhorst, 1987).

A remarkable feature of the Kromme estuary is the short timespan for a recovery to seawater salinities once the freshwater inflow has ceased. Neither the Sand nor the Geelhoutboom rivers, which are the biggest tributaries to the Kromme estuary, can be considered as viable freshwater contributors to the Kromme estuary.

Although hypersalinities were measured on occasion in the Swartkops estuary (McLachlan and Grindley, 1974; McCallum, 1974. Marais, 1976; Emmerson, 1985), its situation is not nearly as severe as in the Kromme estuary. The periods of hypersalinities seem to be isolated incidences, since more than often a salinity gradient was recorded. MacKay (1993) suggested that seepage of highly saline water from the salt concentration pans near Bar None could play a role in maintaining high salinities in the upper reaches. The norm for the Swartkops estuary is the occurrence of a longitudinal salinity gradient. Its variability is usually high, especially during dry years when rainfalls are rare and during episodic floods, which occur frequently (e.g. Pocock, 1955; Macnae, 1957; McLachlan and Grindley, 1974; Wooldridge and Melville-Smith, 1979; Marais, 1982; Baird et al. 1986; Hanekom, 1989).

The Sundays estuary was never reported to have salinities close to seawater at its tidal head. Although the catchment area lies in a semi-arid region, riverflow seems to be strong enough to support a longitudinal salinity gradient at all times. In addition, the estuary is periodically subjected to floods (Reddering and Esterhuysen, 1981). Nevertheless, further impoundments on the river could lead to high salinities in the estuary.

3.4.3 Salinity stratification

The amount of freshwater input into an estuary not or 'y determines the longitudinal salinity gradients, but also the extent to which the watercolumn will be stratified. At the tidal head of the Kromme estuary the riverbed is 2 to 3 m deep and rises to the surface in a steep incline. In the case of low to moderate freshwater inflow, water flowing in from the rapids above smoothes over the surface and is too buoyant to reach greater depths. It is clear that considerable freshwater inflow would be necessary to overcome the almost perpendicular step from the rapids into the estuary to flush out the deep lying waters. In the case of moderate freshwater inflow, stratification can also occur in the middle reaches of the Kromme estuary. The lower reaches are usually never stratified, due to a sandbar ca 4.5 km upstream of the mouth, which forces stratified water to be mixed once it reaches the shallow areas. However, stratification can occur below the sandbar when intruding saltwater dilutes low salinity water after floods.

Various authors reported little stratification in the Swartkops estuary during low river flow (e.g. Wooldridge and Melville-Smith, 1979; Melville-Smith and Baird, 1980; Emmerson, 1985; MacKay, 1993) and highly stratified waters during and shortly after floods (e.g. Hanekom, 1989; MacKay, 1993). The same pattern was observed during the present study. Little stratification was recorded in the case of only small amounts of freshwater entering the estuary, but differences between surface and bottom waters of 15 to 20 ppt were recorded during periods of high freshwater input. During periods of high rainfall, freshwater inflows from the Motherwell and Markman canals near Brickfields as well as from the Chatty river helps to lower salinities in the surface layers at their confluence with the Swartkops estuary (MacKay, 1993). In addition, stratification can be built up due to the entrapment of highly saline water behind sediment bars. Such a possibility was suggested by MacKay (1993) at sediment bars situated at 1, 6 and 11 km from the mouth. Similar to the Kromme estuary, the lower reaches of the Swartkops estuary are usually well mixed due to a sandbar at Brickfields which inhibits the downstream movement of a stratified watercolumn.

In the Sundays estuary, stratification is always present, suggesting a consistent freshwater inflow. Stratification is often reported to be highest in the middle reaches of the estuary (Wooldridge and Bailey, 1982; Emmerson, 1989; Hilmer and Bate, 1990; MacKay and Schumann, 1990). During the present study, a strong vertical gradient of up to 20 ppt was only measured in the upper reaches, but these observations were made during spring tides only, when stratification is usually less pronounced than at neap tides. Deep scour holes which are located along the estuary and lack complete flushing, furthermore accentuate the stratification (Reddering and Esterhuysen, 1981).

3.4.4 Creation and Maintenance of a longitudinal salinity gradient

The existing freshwater release policy for the Kromme estuary, which comprises an amount of 2 million m^3 per annum, is considered to compensate for the evaporative losses of the estuary (Jezewski and Roberts, 1986). Various studies with the present amount of freshwater allocated to the estuary were conducted by EMATEK (CSIR), Stellenbosch, when a number of inflow scenarios were tested for their best benefit to the ecology of the estuary. The inflow scenarios were, *inter alia*, monthly releases of 1.67×10^5 $m^3 \cdot sec^{-1}$ over a 36 h period, secondly, releasing the total suggested amount of 2 million m^3 in one major release per year, and thirdly, dividing the total amount into two separate releases per year (Table 3.6). For all three scenarios, the initial salinity in the estuary was considered to be 35 ppt along its entire length. None of the inflow scenarios gave satisfactory results. The effects of the monthly release of 1.67×10^{6} m^3 was largely confined to the upstream reaches of the estuary above its confluence with the Geelhoutboom estuary. Salinities at the head of the Kromme estuary only decreased between 16 and 20 ppt (from 35 ppt) immediately following the release. The evaporative losses would apparently be compensated for by this proposed release policy (see above). However, hypersaline conditions will occur during dry years (see EMATEK (CSIR), 1994). After releasing 2 million m^3 as one major release, a recovery to seawater salinities will take 5 months. The third scenario of releasing 2 million m^3 as two releases per year will only show effects for a period of 3 1/2 months in the estuary, until seawater salinities become established once again. With both the latter inflow scenarios, the prevention of hypersalinities can not be guaranteed. The only release policy reducing the occurrence of hypersalinities to a one month duration would be two releases of the presently allocated amount of freshwater per year; one in November and again one in March (see EMATEK (CSIR), 1994). Additional information on release scenarios and their effects on salinity gradients is presented in Table 3.6.

During the present study a salinity gradient of 35 ppt along the longitudinal axis of the Kromme estuary was created with a continuous freshwater inflow of 0.5 $m^3 \cdot sec^{-1}$ over a period of 1 month. In this scenario, the required volume of freshwater would amount to $2.6 \times 10^6 m^3$ per month. If the objective is to create a salinity gradient in a shorter period of time (i.e. less than one month), a release of nearly the same amount of freshwater, i.e. $2 \times 10^6 m^3$, as one major release would be necessary. The release of smaller amounts of freshwater would reduce the salinity at the tidal head to a small extent, but would not serve the purpose of establishing a longitudinal salinity gradient over a longer period of time throughout the estuary (EMATEK (CSIR), 1994). Once a salinity gradient is established in the estuary, smaller, but frequent releases of freshwater will be necessary to maintain the gradient. Especially since a release of 2×10^6 m^3 (i.e. the total amount of water allocated to the estuary) as one major release will keep a salinity gradient of ca 25 ppt for only one month after the release (EMATEK (CSIR), 1994), additional freshwater input has to continue soon afterwards as not to defy the purpose of the initial release.

The Swartkops estuary, on the other hand, does not suffer from major water abstractions in its catchment area and this study demonstrated that a longitudinal salinity gradient is the norm in the Swartkops estuary. However, further impounding of the Swartkops or Elands river could lead to an increase of the marine influence on the estuary.

3.5 CONCLUSIONS

The Impofu dam severely restricts freshwater input into the Kromme estuary. There is no indication, whatsoever, that a longitudinal salinity gradient could be maintained throughout the year through natural runoff from below or from spillovers at the dam, even during years of high rainfall. The present release policy is neither adequate for maintaining a salinity gradient nor for preventing the occurrence of hypersalinities in the upper reaches. Furthermore, the present release policy does not seem to be implemented on a regular basis, which is apparent from the lack of freshwater releases illustrated in Fig. 3.13.

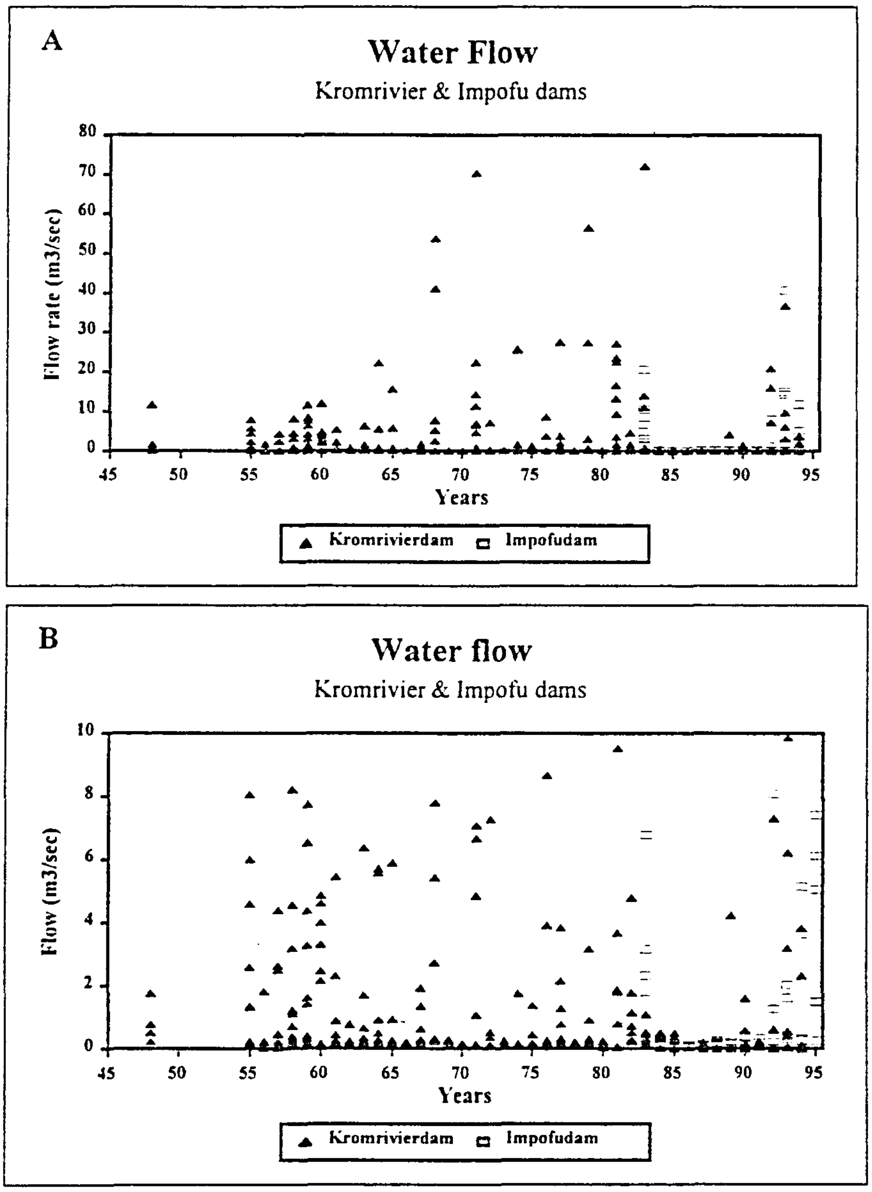


Fig. 3.13: Water flow at the Kromrivier and Impofu dam. Datapoints are monthly flow rates, which were supplied by the Department of Water Affairs (Pretoria). B is an enlargement of A.

To the contrary, the Swartkops and Sundays estuaries exhibit salinity gradients along their longitudinal axes at all times, although it can occasionally be reversed in the Swartkops estuary. A relatively high evaporative water requirement in the Swartkops estuary of almost 12 million m^3 per annum compared to 3 million m^3 per annum for the Sundays estuary (Jezewski and Roberts, 1986) might be partly responsible. Further impoundment of either the Swartkops (or one of its tributaries) or the Sundays river will very likely result in a reduced freshwater inflow into their estuaries.

3.6 REFERENCES:

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CHAPTER 4
THE INFLUENCE OF FRESHWATER INFLOW ON THE NUTRIENT STATUS AND PHYTOPLANKTON BIOMASS IN THE KROMME, SWARTKOPS AND SUNDAYS ESTUARIES

4.1 INTRODUCTION:

Estuaries are by no means isolated or self-contained ecosystems, but on the contrary rely largely on riverine and oceanic contributions to support the generation and maintenance of their high productivity and biotic diversity. Nutrients are the very basis of primary production and their concentrations, as well as their rates of inflow and exchanges, are one of the most important features contributing to the productivity of estuarine waters. The nutrient status of estuaries is determined by the proportional influence of their various sources, which include *inter alia* terrigenous runoff, oceanic waters, the atmosphere, sediments and internal cycling (Webb, 1981). Riverine input is in general considered as being the major nutrient contributor to an estuary (Liss, 1976; Aston, 1980; Funicelli, 1984). Nevertheless, concentrations of the same magnitude in riverine and estuarine waters and nutrient deprivation in rivers have been reported (Howard-Williams, 1977; Branch and Grindley, 1979; Bally and McQuaid, 1985). The fate awaiting the various nutrient species in the estuary are dependent on biological, physical and chemical interactions (Aston, 1980; Webb, 1981; Smith et al., 1985; Eyre, 1994), which include adsorption/desorption by sediments and particulate material in the watercolumn, incorporation into plant material, or export to the sea. Nutrients may be utilised and regenerated to various extents along the length of an estuary and the estuary may act as a source to adjacent ecosystems or as a sink for nutrients (Head, 1970; Biggs and Cronin, 1981; Pritchard and Schubel, 1981; Chapman and Thornton, 1986; Baird and Winter, 1990; Falcao and Vale, 1990; de la Lanza Espino and Rodriguez-Medina, 1993; Eyre, 1994). Primary producers in turn will be tuned to the spatial and temporal distribution of the nitrogen, phosphorus and carbon species, and consequently determine the magnitude of secondary productivity. Alterations to the nutrient status of the estuary are often brought about by anthropogenic influences on the nutrient concentrations. In general these modifications include firstly the deprivation of the in most cases very important riverine source, causing nutrient depletion in the estuary. On the other hand, pollution generates overenrichment, which in severe cases can lead to eutrophication of the system (Biggs and Cronin, 1981; Kennish, 1992; Hopkinson and Vallino, 1995).

In this study the nutrient status as well as phytoplankton biomass in terms of chlorophyll-a was investigated in the Kromme, Swartkops and Sundays estuaries. In addition, it was attempted to describe possible interactions between nutrients and phytoplankton and to relate their concentrations to various abiotic factors. The determination of the similarity/dissimilarity between the different reaches within the three estuaries as well as between estuaries in terms of nutrients and chlorophyll-a was another point of this investigation.

4.2 MATERIALS AND METHODS

4.2.1 Sampling techniques and analysis of samples:

The Kromme, Swartkops and Sundays estuaries were sampled bimonthly from June 1993 to June 1994. Sampling took place at spring low tides, when the riverine influence on the estuary was at a maximum. On each of the seven sampling occasions, the physico-chemical parameters salinity, temperature, pH, oxygen concentration and saturation, and turbidity were measured at several stations along the estuary and at one station in the river just above the tidal head of the estuary (Fig. 2.2). At the same points duplicate water samples for the determination of nitrate, nitrite, ammonia and soluble reactive phosphorus, and single samples for Total particulate nitrogen (TPN) and chlorophyll-a were taken at depth intervals of 0.5 m from surface to bottom. The total number of sampling stations was six for the Kromme and four each for the Swartkops and Sundays estuaries (Fig. 2.2).

In addition, due to an unexpected spillover at the Impofu dam in the Kromme river following heavy rains, a short term study of the effect of the freshwater on various abiotic parameters and selected biota was conducted in the Kromme estuary. The results of the nutrient and phytoplankton investigations are presented in this chapter, and these measurements served as additional data to compare concentrations during periods of freshwater inflow to those of negligible or no freshwater inputs. Data for this short term study were collected on five sampling occasions between September 1994 and March 1995. The number of sampling occasions amounts to 12 for the Kromme estuary and respectively seven for the Swartkops and Sundays estuaries.

Salinity and temperature were measured by means of a CTDS Valeport Ser. 600, a Jenway 3100 and a Jenway 9070 O_2-meter were used for the determination of pH and dissolved oxygen respectively. A Secchi disk was used to estimate turbidity. Freshwater inflow into the Swartkops and Sundays estuaries was measured at the riverine sampling station (Fig. 2.2), whereas the rate of freshwater inflow into the Kromme estuary were obtained from information of the Department of Water Affairs and Forestry (for further detail see Chapter 3, Materials and Methods). Water samples were kept on ice until arriving at the laboratory where they were filtered through Schleicher and Schüll glassfiber filters (No. 6) and the filtrate analysed the same day. The methods for analysing the various nutrient species are given by Bate and Heelas (1975) for nitrate and nitrite, Strickland (1972) for phosphate and ammonia, and Bremner (1965) for TPN.

Chlorophyll-a was determined by filtering 500 ml of water through Schleicher and Schüll glassfiber filters (No. 6) for each sampling station in the field. The filter paper was placed in 10 ml of 95 % ethanol and kept on ice in a dark environment until arriving at the laboratory. The samples were stored overnight at approximately 0°C and analysed he next day by the means of High Performance Liquid Chromatography. After filtering the 10 ml samples again through glassfiber filters, they were injected into a Micro Pak C-18 reverse-phase column and eluted isocratically with a 70 % methanol:30 % acetone solution. The supernatant was analysed for chlorophyll-a at 435 nm by a Waters Lamda-Max Model 481 LC spectrophotometric detector. Chlorophyll-a concentrations (measured as peak area) were then calculated using a Waters 740 data module (du Preez, pers. comm.). Chorophyll-a extracted from the red seaweed *Plocamium corallorhiza* served for calibration .

4.2.2 Statistical methods:

Statistical analysis was mainly aimed at the investigation of the dependence/independence of the nutrient and chlorophyll-a concentrations on the amount of freshwater the individual estuaries received. Firstly, paired t-tests were used to show whether a longitudinal gradient exists between the lower and the upper reaches of the estuaries for the nutrient and chlorophyll-a concentrations as well as salinity (see 4.3.2.2). Here, the gradient on each individual sampling occasion was of particular concern, as opposed to a gradient derived from pooled data for the upper and lower reaches. The functional dependence of the nutrient and chlorophyll-a concentrations on freshwater inflow and salinity in the upper reaches of the estuaries was investigated by single regressions (see 4.3.4.1). The same method was applied for the whole estuary. Here nutrient measurements were related to salinity and freshwater inflow (see 4.3.4.2). Chlorophyll-a data were affiliated with various nutrients and abiotic parameters (see 4.3.4.2). Before performing the single regressions, single correlations were carried out to demonstrate the existence/non-existence of a dependence between the various parameters.

Differences of nutrient and chlorophyll-a concentrations as well as salinity between the different reaches within an estuary, including the riverine station, were investigated by multiple comparison (see 4.3.5). Multiple discriminant analysis was applied for essentially the same purpose as multiple comparison. Firstly, differences between the different reaches within an estuary regarding the above mentioned parameters were investigated, where the riverine station was excluded from the analysis. Secondly, this method served for the demonstration of differences for the same parameters between the different reaches between the three estuaries. The riverine station was included into the analysis for this instance (see 4.3.5, 4.3.6).

4.3 RESULTS

4.3.1 Abiotic parameters

4.3.1.1 Mean estuarine values:

Mean estuarine values of temperature, pH, oxygen concentration and saturation did not vary to a great extent between the Kromme, Swartkops and Sundays estuaries (Table 4.1). Temperature measurements were around 19°C, pH around 8, and oxygen concentration at ca 7 $mg \cdot l^{-1}$ at 85 to 90 % saturation (Table 4.1). The three estuaries did differ though in their salinity structure and the degree of turbidity.

Table 4.1: Physico-chemical parameters of the Kromme, Swartkops and Sundays estuaries. Data are mean values for the whole study period with, standard deviations and *n* in parentheses.

	Kromme	Geelhoutboom	Swartkops	Sundays
PO_4^{3-} ($\mu g \cdot l^{-1}$)	17.2 (26.5; 382)	40.1 (87.1; 68)	84.7 (69.6; 208)	17 (11.5; 193)
NO_3^- ($\mu g \cdot l^{-1}$)	123 (118.6 ;382)	200 (277.4; 68)	191.8 (199.2; 208)	494.6 (433.7;
NO_2^- ($\mu g \cdot l^{-1}$)	11.2 (18.2 ;341)	20.4 (26.7; 62)	9 (10.6; 208)	10.6 (7.2; 194)
NH_4^+ ($\mu g \cdot l^{-1}$)	77.4 (70.4; 356)	124.3 (132.5; 62)	100.2 (63.8; 208)	100.9 (63.8; 194)
TPN ($\mu g \cdot l^{-1}$)	33.9 (26.1; 116)	59.2 (49.3; 20)	44.9 (38.8; 96)	77.2 (83.6; 100)
Chl-a ($\mu g \cdot l^{-1}$)	4.2 (4.9; 214)	6 (5.5; 42)	7.8 (8.6; 103)	17.9 (14.1; 97)
Salinity (ppt)	28.7 (8.7; 272)	26.5 (9.3; 38)	21.2 (12.4; 115)	14.1 (11.8; 97)
Temperature (°C)	18.8 (3.6; 272)	19.4 (4.1; 38)	18.8 (4.2; 115)	19.1 (4.4; 97)
pH	7.9 (0.2; 111)	7.9 (0.2; 20)	7.8 (0.3 ;90)	8.1 (0.2; 81)
O_2 ($mg \cdot l^{-1}$)	7.3 (0.9; 76)	7 (1.3; 15)	7.2 (1.7; 64)	7.2 (1.6; 65)
O_2 (% Saturation)	89 (12; 12)	86 (13; 13)	90 (11; 62)	84 (17; 65)
Secchi (cm)	135 (47; 48)	45 (15; 12)	96 (47; 19)	89 (49; 28)

The Kromme estuary exhibited the highest mean salinity (28.7 ppt ±8.7), followed closely by its biggest tributary, the Geelhoutboom estuary (26.9 ppt ±8.6) (Table 4.1). The Sundays estuary had the lowest mean salinity value of 14.1 ppt (±11.8), whereas the salinity in the Swartkops estuary had a mean value of 21.2 ppt (±12.4). Turbidity was lowest in the Kromme estuary (mean Secchi reading: 135 cm ±47), whereas measurements of the Swartkops and Sundays estuaries were within a close range, namely 96 cm (±47) and 89 cm (±49) respectively. The waters were the least transparent in the lower reaches of the Geelhoutboom estuary, with a mean Secchi reading of only 45 cm (±15) (Table 4.1).

4.3.1.2 Longitudinal gradients:

No distinct longitudinal pH gradients were apparent in any of the three estuaries (Fig. 4.1; Table 4.2, 4.3, 4.4). Temperatures differed between 2 to 3 degrees between the lower and upper reaches (Fig. 4.1; Table 4.2, 4.3, 4.4). Both the Swartkops and Sundays estuaries exhibited a longitudinal salinity gradient, which ranged from ca 33 to 15 ppt in the Swartkops and 27 - 10 ppt in the Sundays estuary. In the Kromme estuary only a slight gradient from ca 32 ppt at the mouth to 24 ppt at the head was measured, where salinity values were only lowered to some extent during the occasional minor floods (Fig. 4.1; Table 4.2, 4.3, 4.4; see also Chapter 3).

O_2 saturation levels changed from 87% ±10 at the head to 94% ±7 at the mouth of the Kromme estuary. The Swartkops estuary showed no distinct longitudinal gradient in both O_2 concentration (6.9 $mg \cdot l^{-1}$ in the upper to 7.0 $mg \cdot l^{-1}$ in the lower reaches) and saturation levels (87 % in the upper to 91 % in the lower reaches). The Sundays estuary had the strongest gradient of the three systems, which ranged from 6.9 $mg \cdot l^{-1}$ (at 83 % saturation) in the upper reaches to 8.3 $mg \cdot l^{-1}$ (at 95% saturation) in the lower reaches. The river water entering the individual estuaries was well oxygenated in both the Kromme and Swartkops river (8.9 and 9.2 $mg \cdot l^{-1}$ respectively), whereas the oxygen content in the Sundays river was comparatively low at 6.8 $mg \cdot l^{-1}$. The river water enters the Kromme and Swartkops estuaries via a series of rapids and is thus well mixed and oxygenated, whereas the headwaters of the Sundays estuary are still (Fig. 4.1; Table 4.2, 4.3, 4.4).

Turbidity increases from head to mouth in both the Kromme (mean Secchi reading: 179 cm ±60 to 133 cm ±41) and Swartkops (102 cm ±65 to 86 cm ±31) estuaries. Minimum turbidity was measured in the lower and upper reaches in the Kromme estuary, whereas in the Swartkops estuary the watercolumn became increasingly transparent towards the upper reaches (Table 4.2, 4.3; Fig. 4.1). In the Sundays estuary, turbidity was lowest near the mouth, with a turbidity maximum in the middle reaches (72 cm ±28) and upper reaches (65 cm ±25) (Fig. 4.1; Table 4.4).

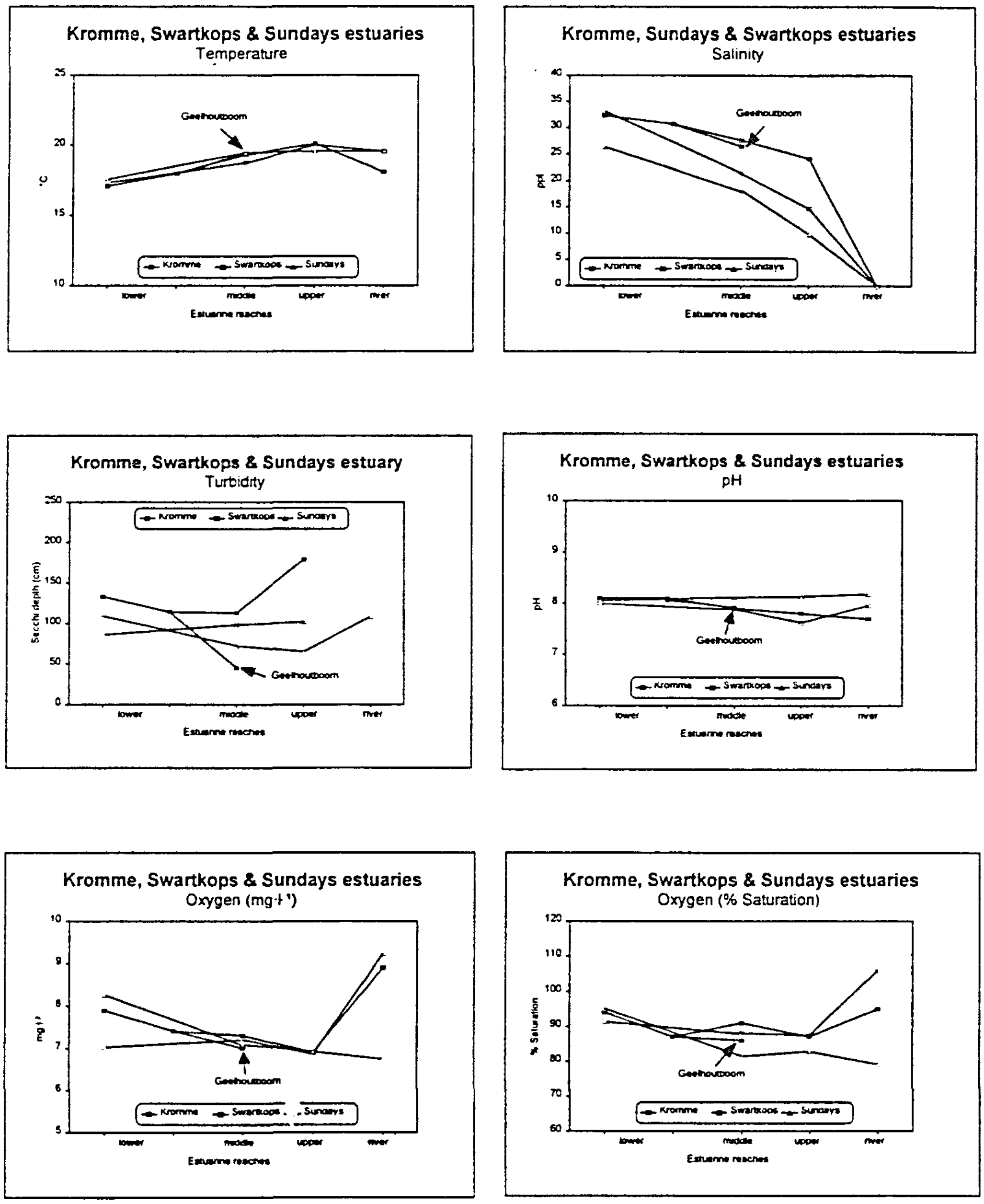


Fig. 4.1: Longitudinal gradients for various physico-chemical parameters in the Kromme, Swartkops and Sundays estuaries. Datapoints are mean values for the whole study period.

Table 4.2: Physico-chemical parameters of the different reaches in the Kromme estuary. Data are mean values for the whole study period, with standard deviations and *n* in parantheses.

	mouth region	lower reaches	Geelhoutboom	middle reaches	upper reaches	Kromme river
PO_4^{3-} ($\mu g \cdot l^{-1}$)	17.3 (23.4; 70)	16.8 (24.1; 94)	40.1 (87.1; 68)	17.5 (27.9; 117)	17.2 (29.0; 101)	19.0 (15.7; 11)
NO_3^- ($\mu g \cdot l^{-1}$)	128.2 (118.9; 70)	119.6 9115.7; 94)	200.0 (277.4; 68)	121.6 (114.4; 117)	124.1 (127.3; 101)	210.6 (56.8; 12)
NO_2^- ($\mu g \cdot l^{-1}$)	11.6 (17.6; 66)	11.3 (17.7; 88)	20.4 (26.7; 62)	11.7 (19.1; 102)	10.2 (18.3; 85)	21.0 (24.6; 10)
NH_4^+ ($\mu g \cdot l^{-1}$)	78.6 (68.0; 66)	69.0 (44.0; 88)	124.3 (132.5; 62)	84.9 (73.7; 109)	75.7 (86.6; 93)	126.0 (129.6; 10)
PON ($\mu g \cdot l^{-1}$)	28.3 (19.1; 23)	31.3 (15.2; 27)	59.2 (49.3; 20)	44.3 (34.6; 37)	28.0 (23.1; 30)	25.5 (36.0; 2)
Chl-a ($\mu g \cdot l^{-1}$)	4.8 (3.0; 38)	4.7 (3.1; 51)	6.0 (5.5; 42)	8.0 (8.8; 53)	6.7 (7.1; 50)	2.2 (0.8; 2)
Salinity (ppt)	32.2 (6.0; 44)	30.7 (6.9; 68)	26.9 (8.6; 47)	27.6 (9.1; 92)	24.2 (10.7; 75)	0.0 (0.0; 8)
Temperature (°C)	17.1 (2.5; 44)	18.0 (2.8; 67)	19.4 (4.1; 38)	19.3 (3.8; 89)	20.1 (4.0; 72)	18.1 (2.8; 2)
pH	8.1 (0.1; 17)	8.1 (0.2; 28)	7.9 (0.2; 20)	7.9 (0.2; 36)	7.8 (0.2; 30)	7.7 (0.1; 2)
O_2 ($mg \cdot l^{-1}$)	7.9 (1.0; 11)	7.4 (1.0; 21)	7.0 (1.3; 15)	7.3 (0.8; 24)	6.9 (0.8; 20)	8.9 (0.1; 2)
O_2 (% Saturation)	94 (7; 10)	87 (19; 20)	86 (13; 13)	91 (6; 23)	87 (10; 19)	95 (1; 2)
Secchi (cm)	133 (41; 12)	114 (25; 12)	45 (15; 12)	113 (17; 12)	179 (60; 12)	

Table 4.3: Physico-chemical parameters of the different reaches in the Swartkops estuary. Data are mean values for the whole study period, with standard deviations and *n* in parentheses.

	lower reaches	middle reaches	upper reaches	Swartkops river
PO_4^{3-} ($\mu g \cdot l^{-1}$)	24.1 (3.7; 62)	80.2 (26.9; 68)	120.7 (58.6; 64)	210.5 (122.0; 14)
NO_3^- ($\mu g \cdot l^{-1}$)	173.2 (174.8; 62)	198.2 (168.8; 68)	173.5 (185.1; 64)	326.6 (390.5; 14)
NO_2^- ($\mu g \cdot l^{-1}$)	10.8 (12.2; 62)	10.4 (12.5; 68)	5.6 (5.7; 64)	9.7 (6.0; 140
NH_4^+ ($\mu g \cdot l^{-1}$)	100.8 (32.8; 62)	105.4 (82.0; 68)	94.9 (64.1; 64)	96.3 (69.3; 14)
TPN ($\mu g \cdot l^{-1}$)	35.8 (28.4; 28)	48.8 (46.1; 31)	46.4 (39.5; 31)	59.7 936.4; 6)
Chl-a ($\mu g \cdot l^{-1}$)	4.1 (4.4; 29)	6.7 (4.1; 33)	8.6 95.0; 33)	22.3 (22.7; 8)
Salinity (ppt)	33.1 (2.8; 33)	21.4 (9.8; 36)	14.7 (11.0; 39)	0 (0.0; 7)
Temperature (°C)	17.4 (3.5; 33)	18.7 (4.5; 36)	20 (4.2; 39)	19.5 (4.8; 7)
pH	8 (0.1; 26)	7.9 (0.3; 28)	7.6 (0.1; 30)	8 (0.8; 6)
O_2 ($mg \cdot l^{-1}$)	7 (1.9; 18)	7.2 (0.9; 21)	6.9 (1.9; 21)	9.2 (2.3; 4)
O_2 (% Saturation)	91 (8; 17)	88 (8; 21)	87 (12; 20)	106 (20; 4)
Secchi (cm)	86 (31; 7)	98 (56; 6)	102 (65; 5)	

Table 4.4: Physico-chemical parameters of the different reaches in the Sundays estuary. Data are mean values for the whole study period, with standard deviations and *n* in parentheses.

	lower reaches	middle reaches	upper reaches	Sundays river
PO_4^{3-} ($\mu g \cdot l^{-1}$)	13.5 (11.3; 43)	15.5 (11.1; 58)	19.8 (11.8; 52)	19.6 (10.6; 40)
NO_3^- ($\mu g \cdot l^{-1}$)	311.9 9228.9; 44)	350.2 (303.3; 58)	471.6 (320.3; 52)	934.7 (579.9; 40)
NO_2^- ($\mu g \cdot l^{-1}$)	9.6 96.4; 44)	10.7 (8.1; 58)	14 (7.2; 52)	7.2 (4.5; 40)
NH_4^- ($\mu g \cdot l^{-1}$)	93 (55.0; 44)	103.2 (73.4; 58)	123 (73.5; 52)	77.5 (23.9; 40)
TPN ($\mu g \cdot l^{-1}$)	44.3 (37.8; 22)	91.1 (79.5; 29)	97.4 (103.3; 27)	67.1 (88.7; 22)
Chl-a ($\mu g \cdot l^{-1}$)	8.6 (6.4; 22)	22.8 (13.4; 29)	22.4 (18.3; 26)	10.7 (5.7; 20)
Salinity (ppt)	26.5 (3.6; 22)	18.3 (8.3; 29)	9.9 (10.6; 26)	0 (0.0; 20)
Temperature (°C)	17.7 (3.9; 22)	19.4 (4.4; 29)	19.6 (4.4; 26)	19.6 (4.7; 20)
pH	8.1 (0.2; 17)	8.1 (0.2; 25)	8.1 (0.2; 22)	8.2 (0.2; 17)
O_2 ($mg \cdot l^{-1}$)	8.3 (1.1; 13)	7.1 (1.8; 20)	6.9 (1.4; 18)	6.8 (1.4; 14)
O_2 (% Saturation)	95 (11; 130	82 (20; 20)	83 (18; 18)	79 (15; 14)
Secchi (cm)	111 (54; 7)	72 (28; 7)	65 (25; 7)	109 (68; 7)

4.3.2 Nutrients

4.3.2.1 Mean estuarine values

Nutrient concentrations differed to a great extent between the Kromme, Swartkops and Sundays estuaries, with the exception of ammonia and nitrite (Fig. 4.2, Table 4.1). Overall lowest nutrient concentrations were measured in the Kromme estuary, and highest in the Sundays estuary except in the case of phosphate (Table 4.1). Highest phos hate concentrations were measured in the Swartkops estuary at 84.7 $\mu g \cdot l^{-1}$ (Table 4.1). The Geelhoutboom carried higher nutrient loads than the Kromme estuary (Table 4.1). Concentrations for phosphates (40.1 $\mu g \cdot l^{-1}$), nitrate (200.0 $\mu g \cdot l^{-1}$) and nitrite (20.4 $\mu g \cdot l^{-1}$), ammonia (124.3 $\mu g \cdot l^{-1}$) and TPN (59.2 $\mu g \cdot l^{-1}$) were around double than those in the mainstream of the Kromme estuary (Table 4.1) and even higher compared to concentrations measured in the freshwater discharging at the tidal head of the Kromme estuary (Table 4.2). The Geelhoutboom was richer in nutrients than the Swartkops and Sundays estuaries, with the exception of phosphate in the Swartkops estuary and nitrate and TPN in the Sundays estuary (Table 4.1).

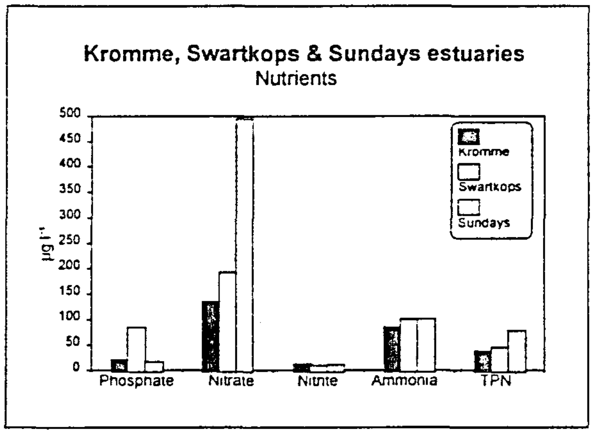


Fig. 4.2.: Mean estuarine nutrient concentrations in the Kromme, Swartkops and Sundays estuaries. Bars denote mean values for the whole study period.

4.3.2.2 Longitudinal nutrient gradients

Concentrations of the nutrients along the longitudinal axes of the three estuaries showed variable trends, with the exception of the Sundays estuary, where all nutrient species increased from the lower to the upper reaches in their concentrations (Table 4.2, 4.3, 4.4; Fig 4.3).

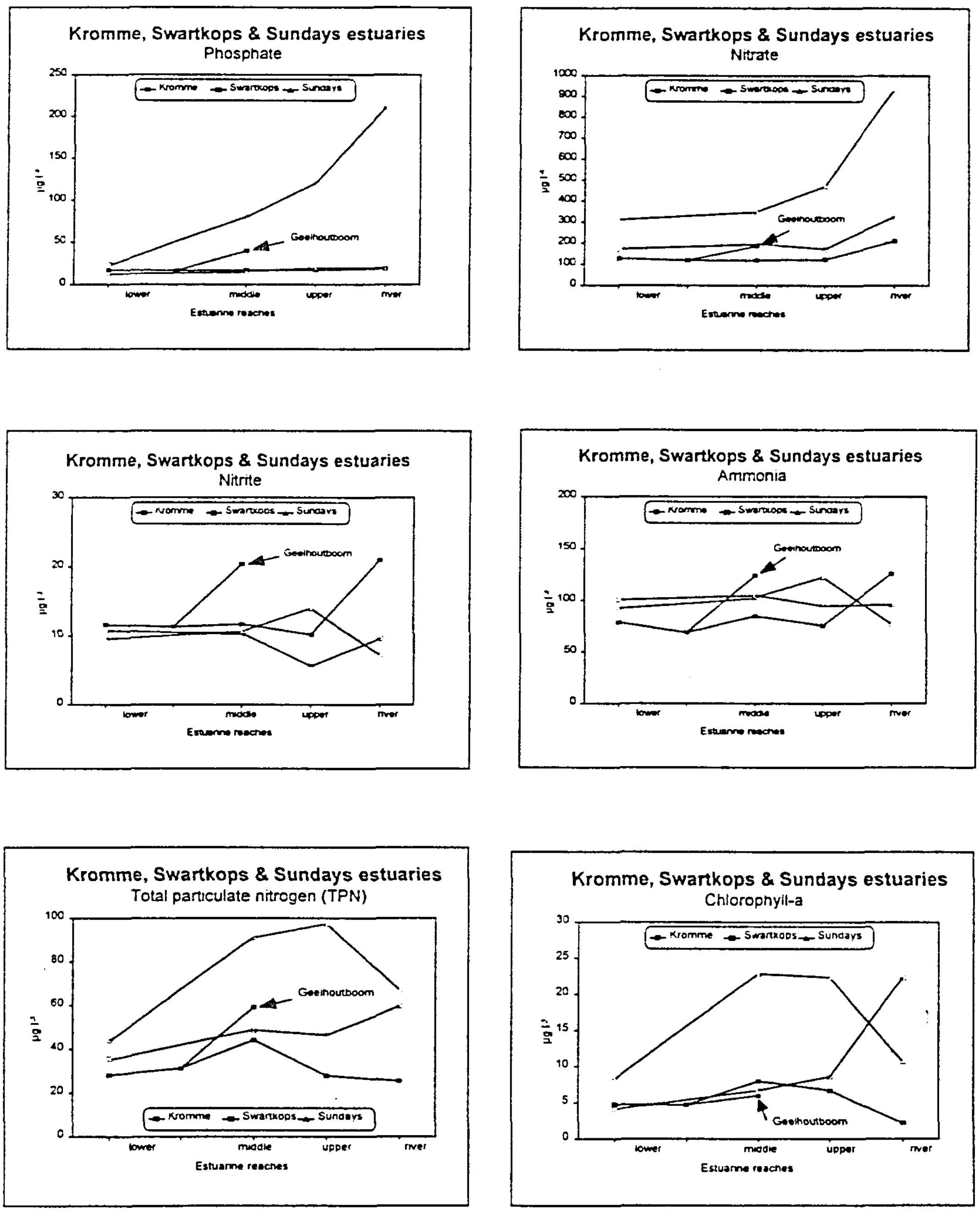


Fig.: 4.3: Longitudinal gradients for several nutrients and chlorophyll-a in the Kromme, Swartkops and Sundays estuaries. Datapoints are mean values for the whole study period.

Kromme estuary:

In the Kromme estuary phosphate, nitrate and nitrite concentrations remained virtually constant along the longitudinal axis (Table 4.2, Fig. 4.3). Ammonia showed slightly higher concentrations in the middle and upper reaches as compared to the lower and mouth region. Peak concentrations of TPN were measured in the middle reaches. During periods of freshwater inflow concentrations for all nutrients (PO_4, NO_3, NO_2, NH_4, TPN) were elevated at all stations in the estuary (Table 4.5, Fig. 4.4), emphasising the Kromme river as a vital nutrient supplier. Only ammonia and TPN concentrations showed similar values in the lower reaches of the estuary.

The biggest differences in nutrient concentrations between periods of freshwater inflow and periods of no inflows into the system were apparent in the case of phosphate, nitrate and nitrite. During dry periods phosphate concentrations showed a slight negative gradient from the mouth to the head of the estuary, whereas no gradient was measured when freshwater was discharging into the estuary (Table 4.5). Phosphate concentrations were elevated during those periods. A similar pattern was observed for nitrate, where concentrations in the upper reaches were even four times higher when the estuary received freshwater (170.4 $\mu g \cdot l^{-1}$ ±136.1) as opposed to periods of no freshwater inflow (43.9 $\mu g \cdot l^{-1}$ ± 46.9) (Table 4.5). Nitrite concentrations increased by a factor of approximately 4 to 5 at all stations when freshwater was discharged into the system (Table 4.5). In the case of ammonia and TPN, concentrations were elevated only in the middle and upper reaches when freshwater inflow was present, leaving its lower reaches unaffected.

Since the Kromme estuary only received freshwater when the Impofu dam overflowed as a consequence of heavy rains, drainage into the Geelhoutboom from its catchment area occurred during approximately the same periods. After-effects were the elevation of phosphate, nitrate, nitrite and ammonia concentrations in the Geelhoutboom to levels which exceeded those measured in the Kromme estuary at the same time. TPN concentrations, on the other hand, had decreased during those even s in the Geelhoutboom estuary (Table 4.5, Fig. 4.4).

Table 4.5: Nutrient and chlorophyll-a measurements of the different reaches in the Kromme estuary for periods of present/absent freshwater inflow (FI present/FI absent). Data are mean values for the study period, with standard deviations and *n* in parantheses.

		mouth region	lower reaches	Geelhoutboom	middle reaches	upper reaches	Kromme river
PO_4^{3-} ($\mu g \cdot l^{-1}$)	FI present	21.9 (28.5; 44)	21.4 (29.8; 58)	55.7 (105.4; 44)	23.1 (34.5; 72)	23.7 (34.8; 64)	19.0 (15.7; 110
	FI absent	9.6 (4.2; 26)	9.4 (2.4; 36)	11.4 (2.8; 24)	8.5 (2.1; 45)	5.9 (1.8; 370	
NO_3^- ($\mu g \cdot l^{-1}$)	FI present	157.8 (137.8; 44)	155.1 (131.7; 58)	239.3 (314.6; 44)	159.4 (126.7; 72)	17.4 (136.1; 64)	210.6 (56.8; 12)
	FI absent	78.2 (47.2; 26)	62.4 (43.3; 36)	94.3 (100.3; 24)	61.2 (50.1; 45)	43.9 (46.9; 37)	
NO_2^- ($\mu g \cdot l^{-1}$)	FI present	16.5 (21.3; 40)	16.3 (21.5; 52)	30.0 (30.4; 38)	17.7 (23.8; 57)	15.5 (23.0; 48)	21.0 924.6; 10)
	FI absent	4.1 (2.4; 26)	4.0 (2.9; 36)	5.3 (2.7; 24)	4.1 92.3; 450	3.4 (2.7; 37)	
NH_4^+ ($\mu g \cdot l^{-1}$)	FI present	77.7 (78.5; 40)	69.3 (52.7; 52)	155.4 (160.9; 38)	94.9 (90.9; 640	85.3 (106.7; 56)	126.0 (129.6; 10)
	FI absent	80.0 (49.3; 26)	68.6 (27.6; 36)	74.9 (27.4; 24)	70.7 (33.9; 45)	61.3 (37.5; 37)	
PON ($\mu g \cdot l^{-1}$)	FI present	31.9 (25.5; 9)	27.9 (20.2; 9)	44.9 (52.9; 9)	66.8 (47.2; 14)	37.4 (33.8; 12)	25.5 (36; 2)
	FI absent	26.0 (14.3; 14)	33.1 (12.3; 18)	70.3 (42.7; 12)	30.6 (10.9; 23)	21.7 (8.0; 18)	
Chl-a ($\mu g \cdot l^{-1}$)	FI present	4.5 (2.8; 27)	5.7 (3.5; 30)	8.5 (6.4; 20)	10.7 (10.3; 33)	8.8 (8.3; 31)	
	FI absent	5.6 (3.3; 11)	3.4 (1.9; 21)	4.5 (1.8; 12)	3.6 (1.3; 20)	3.2 (1.1; 22)	

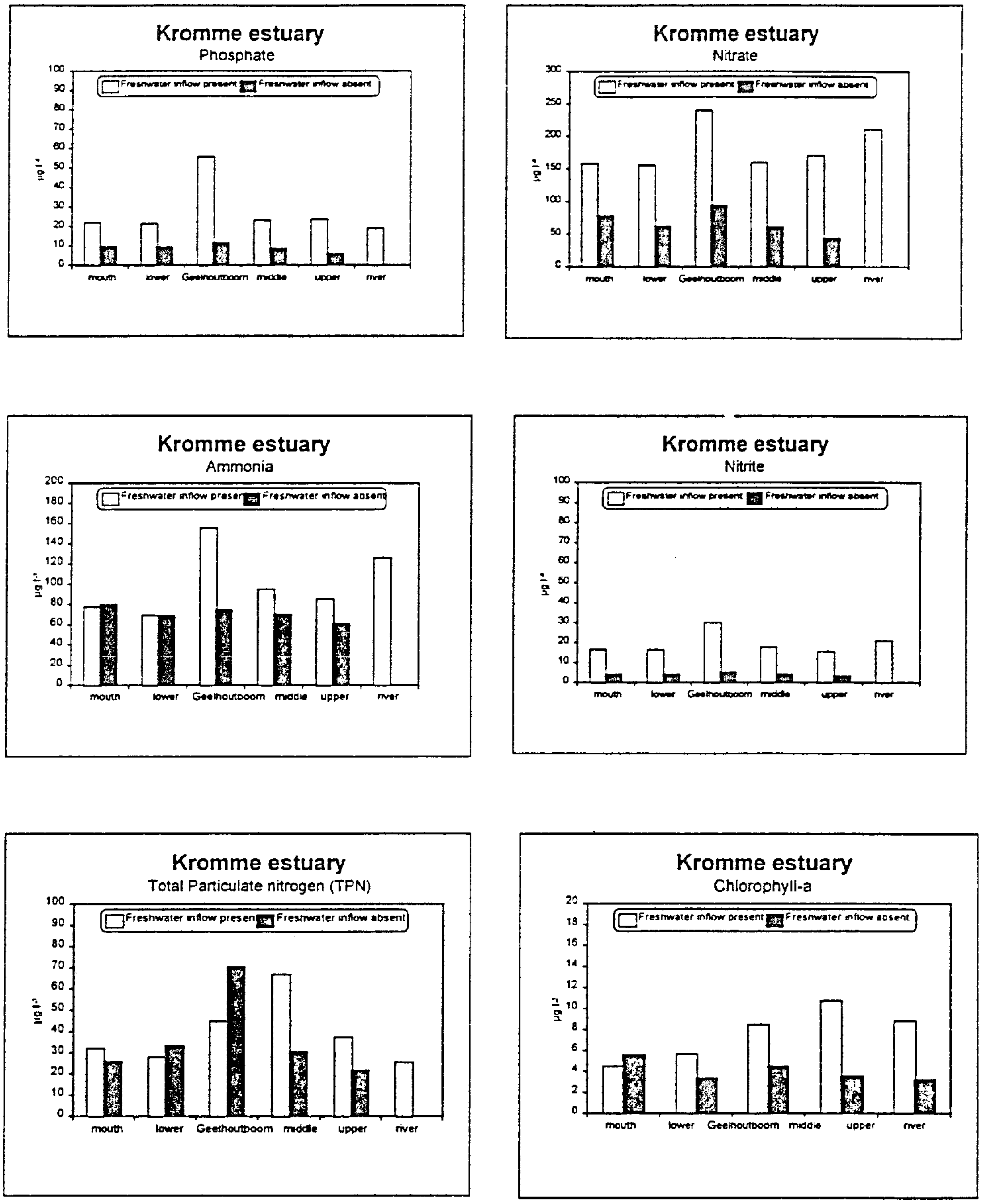


Fig. 4.4: Nutrient and chlorophyll-a concentrations for the Kromme and Geelhoutboom estuaries for periods of occurrence and non-occurrence of freshwater inflow. Bars denote mean values for the respective periods of present/absent freshwater inflow.

Measurements from the upper and mouth region of the Kromme estuary, and from the Geelhoutboom and the mouth region of the Kromme estuary were respectively subjected to a paired t-test in order to establish whether a longitudinal nutrient and salinity gradient is statistically significant. Two data sets were investigated, one including measurements taken in the Kromme and Geelhoutboom estuaries during both periods of freshwater inflow and dry periods, and a second one considering measurements taken during periods of freshwater inflow only. The latter set only accounts for the Kromme estuary, since no freshwater inflow rates are available for the Geelhoutboom estuary. Analysis of the two different data sets should allow one to establish the influence of freshwater inflow on nutrient gradients in the estuary. Results showed that for neither scenario a statistically significant longitudinal nutrient and chlorophyll-a gradient was apparent (Table 4.6 A), although a salinity gradient was present in both cases (Table 4.6 A). Similarly, none of the dissolved inorganic nutrients exhibit gradients from the Geelhoutboom to the mouth regions of the Kromme estuary, yet TPN and salinity differed significantly ($p < 0.05$) between the two regions (Table 4.6 A).

Table 4.6 A: Paired t-tests between the mouth (Station 1) and the head (Station 5) of the Kromme estuary and between the mouth of the Kromme estuary (Station 1) and the Geelhoutboom estuary (Station3) to investigate the existence of a longitudinal nutrient, chlorophyll-a and salinity gradient. S^{*}: p<0.05; S^{**}: p<0.01; S^{***}: p<0.001. $\alpha = 0.05$

Measurements taken during periods of occurrence and non-occurrence of freshwater inflow:

		t	p	n	Significance
Mouth (St 1)	PO_4^{3+}	-0.06	0.96	12	NS
Head (St. 5)	$NO_3^{=}$	0.01	0.99	12	NS
	NO_2^{-}	1.26	0.24	10	NS
	NH_4^{+}	-0.02	0.99	11	NS
	TPN	-0.16	0.88	7	NS
	Chl-a	-1.36	0.2	12	NS
	Salinity	3.89	0	12	S^{**}
Mouth (St. 1)	PO_4^{3+}	-1.16	0.27	12	NS
Geelhoutboo	$NO_3^{=}$	-1.43	0.18	12	NS
	NO_2^{-}	-1.5	0.17	11	NS
	NH_4^{+}	-1.91	0.09	11	NS
	TPN	-2.62	0.04	7	S^{*}
	Chl-a	-1.68	0.12	12	NS
	Salinity	4.16	0	12	

Table 4.6 A cont.

Measurements taken during periods of freshwater inflow only

		t	p	n	Significance
Mouth (St. 1) vs.	PO_4^{3-}	-0.75	0.48	8	NS
Head (St. 5)	$NO_3^{=}$	-0.7	0.51	8	NS
	NO_2^{-}	1.25	0.27	6	NS
	NH_4^{+}	-0.27	0.8	7	NS
	TPN	-0.35	0.76	3	NS
	Chl-a	1.77	0.13	7	NS
	Salinity	6	0	8	S**

Swartkops estuary:

Phosphate was the only nutrient increasing upriver in concentration in the Swartkops estuary, ranging from 24.1 $\mu g \cdot l^{-1}$ (±13.7) in the lower to 120.7 $\mu g \cdot l^{-1}$ (±58.6) in the upper reaches (Table 4.3, Fig. 4.3). Nitrite concentrations showed an opposite trend by decreasing towards the upper reaches, whereas ammonia remained fairly constant throughout the estuary at approximately 100 $\mu g \cdot l^{-1}$. Both nitrate and TPN were measured in their highest concentrations in the middle reaches at 198.2 $\mu g \cdot l^{-1}$ (±168.8) and 48.8 $\mu g \cdot l^{-1}$ (±46.1) respectively (Table 4.3). A paired t-test between the lower and the upper reaches indicated a statistically significant longitudinal gradient for salinity and phosphate, whereas none of the other nutrients investigated featured the same trend (see Table 4.6 B).

Table 4.6 B: Paired t-tests between the lower (Station 1) and upper reaches (Station 3) of the Swartkops estuary to investigate the existence of a longitudinal nutrient, chlorophyll-a and salinity gradient. S^{*}: $p<0.05$; S^{**}: $p<0.01$; S^{***}: $p<0.001$. $\alpha = 0.05$

	t	p	n	Significance
PO_4^{3-}	-7.41	< 0.001	7	S^{***}
$NO_3^{=}$	-0.35	0.74	7	NS
NO_2^{-}	1.34	0.23	7	NS
NH_4^{+}	0.23	0.83	7	NS
TPN	-0.92	0.39	7	NS
Chl-a	-2.84	0.03	7	S^{*}
Salinity	5.79	0	7	S^{**}

Sundays estuary:

In the Sundays estuary all nutrient species examined increased in concentration from the lower to the upper reaches (Table 4.4, Fig. 4.3). Phosphate and nitrite, which were never encountered in high concentrations, displayed the smallest gradient along the longitudinal axis. Nitrate concentrations were 2 to 3 times higher than those measured in the Kromme and Swartkops estuaries. Mean values in the Sundays estuary ranged from 312 $\mu g \cdot l^{-1}$ in the lower to 472 $\mu g \cdot l^{-1}$ in its upper reaches (Table 4.4). Ammonia concentrations were higher in the Sundays estuary than in the other two estuaries, with concentrations of 93.0 $\mu g \cdot l^{-1}$ in its lower and 123.0 $\mu g \cdot l^{-1}$ in its upper reaches. TPN values in the upper reaches (97.4 $\mu g \cdot l^{-1}$) were more than double those in its lower reaches (44.3 $\mu g \cdot l^{-1}$), and the highest of the three estuaries under study. A statistically significant difference and therefore a longitudinal gradient between the lower and upper reaches was apparent for nitrate, nitrite and TPN as well as for salinity (see Table 4.6 C).

Table 4.6 C: Paired t-tests between the lower (Station 1) and upper reaches (Station 3) of the Sundays estuary to investigate the existence of a longitudinal nutrient, chlorophyll-a and salinity gradient. S^*: $p<0.05$; S^{**}: $p<0.01$; S^{***}: $p<0.001$. $\alpha = 0.05$

	t	p	n	Significance
PO_4^{3-}	-2.24	0.07	7	NS
$NO_3^=$	-4.98	0	7	S^{**}
NO_2^-	-3.01	0.02	7	S^*
NH_4^+	-1.04	0.34	7	NS
TPN	-3.81	0.01	7	S^{**}
Chl-a	-2.45	0.05	7	S^*
Salinity	4.84	0	7	S^{**}

4.3.3 Chlorophyll-a concentrations:

4.3.3.1 Mean estuarine values:

Similar to mean nutrient concentrations, the Kromme estuary supported the lowest chlorophyll-a concentrations (4.2 $\mu g \cdot l^{-1}$), compared to the Swartkops (7.8 $\mu g \cdot l^{-1}$) and Sundays (17.0 $\mu g \cdot l^{-1}$) estuaries (Table 4.1). In the Geelhoutboom estuary chlorophyll-a concentrations were measured at 6.0 $\mu g \cdot l^{-1}$ (Table 4.1).

4.3.3.2 Longitudinal chlorophyll-a gradients:

No gradual in- or decrease in chlorophyll-a concentrations were observed along the longitudinal axis in the Kromme estuary (Fig. 4.3, Table 4.2). Chlorophyll-a concentrations were slightly higher in the middle reaches, where concentrations reached 8.0 $\mu g \cdot l^{-1}$, whereas mean levels of 6.7 $\mu g \cdot l^{-1}$ were measured in the upper reaches. In the Swartkops estuary a gradual increase of chlorophyll-a concentrations from 4.1 $\mu g \cdot l^{-1}$ in its lower to 8.6 $\mu g \cdot l^{-1}$ in its upper reaches was observed (Fig. 4.3, Table 4.3). Chlorophyll-a was most prominent in the middle and upper reaches of the Sundays estuary, with concentrations of 22.8 $\mu g \cdot l^{-1}$ and 22.4 $\mu g \cdot l^{-1}$ respectively (Fig. 4.3, Table 4.4). A longitudinal gradient from the lower to the upper reaches was statistically significant in the

Swartkops and Sundays estuaries, but neither for the Kromme nor the Geelhoutboom estuary (Table 4.6 A, B, C).

4.3.4 Interactions between nutrients, chlorophyll-a and selected abiotic parameters:

Since the nutrient status, and consequently phytoplankton biomass, of the estuary may be affected by the riverine source, the relationship between nutrient and chlorophyll-a to the rate of freshwater discharge into the respective estuary was investigated. Single correlations, which were preferred to multiple correlations due to signs of multicollinearity, were strong in some cases. Therefore single regressions were performed to investigate eventual functional dependenc. :s of nutrients and chlorophyll-a on various abiotic parameters.

4.3.4.1 The upper reaches:

Firstly, only the upper reaches of the three estuaries were considered, since this should give an idea of the direct impact of freshwater input into the estuaries. At the head of the Kromme estuary, a system with only occasional freshwater input, phosphate and nitrate were strongly positively related with the rate of freshwater inflow (93 and 47 % respectively), and accordingly showed a negative relation with salinity (-49 and - 55 % respectively) (see Table 4.7 A). There was no statistically significant relationship for any of the other parameters (nitrite, ammonia, TPN and chlorophyll-a) with any of the two dependency factors (Table 4.7 A).

Table 4.7 A: Linear correlation/regression of nutrients and Chlorophyll-a with salinity and freshwater inflow at the head of the Kromme estuary (Station 5). S^{*}: $p<0.05$; S^{**}: $p<0.01$; S^{***}: $p<0.001$. $\alpha = 0.05$

		r	r^2	t	p	n	Significance
PO_4^{3-}	Salinity	-0.69	0.49	-6.8	< 0.001	51	S^{***}
	Freshwater inflow	0.96	0.93	25.53	< 0.001	51	S^{***}
$NO_3^{=}$	Salinity	-0.74	0.55	-7.71	< 0.001	51	S^{***}
	Freshwater inflow	0.69	0.47	6.6	< 0.001	51	S^{***}
NO_2^{-}	Salinity	-0.08	0.7	-0.54	0.59	43	NS
	Freshwater inflow	-0.1	0.01	-0.54	0.54	43	NS
NH_4^{-}	Salinity	-0.11	0.01	-0.71	0.48	47	NS
	Freshwater inflow	0.08	0.01	0.54	0.59	47	NS
TPN	Salinity	-0.56	0.31	-1.51	0.19	7	NS
	Freshwater inflow	0.22	0.05	0.5	0.64	7	NS
Chl-a	Salinity	-0.33	0.11	-1.09	0.3	12	NS
	Freshwater inflow	-0.24	0.06	-0.77	0.46	12	NS

In the upper reaches of the Swartkops estuary the only variable related to freshwater inflow was nitrite, since it exhibited a significant negative relationship with salinity ($r = -0.51$, $r^2 = 0.26$) and was positively correlated with freshwater inflow ($r = 0.65$, $r^2 = 0.43$) (Table 4.8 B). Considerably higher phosphate concentrations were measured in the river water as compared to the estuary (Table 4.3). However, no significant relationship was apparent with neither salinity nor freshwater inflow regarding phosphate concentrations (Table 4.7 B). It is therefore assumed that higher rates of river flow rather dilute the phosphate concentrations in the river than contribute to increases in their concentration in the upper reaches of the estuary relative to the amount of freshwater inflow (Table 4.7 B).

Table 4.7 B: Linear correlation/regression of nutrients and Chlorophyll-a with salinity and freshwater inflow in the upper reaches of the Swartkops estuary (Station 3). S*: $p<0.05$; S**: $p<0.01$; S***: $p<0.001$. $\alpha = 0.05$

		r	r^2	t	p	n	Significance
PO_4^{3-}	Salinity	0.21	0.04	1.17	0.25	32	NS
	Freshwater inflow	-0.2	0.04	-1.11	0.28	32	NS
$NO_3^=$	Salinity	0.04	0	0.24	0.81	32	NS
	Freshwater inflow	0.17	0.03	0.97	0.34	32	NS
NO_2^-	Salinity	-0.51	0.26	-3.27	0	32	S**
	Freshwater inflow	0.65	0.43	4.72	< 0.001	32	S***
NH_4^+	Salinity	-0.07	0.01	-0.37	0.72	32	NS
	Freshwater inflow	0.29	0.08	1.63	0.11	32	NS
TPN	Salinity	-0.53	0.27	-1.37	0.23	7	NS
	Freshwater inflow	0.75	0.56	2.52	0.05	7	NS
Chl-a	Salinity	0.53	0.28	1.4	0.22	7	NS
	Freshwater inflow	0.39	0.15	0.94	0.39	7	NS

A similar pattern emerged for the Sundays estuary, where nitrate values were twice as high in the river water than in the upper estuarine reaches (Table 4.4), and the expected correlations with freshwater inflow and salinity failed to be statistically significant (Table 4.7 C). Nitrite and ammonia on the other hand, seem to accumulate in the upper reaches of the Sundays estuary during periods of subaverage freshwater inflow, since both nutrients showed a positive correlation with salinity (Table 4.7 C). Other nutrients as well as chlorophyll-a were not statistically significantly correlated with either freshwater inflow or salinity regarding their particular concentrations in the upper reaches of the estuary (Table 4.7 C).

Table 4.7 C: Linear correlation/regression of nutrients and Chlorophyll-a with salinity and freshwater inflow in the upper reaches of the Sundays estuary (Station 3). S^{*}: $p<0.05$; S^{**}: $p<0.01$; S^{***}: $p<0.001$. $\alpha = 0.05$

		r	r^2	t	p	n	Significance
PO_4^{3-}	Salinity	-0.33	0.11	-1.68	0.11	26	NS
	Freshwater inflow	0.05	0	0.27	0.79	26	NS
$NO_3^{=}$	Salinity	0.12	0.02	0.6	0.55	26	NS
	Freshwater inflow	-0.23	0.05	-1.17	0.26	26	NS
NO_2^{-}	Salinity	0.67	0.45	4.44	< 0.001	26	S^{***}
	Freshwater inflow	-0.41	0.17	-2.19	0.04	26	S^{*}
NH_4^{+}	Salinity	0.5	0.21	2.54	0.02	26	S^{*}
	Freshwater inflow	0.01	0	0.07	0.95	26	NS
TPN	Salinity	0.07	0.01	0.17	0.88	7	NS
	Freshwater inflow	-0.67	0.45	-2.04	0.1	7	NS
Chl-a	Salinity	0.5	0.48	1.29	0.26	7	NS
	Freshwater inflow	-0.06	0	-0.14	0.9	7	NS

4.3.4.2 The entire estuary:

Nutrients:

Having established the effects of freshwater inflow on the nutrient and chlorophyll-a concentrations in the upper reaches of the Kromme, Swartkops and Sundays estuaries, the nutrient concentrations in the entire estt ary were subsequently investigated for their possible dependence on the freshwater quantum the individual systems receive. Single correlations of the different nutrient species versus salinity served to outline this relationship. Since the results showed strong correlations in some cases, single regressions were performed in addition (similar to 4.3.4.1).

All dissolved inorganic nutrients except nitrite showed significant negative correlations with salinity in the Kromme estuary and therefore increase in their concentrations with increasing freshwater inflow. Phosphate and nitrate scored the highest correlation coefficients (0.69 and 0.75 respectively), and are functionally dependent on freshwater inflow to 91 and 53 % respectively (Table 4.8 A). An additional significant relationship was apparent for TPN, although the variation accounted for was small ($r = 0.19$). In the lower reaches of the Geelhoutboom estuary the concentrations of all the dissolved inorganic nutrients were affected by freshwater inflow, which is evident from their strong negative correlation with salinity (Table 4.8 A). Freshwater inflow was not included as a variable in both the correlation and regression procedure, since these particular data are not available for the Geelhoutboom estuary.

Table 4.8 A: Linear correlation and regression coefficients of various nutrients versus salinity and freshwater inflow for the Kromme estuary (Stations 1, 2, 4, 5) and versus salinity for the Geelhoutboom estuary (Station 3). S^{*}: $p<0.05$; S^{**}: $p<0.01$; S^{***}: $p<0.001$. $\alpha = 0.05$

Kromme		r	r^2	t	p	n	Significance
PO_4^{3+}	Salinity	-0.69	0.48	-18.59	< 0.001	382	S^{***}
	Freshwater inflow	0.95	0.91	62.35	< 0.001	382	S^{***}
$NO_3^{=}$	Salinity	-0.75	0.56	-21.86	< 0.001	382	S^{***}
	Freshwater inflow	0.73	0.53	20.6	< 0.001	382	S^{***}
NO_2^{-}	Salinity	-0.01	0	-0.09	0.93	341	NS
	Freshwater inflow	0	0	-0.62	0.54	341	NS
NH_4^{+}	Salinity	-0.29	0.09	-5.72	< 0.001	356	S^{***}
	Freshwater inflow	0.47	0.22	9.92	<0.001	356	S^{***}
TPN	Salinity	-0.18	0.03	-1.96	0.05	116	NS
	Freshwater inflow	0.19	0.04	2.06	0.04	116	S^{*}

Geelhoutboom		r	r^2	t	p	n	Significance
PO_4^{3+}	Salinity	-79.5	0.63	-10.65	< 0.001	68	S^{***}
$NO_3^{=}$	Salinity	-82.54	0.68	-11.88	< 0.001	68	S^{***}
NO_2^{-}	Salinity	-57.94	0.32	-5.37	< 0.001	62	S^{***}
NH_4^{+}	Salinity	-76.53	0.59	-9.21	< 0.001	62	S^{***}
TPN	Salinity	35.32	0.13	1.6	0.13	20	NS

In both the Swartkops and Sundays estuaries significant correlations were not as numerous and as strong compared to the Kromme or Geelhoutboom estuaries. Phosphates and TPN showed significant negative correlations with salinity in the Swartkops estuary and all nutrients, except phosphate, showed some dependence on freshwater inflow. In the Sundays estuary only phosphate concentrations were significantly higher when salinities were low, although only in the case of nitrate were correlations with freshwater inflow not significant (Table 4.8 B, C).

Table 4.8 B: Linear correlations/regressions of various nutrients versus salinity and freshwater inflow for the Swartkops estuary (Stations 1, 2, 3). S^*: $p<0.05$; S^{**}: $p<0.01$; S^{***}: $p<0.001$. $\alpha = 0.05$

		r	r^2	t	p	n	Significance
PO_4^{3-}	Salinity	-0.43	0.18	-6.46	< 0.001	194	S^{***}
	Freshwater inflow	-0.09	0.01	-1.27	0.21	194	NS
NO_3^-	Salinity	-0.06	0	0.85	0.4	194	NS
	Freshwater inflow	0.26	0.07	3.68	< 0.001	194	S^{***}
NO_2^-	Salinity	-0.01	0	-0.12	0.9	194	NS
	Freshwater inflow	0.29	0.09	4.22	< 0.001	194	S^{***}
NH_4^+	Salinity	-0.07	0.01	-9.77	0.33	194	NS
	Freshwater inflow	0.21	0.04	2.97	0	194	S^{**}
TPN	Salinity	-0.29	0.09	-2.87	0.01	90	S^{**}
	Freshwater inflow	0.68	0.46	8.61	< 0.001	90	S^{***}

Table 4.8 C: Linear correlations/regressions of various nutrients versus salinity and freshwater inflow for the Sundays estuary (Stations 1, 2, 3). S^{*}: $p<0.05$; S^{**}: $p<0.01$; S^{***}: $p<0.001$. $\alpha = 0.05$

		r	r^2	t	p	n	Significance
PO_4^{3-}	Salinity	-0.28	0.08	-3.63	< 0.001	156	S^{***}
	Freshwater inflow	0	0	0.01	0.99	156	NS
$NO_3^{=}$	Salinity	-0.11	0.01	-1.37	0.17	156	NS
	Freshwater inflow	-0.08	0.01	-0.96	0.34	156	NS
NO_2^{-}	Salinity	0.09	0.01	1.09	0.28	156	NS
	Freshwater inflow	-0.38	0.14	-5.1	< 0.001	156	S^{***}
NH_4^{+}	Salinity	0.02	0	-0.20	0.84	156	NS
	Freshwater inflow	0.3	0.09	3.91	< 0.001	156	S^{***}
TPN	Salinity	0.02	0	0.13	0.9	78	NS
	Freshwater inflow	-0.4	0.16	-3.8	< 0.001	78	S^{***}

Chlorophyll-a:

Possible physico-chemical variables including nutrient concentrations as well as salinity, freshwater inflow and turbidity were examined for their effect on chlorophyll-a concentrations in the Kromme, Swartkops and Sundays estuaries. Although nutrients and chlorophyll-a are interwoven in a short cycle of uptake and regeneration, it was nevertheless attempted to find some indication that in- or decreased nutrient concentrations have implications on chlorophyll-a levels.

In the Kromme estuary no significant correlations between chlorophyll-a and the dissolved inorganic nutrients were found. TPN, on the other hand, was highly correlated with chlorophyll-a concentrations (Table 4.9 A). Lowered salinity values were, nevertheless, significantly correlated with higher chlorophyll-a concentrations (Table 4.9 A). In the Geelhoutboom none of the variables investigated seemed to have had a major influence on chlorophyll-a concentrations (Table 4.9 A). In the Swartkops estuary, high chlorophyll-a goes hand in hand with higher phosphate abundance and lower ammonia concentrations (Table 4.9 B). Turbidity seems to play a major role, since approximately 53 % of the variation in chlorophyll-a concentrations appear to be explained by this particular variable (Table 4.9 B). In the Sundays estuary phosphate was the only parameter showing a significant relationship to chlorophyll-a concentrations (Table 4.9 C).

Table 4.9 A: Linear correlation/regression of Chlorophyll-a versus nutrients, salinity, freshwater inflow and turbidity for the Kromme and Geelhoutboom estuaries. S^{*}: $p<0.05$; S^{**}: $p<0.01$; S^{***}: $p<0.001$. $\alpha = 0.05$

Kromme	r	r^2	t	p	n	Significance
PO_4^{3-}	-0.35	0.12	-1.89	0.07	28	NS
NO_3^-	-0.35	0.12	-1.89	0.07	28	NS
NO_2^-	-0.21	0.04	-1.1	0.28	28	NS
NH_4^+	-0.33	0.11	-1.8	0.08	28	NS
TPN	0.7	0.49	4.99	< 0.001	28	S^{***}
Salinity	-0.45	0.2	-3.37	0	48	S^{**}
Freshwater inflow	-0.35	0.12	-1.88	0.07	28	NS
Turbidity	-0.09	0.01	-0.58	0.57	48	NS

Geelhoutboom	r	r^2	t	p	n	Significance
PO_4^{3-}	-0.44	0.19	-1.08	0.33	7	NS
NO_3^-	-0.49	0.24	-1.27	0.26	7	NS
NO_2^-	-0.42	0.18	-1.04	0.35	7	NS
NH_4^+	-0.42	0.18	-1.05	0.34	7	NS
TPN	0.21	0.04	0.48	0.65	7	NS
Salinity	-0.41	0..7	-1.44	0.18	12	NS
Freshwater inflow	-0.41	0.17	-0.99	0.37	7	NS
Turbidity	0.36	0.13	1.23	0.25	12	NS

Table 4.9 B: Linear correlation/regression of Chlorophyll-a versus nutrients, salinity, freshwater inflow and turbidity for the Swartkops estuary. S^*: $p<0.05$; S^{**}: $p<0.01$; S^{***}: $p<0.001$. $\alpha = 0.05$

	r	r^2	t	p	n	Significance
PO_4^{3-}	0.49	0.24	2.43	0.03	21	S^*
NO_3^-	-0.36	0.13	-1.67	0.11	21	NS
NO_2^-	-0.39	0.16	-1.87	0.08	21	NS
NH_4^+	-0.59	0.35	-3.19	0.01	21	S^{**}
TPN	0.1	0.01	0.43	0.67	21	NS
Salinity	-0.1	0.01	-0.42	0.68	21	NS
Freshwater inflow	-0.2	0.04	-0.9	0.38	21	NS
Turbidity	0.73	0.53	4.35	< 0.001	19	S^{***}

Table 4.9 C: Linear correlation/regression of Chlorophyll-a versus nutrients, salinity, freshwater inflow and turbidity in the entire Sundays estuary (Stations 1, 2, 3). S^*: $p<0.05$; S^{**}: $p<0.01$; S^{***}: $p<0.001$. $\alpha = 0.05$

	r	r^2	t	p	n	Significance
PO_4^{3-}	-0.49	0.25	-2.48	0.02	21	S^*
NO_3^-	-0.02	0	-0.08	0.94	21	NS
NO_2^-	-0.04	0	-0.15	0.88	21	NS
NH_4^+	-0.1	0.01	-0.46	0.65	21	NS
TPN	0.43	0.19	1.97	0.07	19	NS
Salinity	-0.12	0.02	-0.54	0.6	21	NS
Freshwater inflow	-0.19	0.04	-0.85	0.41	21	NS
Turbidity	-0.21	0.05	-0.94	0.36	21	NS

4.3.5 A comparison of the different reaches within the Kromme, Swartkops and Sundays systems:

Multiple comparison and multiple discriminant analysis were used in an attempt to elucidate differences between the various reaches of the estuaries under study. The parameters under investigation comprised phosphate, nitrate, nitrite, ammonia, TPN, chlorophyll-a and salinity. The reaches included in multiple comparisons were all estaurine plus the riverine section. In the case of chlorophyll-a, only the estaurine reaches were considered. The role of the respective river as a nutrient source to its estuary was one of the fe itures under consideration, therefore the inclusion of the riverine region. Freshwater phytoplankton populations on the other hand do not survive in estuarine waters, since osmotic stress induces mortality. Therefore it was concluded that no relationship exists between freshwater and estuarine/marine phytoplankton populations, and in consequence the riverine station was excluded from the analysis. The same reasoning is used for the elimination of the riverine section in the multiple discriminant analysis, which was a stepwise procedure and where chlorophyll-a was considered as a discriminating variable. Samples, which were taken in the Kromme estuary during the period from September 1994 to March 1995 (see 4.2 Materials and Methods) were not analysed for TPN. Since casewise deletion of data during the statistical analysis would have lead to a considerable loss of information, TPN was excluded from the discriminant analysis for the Kromme estuary. In multiple comparison, the riverine section of the Kromme estuary was excluded for TPN due to too small a sample size in this section.

In addition to nutrients and salinity, all estuarine stations were subjected to multiple comparison for chlorophyll-a, but no distinction between the different stations was apparent in any of the three estuaries (Table 4.10 A., B, C)

4.3.5.1 Kromme estuary:

Multiple comparison:

For the procedure of multiple comparison again two separate datasets (the first including data of both periods of occurrence and non-occurrence of freshwater inflow, and the second including measurements taken during periods of freshwater inflow into the estuary only) were included (similar to 4.3.2.2). Taking all 6 stations of the Kromme estuary (Fig. 2.2), none of them differed with regard to the dissolved inorganic nutrient concentrations as well as salinity (Table 4.10 A). TPN concentrations, on the other hand, were different in the mouth and lower reaches of the Kromme estuary from the Geelhoutboom. In this case data of both the occurrence and non-occurrence of freshwater inflow for the two estuaries were included. but none of the estuarine stations were different during periods of freshwater inflow only (Table 4.10 A). Regarding salinity, in the first scenario only the freshwater station was separated from the estuarine stations. whereas for the second dataset, which represents only periods of freshwater inflow, the upper reaches in addition had statistically significantly different (i.e. lower) salinities than the rest of the estuary (Table 4.10 A).

Table 4.10 A: Multiple comparison of all the reaches in the Kromme (S ation 1, 2, 4, 5) and Geelhoutboom (Station 3) estuaries as well as its headwaters (Station 6) to show eventual dissimilarities in terms of nutrient and chlorophyll-a concentrations as well as salinity. $\alpha = 0.05$

Measurements taken during periods of occurrence and non-occurrence of freshwater inflow:

	Anova			Newman-Keuls	
	F	p	n		p
PO_4^{3-}	0.41	0.84	66	St1 = St2 = St3 = St4 = St5 = St6	
$NO_3^{=}$	0.53	0.75	66	St1 = St2 = St3 = St4 = St5 = St6	
NO_2^{-}	0.38	0.86	59	St1 = St2 = St3 = St4 = St5 = St6	
NH_4^{+}	0.82	0.54	60	St1 = St2 = St3 = St4 = St5 = St6	
TPN	2.99	0.04	34	St1 = St2 = St4 = St5	
				St4,5 = St3	
				St3 ≠ St1	$p = 0.045$
				St3 ≠ St2	$p = 0.043$
Chl-a	1.14	0.35	60	St1 = St2 = St3 = St4 = St5	
Salinity	12.9	< 0.001	66	St1 = St2 = St3 = St4 = St5	
				St1, St2, St3, St4, St5 ≠ St6	$p < 0.001$

Multiple discriminant analysis:

The lower reaches of the Kromme estuary, which are represented by the averaged data of station 1 and 2, the middle and upper reaches, as well as the lower reaches of the Geelhoutboom were the four groups to be identified by the discriminant analysis. Salinity, nitrate, ammonia and chlorophyll-a were included in the stepwise analysis, although the difference between the group means (the groups being the different reaches of the estuary) were not statistically significant (Table 4.11 A). It must be taken into consideration that the p-values do give certain guidelines. However, if sample sizes are small, they should not be taken too seriously as a measure of significance, unless, of course, they are far from the proposed significance level (Hair et al., 1992). The discriminant functions failed to be significant for the Kromme estuary, distances between the reaches were minor and only the measurements of the lower reaches did score high in the percentage of right classification into its group (Table 4.11 A, Fig. 4.8). The first discriminant function, which differentiates the first group (the lower reaches of the estuary) from all the other groups (i.e. all the other reaches of the estuary), identified salinity as a main factor for the discrimination between the lower reaches and the rest of the estuary (Table 4.11 A). The next most important factor to differentiate between the upper reaches and the rest of the estuary was ammonia, and, lastly, the discriminating factor in the third discriminant function, which separated the middle reaches from the rest of the estuary, was chlorophyll-a (Table 4.11 A). However, these last considerations are of no great value and must be regarded as pure speculation, since p-values of none of the different steps in the analysis came near the 0.05 significance level, and the distance between the groups was of no statistical significance (Table 4.11 A. Fig. 4.8).

4.3.5.2 Swartkops estuary:

Multiple comparison:

After applying multiple comparison, phosphate concentrations and salinity were the two parameters which pointed to a distinction between the different reaches in the Swartkops estuary as well as its headwaters (Table 4.10 B). Phosphate concentrations in the riverine and upper section of the Swartkops showed dissimilarities from the middle and lower reaches. Although phosphate concentrations do show a steady increase from mouth to head in the Swartkops estuary (Table 4.3, Fig. 4.3), the difference between the lower and middle reaches on the one hand and between the middle and upper reaches on the other hand was not statistically significant (Table 4.10 B). Comparatively high phosphate concentrations in the river might be responsible for this outcome. Regarding salinity measurements, a distinction was made between all stations, except the middle and upper reaches were considered to be alike (Table 4.10 B). The actual mean longitudinal salinity gradient was steadily decreasing towards the upper reaches (Table 4.3).

Table 4.10 B: Multiple comparison of 4 reaches in the Swartkops estuary (Stations 1, 2, 3) and river (Station 4) to show eventual dissimilarities in terms of nutrient and chlorophyll-a concentrations as well as salinity. $\alpha = 0.05$

	Anova			Newman-Keuls	
	F	p	n		p
PO_4^{3-}	9.24	0	28	St1 = St2	
				St1 ≠ St3	p = 0.031
				St1 ≠ St4	p < 0.001
				St2 ≠ St4	p = 0.004
				St2 = St3	
				St3 ≠ St4	p = 0.026
NO_3^-	0.22	0.8	28	St1 = St2 = St3 = St4	
NO_2^-	0.46	0.64	28	St1 = St2 = St3 = St4	
NH_4^+	0.13	0.88	28	St1 = St2 = St3 = St4	
PON	0.14	0.94	26	St1 = St2 = St3 = St4	
Chl-a	2.03	0.16	28	St1 = St2 = St3	
Salinity	31.45	< 0.001	28	St1 ≠ St2	p = 0.004
				St1 ≠ St3	p < 0.001
				St1 ≠ St4	p < 0.001
				St2 ≠ St4	
				St3 ≠ St4	p < 0.001
				St2 = St3	

Mul iple discriminant analysis:

Those variables included in the stepwise discriminant analysis for the Swartkops estuary were closer to the proposed 0.05 significance level with regard to the Kromme estuary (Table 4.11 B). Phosphate, salinity and nitrite were included as discriminating factors, although only in the case of phosphate were differences between the reaches in the estuary statistically significant. The first discriminant function, distinguishing between the lower vs. the middle and upper reaches, was highly significant ($p < 0.001$) and accounted for approximately 87 % (= square canonical R) of the variance in the reaches of the estuary (Table 4.11 B). The hit ratio or percent data correctly classified to the different groups was overall 90.5 %, where the lower reaches seemed to be the best defined group (Table 4.11

B, Fig. 4.8). Phosphate was the best discriminating factor between the reaches of the estuary, followed by salinity (Table 4.11 B).

4.3.5.3 Sundays estuary:

Multiple comparison:

Multiple comparison detected differences for nitrate between the estuarine reaches and the headwaters of the Sundays estuary. Although nitrate concentrations varied between the estuarine reaches, there differences seem small (312 $\mu g \cdot l^{-1}$ in the lower to 472 $\mu g \cdot l^{-1}$ in its upper reaches) when compared to concentrations in the riverine section (934.7 $\mu g \cdot l^{-1}$) (Table 4.4). For the remaining nutrients no distinction was made between the various regions. Regarding salinity, differences were pointed out between all regions (Table 4.10 C).

Table 4.10 C: Multiple comparison of 4 reaches in the Sundays estuary (Stations 1, 2, 3) and river (Station 4) to show eventual dissimilarities in terms of nutrient and chlorophyll-a concentrations as well as salinity. $\alpha = 0.05$

	Anova			Newman-Keuls	
	F	p	n		p
PO_4^{3+}	0.7	0.56	28	St1 = St2 = St3 = St4	
$NO_3^{=}$	4.6	0.01	28	St1 = St2 = St3	
				St1 ≠ St4	p = 0.012
				St2 ≠ St4	p = 0.018
				St3 ≠ St4	p = 0.027
NO_2^-	1.28	0.31	28	St1 = St2 = St3 = St4	
NH_4	0.95	0.44	28	St1 = St2 = St3 = St4	
PON	0.96	0.43	28	St1 = St2 = St3 = St4	
Chl-a	3.26	0.06	28	St1 = St2 = St3	
Salinity	24.13	< 0.001	28	St1 ≠ St2	p = 0.028
				St1 ≠ St3	p < 0.001
				St1 ≠ St4	p < 0.001
				St2 ≠ St3	p = 0.013
				St2 ≠ St4	p < 0.001
				St3 ≠ St4	p = 0.006

Multiple discriminant analysis:

Five variables were considered for the stepwise multiple discriminant analysis for the Sundays estuary, namely salinity, chlorophyll-a, nitrite, TPN and nitrate (Table 4.11 C). The first discriminant function, separating the lower from the middle and upper reaches, was highly significant ($p < 0.001$) and explains 85 % of the variation in the different reaches of the estuary. A hit ratio of 90.5 % was concordant with that for the Swartkops estuary, and similarly, the lower reaches were the most isolated (Table 4.11 C, Fig. 4.8). The most powerful discriminating factors between the different reaches of the Sundays estuary were salinity and chlorophyll-a (Table 4.11 C).

Table 4.11 A: Discriminant analysis results of the different reaches in the Kromme estuary.

Summary of stepwise analysis:

Variable	Step	F to enter	p-level	No. of vars. in analysis	Lambda	F	p-level
Salinity	1	1.07	0.37	1	0.92	1.07	0.37
NO_3	2	1.99	0.13	2	0.8	1.51	0.19
NH_4	3	1.5	0.23	3	0.71	1.5	0.16
Chl-a	4	1.27	0.3	4	0.64	1.44	0.16

Canonical discriminant function:

Discriminant functions removed	Eigenvalue	Canonical R	Wilks' Lambda	Chi-square	DF	p-level
0	0.26	0.46	0.64	16.73	12	0.16
1	0.19	0.4	0.81	7.85	6	0.15
2	0.03	0.18	0.97	1.19	2	0.55

Means of canonical variables (= group centroids):

Group	1st discriminat function	2nd discriminat function	3rd discriminant function
lower	-0.82	-0.12	0.02
Geelhoutboom	0.21	0.57	0.16
middle	0.23	0.1	-0.28
upper	0.44	-0.61	0.11

Classification matrix:

Group	percent correct	lower	Geelhoutboom	middle	upper
lower	72.73	8	2	0	1
Geelhoutboom	18.18	3	2	3	3
middle	27.27	4	1	3	3
upper	45.46	3	0	3	5
Total	40.91	18	5	9	12

Proportional chance criterion: 25%

Discriminant loadings:

	1st discriminat function	2nd discriminat function	3rd discriminant function	Potency Index
Salinity	-0.54	0.11	-0.38	0.17
NO_3	0.1	0.31	0.6	0.05
NH_4	0.15	0.57	0.35	0.25
Chl-a	0.36	0.25	-0.89	0.15

Table 4.11 B: Discriminant analysis results of the different reaches in the Swartkops estuary.

Summary of stepwise analysis:

Variable	Step	F to enter	p-level	No. of vars. in analysis	Lambda	F	p-level
PO_4	1	24.75	<0.001	1	0.26	24.75	<0.001
Salinity	2	3.06	0.08	2	0.19	10.61	<0.001
NO_2	3	2.74	0.1	3	0.14	8.59	<0.001

Canonical discriminant function:

Discriminant functions removed	Eigenvalue	Canonical R	Wilks' Lambda	Chi-square	DF	p-level
0	5.97	0.93	0.14	32	6	<0.001
1	0.06	0.24	0.94	0.93	2	0.63

Means of canonical variables (= group centroids):

Group	1st discriminat function	2nd discriminat function
lower	-2.72	-0.14
middle	0.26	0.31
upper	2.87	-1.91

Classification matrix:

Group	percent correct	lower	middle	upper
lower	100	7	0	0
middle	85.7	0	6	1
upper	85 7	0	1	6
Total	90.5	7	7	7

Proportional chance criterion: 32.7%

Discriminant loadings:

Group	1st discriminat function	2nd discriminat function	Potency Index
PO_4	0.7	-0.15	0.48
Salinity	-0.42	-0.84	0.19
NO_2	-0.1	0.62	0.01

Table 4.11 C: Discriminant analysis results of the different reaches in the Sundays estuary.

Summary of stepwise analysis:

Variable	Step	F to enter	p-level	No. of vars. in analysis	Lambda	F	p-level
Salinity	1	9.52	0	1	0.49	9.52	0
Chl-a	2	4.95	0.02	2	0.31	6.84	<0.001
NO_2	3	4.82	0.02	3	0.19	6.85	<0.001
Total N	4	1.16	0.34	4	0.17	5.46	<0.001
NO_3	5	1.35	0.29	5	0.14	4.71	<0.001

Canonical discriminant function:

Discriminant functions removed	Eigenvalue	Canonical R	Wilks' Lambda	Chi-square	DF	p-level
0	5.66	0.92	0.14	31.56	10	<0.001
1	0.08	0.27	0.93	1.22	4	0.88

Means of canonical variable (= group centroids):

Group	1st discriminat function	2nd discriminat function
lower	2.84	0.15
middle	-0.32	-0.37
upper	-2.52	0.22

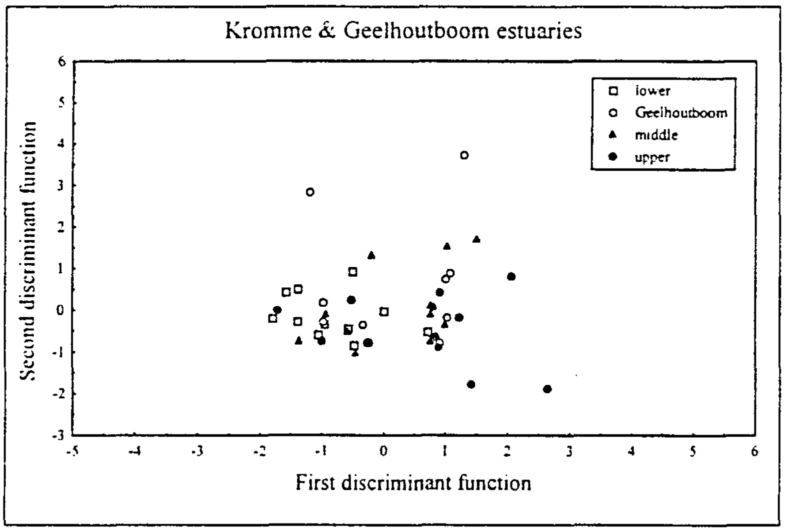
Classification matrix:

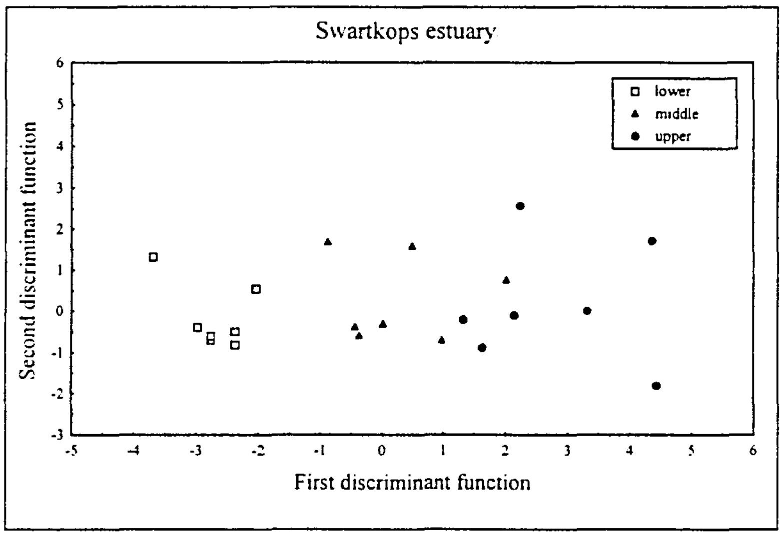
Group	percent correct	lower	middle	upper
lower	100	7	0	0
middle	100	0	7	0
upper	71.4	0	2	5
Total	90.5	7	9	5

Proportional chance criterion: 32.7%

Discriminant loadings:

Group	1st discriminat function	2nd discriminat function	Potency Index
Salinity	0.43	-0.53	0.19
Chl-a	-0.23	-0.97	0.06
No_2	-0.13	0.21	0.02
Total N	-0.17	-0.38	0.03
NO_3	-0.16	0.25	0.02





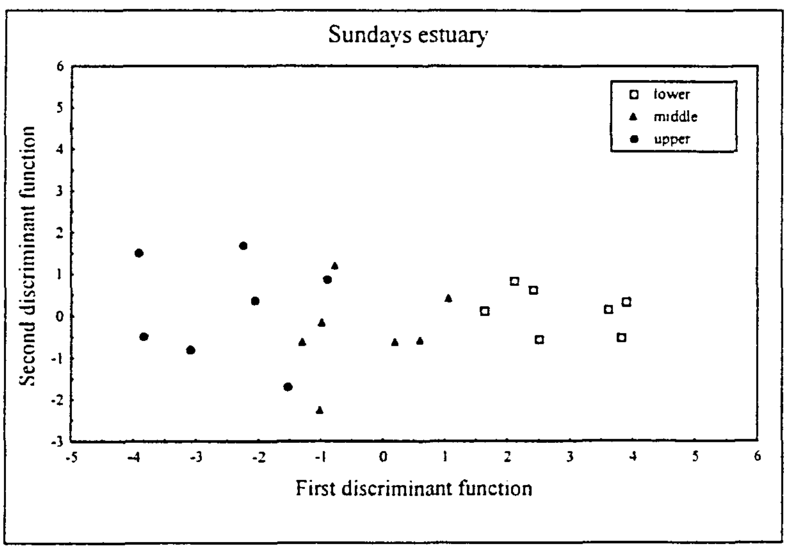


Fig. 4.8: Scatterplots of canonical scores derived for the different reaches in the Kromme, Swartkops and Sundays estuaries by multiple discriminant analysis (see 4.3.5).

The results derived from the two statistical procedures applied, i.e. multiple comparison and multiple discriminant analysis, gave similar, although not perfectly matching results for the three estuaries investigated. Both the statistical procedures were essentially used for the same objective, namely describing the ability of certain parameters to identify different regions of the estuary. Differences in the TPN concentrations between the Geelhoutboom and the Kromme estuary were not detected by the discriminant analysis, but by multiple comparison. Reaches of the Swartkops estuary were different in their phosphate concentrations as well as in salinity in the multiple comparison procedure, and although salinity was included as a discriminant factor, only phosphate reached the desired significance level of $p < 0.05$ in n ultiple discriminant analysis. Regarding the Sundays estuary, chlorophyll-a and nitrite were the two parameters included in addition to salinity in the discriminant analysis (Table 4.10 A, B, C; Table 4.11 A, B, C).

4.3.6 A comparison of the different reaches between the Kromme, Swartkops and Sundays systems:

Possible differences between the Kromme, Swartkops and Sundays estuaries were examined by subjecting their lower, middle and upper reaches as well as their riverine sections respectively to discriminant analysis.

4.3.6.1 Lower reaches:

Regarding their lower reaches, only the first discriminant function, which distinguished the Sundays from. the Kromme and Swartkops estuary, was statistically significant ($p < 0.001$) (Table 4.12 A). The overall percentage of data correctly classified into their groups (i.e. to the Kromme, Swartkops or Sundays estuarine lower reaches) was approximately 73 %, where the lower reaches of the Kromme estuary had the highest hit ratio of ca. 83 % (Table 4.12 A). Phosphate, nitrate and salinity were the parameters separating the lower reaches of the three estuaries to some degree, although the distances between them were considerably small (Table 4.12 A; Fig. 4.9).

4.3.6.2 Middle reaches:

Phosphate, chlorophyll-a, as well as nitrate and salinity, were considered by the stepwise analysis to discriminate between the middle reaches of the Kromme, Swartkops and Sundays estuaries (Table 4.12 B). Both discriminant functions were statistically significant ($p < 0.01$), explaining 69 and 45 % respectively of the variance in the middle reaches, with the first function separating the Sundays from the Kromme and Swartkops estuaries and the second the Kromme from the remaining two estuaries (Table 4.12 B). Approximately 92 % of the data were correctly classified into their groups. The variables with the greatest discriminating power were, in order of importance, phosphate, chlorophyll-a, nitrate and salinity for the first function and phosphate. salinity, nitrate and chlorophyll-a for the second function (Table 4.12 B).

4.3.6.3 The upper reaches:

In the upper reaches of the estuaries, the dissimilarities between the three systems become even more apparent (Table 4.12 C, Fig. 4.9). In addition to the parameters included in the previous analysis (viz. phosphate, nitrate, salinity and chlorophyll-a), nitrite was additionally considered as an important discriminating factor. Both discriminant functions were highly signi icant ($p < 0.001$). The first function separated the Sundays from the Kromme and Swartkops estuaries, whereas the second function isolated the Kromme estuary. Both discriminant functions accounted for a big proportion of the variance of the dissimilarities (Table 4.12 C). The hit ratio was the highest up to this point with 96 % of the data correctly classified. Phosphate measurements differed to the greatest extent between the Sundays and the Kromme and Swartkops estuaries (the first discriminant function), followed by nitrate, chlorophyll-a, salinity and nitrite (Table 4.12 C). In identifying the Kromme as being different from the Swartkops and Sundays estuaries (second discriminant function), it was again phosphate to play the biggest role, whereas salinity, nitrate, chlorophyll-a and nitrite were of lesser importance (Table 4.12 C).

4.3.6.4 The estuarine headwaters:

In the analysis of the riverine section of the three estuaries both discriminant functions were statistically significant and their discerning power was similar to the discriminant functions characterising the middle reaches of the estuary. A hit ratio of 79 % was comparatively low, the Kromme scoring the least at 60 % whereas all data of the Sundays river were correctly classified. As in the previous analyses, the first discriminant function separated the Sundays from the Kromme and Swartkops estuaries and the second the Kromme from the Sundays and Swartkops estuaries. The main discriminating factor for both functions was phosphate which was closely followed by nitrate, whereas nitrite and ammonia played minor roles in the characterisation of the three riverine sections (Table 4.12 D).

Summarising the results obtained from discriminant function analysis for the Kromme, Swartkops and Sundays estuaries, it is apparent that a clear distinction was made among the three estuaries. Since the first discriminant function always singled out the Sundays estuary, it can be considered as

Table 4.12 A: Discriminant analysis results of the lower reaches of the Kromme, Swartkops and Sundays estuaries.

Summary of stepwise analysis:

Variable	Step	F to enter	p-level	No. of vars. in analysis	Lambda	F	p-level
Salinity	1	1.91	0.17	1	0.85	1.91	0.17
PO_4	2	7.92	0	2	0.49	4.57	0
NO_3	3	2.24	0.13	3	0.4	3.92	0

Canonical discriminant function:

Discriminant functions removed	Eigenvalue	Canonical R	Wilks' Lambda	Chi-square	DF	p-level
0	1.34	0.76	0.4	19.41	6	0
1	0.08	0.27	0.93	1.58	2	0.45

Means of canonical variables (= Group centroids)

Group	1st discriminat function	2nd discriminat function
Kromme	-0.22	0.29
Swartkops	-1.26	-0.29
Sundays	1.6	-0.17

Classification matrix:

Classification matrix: Group	percent correct	Kromme	Swartkops	Sundays
Kromme	83.3	10	1	1
Swartkops	71.4	2	5	0
Sundays	57.1	3	0	4
Total	73.1	15	6	5

Proportional chance criterion: 35.7 %

Discriminant loadings:

Group	1st discriminat function	2nd discriminat function	Potency Index
Salinity	-0.36	-0.11	0.12
PO_4	-0.18	-0.18	0.03
NO_3	0.22	-0.84	0.04

Table 4.12 B: Discriminant analysis results of the middle reaches of the Kromme, Swartkops and Sundays estuaries.

Summary of stepwise analysis:

Variable	Step	F to enter	p-level	No. of vars. in analysis	Lambda	F	p-level
PO_4	1	13.53	<0.001	1	0.45	13.53	<0.001
Chl-a	2	6.26	0.01	2	0.28	9.31	<0.001
NO_3	3	4.42	0.03	3	0.2	8.44	<0.001
Salinity	4	1.33	0.29	4	0.17	6.74	<0.001

Canonical discriminant function:

Discriminant functions removed	Eigenvalue	Canonical R	Wilks' Lambda	Chi-square	DF	p-level
0	2.22	0.83	0.17	36.21	8	<0.001
1	0.82	0.67	0.55	12.26	3	0.01

Means of canonical variables (= Group centroids):

Group	1st discriminat function	2nd discriminat function
Kromme	0.28	0.94
Swartkops	1.62	-0.94
Sundays	-2.06	-0.54

Classification matrix:

Group	percent correct	Kromme	Swartkops	Sundays
Kromme	91.7	11	1	0
Swartkops	85.7	1	6	0
Sundays	100	0	0	7
Total	92.3	12	7	7

Proportional chance criterion: 35.7%

Discriminant loadings:

Group	1st discriminat function	2nd discriminat function	Potency Index
PO_4	0.57	-0.8	0.41
Chl-a	-0.54	-0.32	0.24
NO_3	-0.26	-0.4	0.09
Salinity	0.16	0.49	0.08

Table 4.12 C: Discriminant analysis results of the upper reaches of the Kromme, Swartkops and Sundays estuaries.

Summary of stepwise analysis:

Variable	Step	F to enter	p-level	No. of vars. in analysis	Lambda	F	p-level
PO_4	1	26.66	<0.001	1	0.28	26.66	<0.001
NO_3	2	16.1	<0.001	2	0.11	20.39	<0.001
Salinity	3	4.95	0.02	3	0.07	17.4	<0.001
Chl-a	4	5.12	0.02	4	0.05	16.62	<0.001
No_2	5	1.01	0.39	5	0.04	13.48	<0.001

Canonical discriminant function:

Discriminant functions removed	Eigenvalue	Canonical R	Wilks' Lambda	Chi-square	DF	p-level
0	7.35	0.94	0.04	60.89	10	<0.001
1	1.95	0.81	0.34	20.58	4	<0.001

Means of canonical variables (= Group centroids):

Group	1st discriminat function	2nd discriminat function
Kromme	0.34	-1.54
Swartkops	3.06	1.29
Sundays	-3.54	0.9

Classification matrix:

Group	percent correct	Kromme	Swartkops	Sundays
Kromme	90	9	1	0
Swartkops	100	0	7	0
Sundays	100	0	0	7
Total	95.8	9	8	7

Proportional chance criterion: 34.5%

Discriminant loadings:

Group	1st discriminat function	2nd discriminat function	Potency Index
PO_4	0.45	0.73	0.27
NO_3	-0.26	0.37	0.04
Salinity	0.1	-0.44	0.05
Chl-a	-0.24	0.31	0.07
NO_2	-0.09	-0.03	0.01

Table 4.12 D: Discriminant analysis results of the riverine section of the Kromme, Swartkops and Sundays.

Summary of stepwise analysis:

Variable	Step	Canonical R	p-level	No. of vars. in analysis	Lambda	F	p-level
PO_4	1	12.97	<0.001	1	0.38	12.97	<0.001
NO_3	2	5.2	0.02	2	0.23	8.3	<0.001
No_2	3	1.63	0.23	3	0.18	6.25	<0.001
NH_4	4	1.82	0.2	4	0.14	5.35	<0.001

Canonical discriminant function:

Discriminant functions removed	Eigenvalue	Canonical R	Wilks' Lambda	Chi-square	DF	p-level
0	2.69	0.85	0.14	28.22	8	<0.001
1	0.9	0.69	0.53	9.29	3	0.03

Means of canonical variables (= Group centroids):

Group	1st discriminat function	2nd discriminat function
Kromme	0.14	-1.45
Swartkops	1.7	0.57
Sundays	-1.8	0.47

Classification matrix:

Group	percent correct	Kromme	Swartkops	Sundays
Kromme	60	3	0	2
Swartkops	71.4	2	5	0
Sundays	100	0	0	7
Total	79	5	5	9

Proportional chance criterion: 34.1%

Discriminant loadings:

Group	1st discriminat function	2nd discriminat function	Potency Index
PO_4	0.67	0.68	0.45
NO_3	-0.42	0.46	0.18
NO_2	0.05	-0.44	0.05
NH_4	0.09	-0.28	0.03

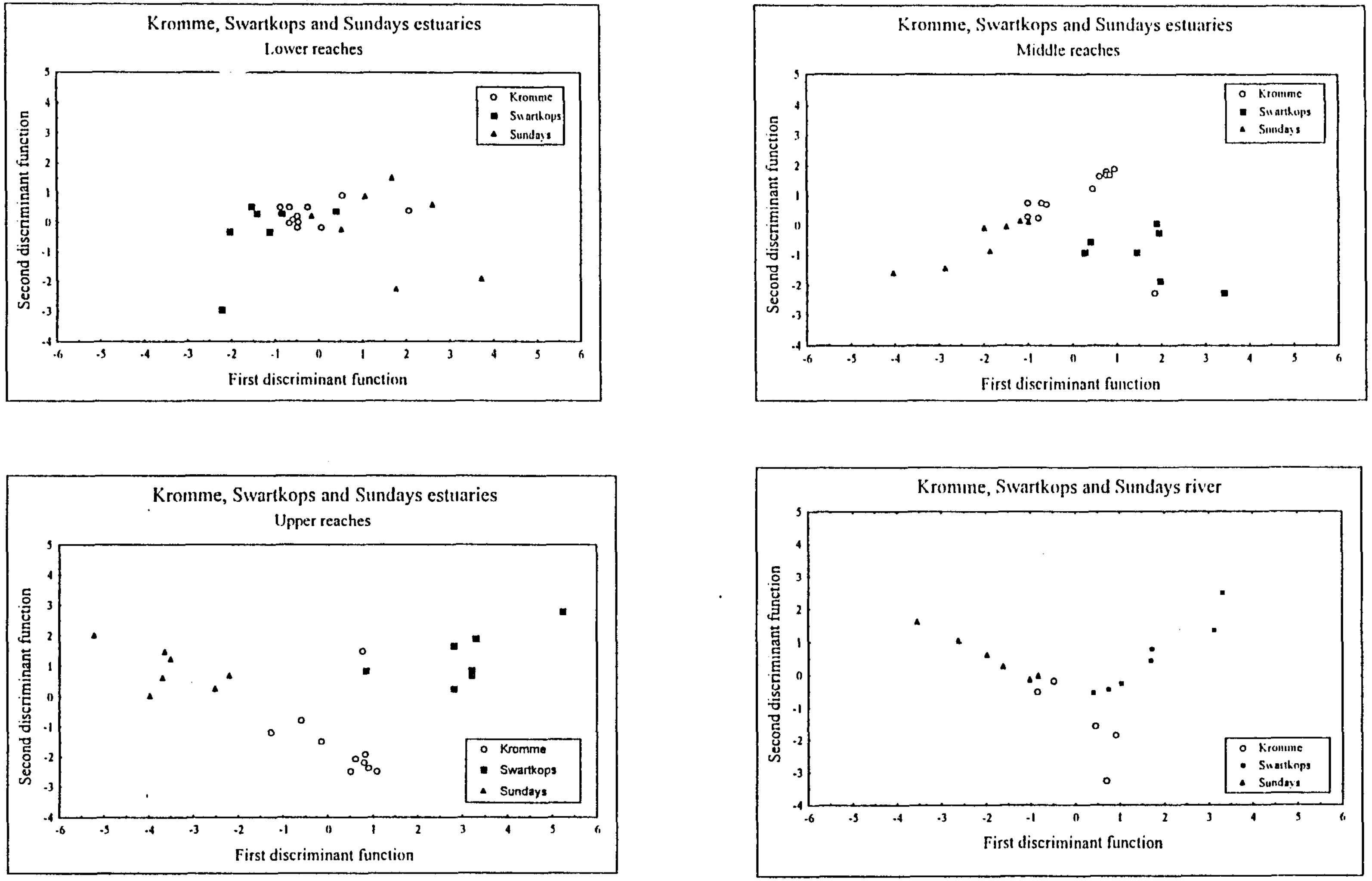


Fig. 4.9: Scatterplots of canonical scores for the lower, middle, upper and riverine sections of the Kromme, Swartkops and Sundays estuaries by multiple discriminant analysis (see 4.3.6).

the system with the most distinctive features. The Kromme estuary was generally separated from the Swartkops and Sundays estuaries by the second function, with the exception of the lower reaches, and is therefore regarded to be the second most distinct system. The Swartkops estuary on the other hand fills an intermediate position between the Sundays and Kromme estuary, since it was never singled out by any of the discriminant functions. As for the variables which were responsible for the distinction between the three estuaries, phosphate and nitrate as well as salinity and chlorophyll-a were found to be discriminating parameters. Phosphate was the variable with the most extensive discriminating power overall in all estuarine regions as well as the riverine section for either of the discriminant functions. In the case of the separation of the Sundays estuary in various reaches, the next important discriminating factor after phosphate was nitrate, except in the middle reaches, where high chlorophyll-a values in the Sundays estuary overruled the differences in nitrate concentrations between the three systems. In the Kromme estuary on the other hand, the high salinity in its middle and upper reaches was the distinguishing factor, whereas nitrate was for the riverine section, since its concentration was the lowest in all three systems. The differences between the three estuaries increased from the lower towards their upper reaches, although this trend was not true for their headwaters.

4.4 DISCUSSION

Freshwater inflow into an estuary at its tidal head or via tributaries is, as stated before, often the most important nutrient source for an estuary (Duedall et al., 1977; Smith, 1977; Naiman and Sibert, 1978; Joint and Pomroy, 1981; Flint, 1985; Litaker, 1987; Lukatelich et al., 1987; Horrigan et al., 1990; Mallin et el., 1991; Harding, 1994; Allanson and Read, 1995). In the case where freshwater inflow rates are very low or non-existent, the contribution from oceanic waters would gain in significance regarding external nutrient input into the system. Since nutrient concentrations in seawater are usually lower than measurements in rivers, estuaries with low or no freshwater input are in general nutrient deprived in comparison to systems experiencing a higher and regular freshwater supply. This general concept has essentially been proved in all three estuaries investigated in this study, although some nutrients seem to be generated within the estuary rather than supplied by external sources. The proportional contribution of the ocean to the respective systems could not be verified, since at the time of sampling (at spring low tides), seawater is displaced towards and beyond the mouth of the estuary to its biggest possible extent. In addition, stratification is the least pronounced at that particular state of the tide, and the potential presence of a well identified saltwedge (and its nutrient content) was consequently not subject to investigation.

4.4.1 Abiotic parameters:

The salinity and temperature regime of the Kromme, Swartkops and Sundays estuaries is presented in detail in Chapter 3 of this thesis. Summarised briefly, due to a fairly low and irregular freshwater supply the Kromme estuary exhibited the highest salinities and the smallest salinity gradient along its longitudinal axis. Under drought conditions the estuary has been considered frequently as becoming a 'mere arm of the sea', but frequent rains leading to spillovers at the Impofu dam supplied some freshwater to the estuary during the study period. Lowest salinities of the three estuaries were measured in the Sundays estuary, as a consequence of the regular freshwater discharge from its river, whereas an intermediate position is attributed to the Swartkops stuary in terms of both freshwater inflow and salinity. A feature of both the Sundays and Swartkops estuaries is high discharge by floods on a fairly regular basis, but the two rivers differ in their flow under non-flood conditions. In the Swartkops estuary seawater salinities have been measured in the upper reaches, and even the occurrence of hypersalinities reported on occasion (see chapter 3).

The temperatures on the contrary were concordant in the three estuaries, regarding both estuarine mean values and longitudinal gradients. The only two measurements from the Kromme river indicated slightly cooler temperatures than both the Swartkops or Sundays rivers.

In the Kromme estuary, pH values, oxygen content and saturation obtained during the present study were well within previously reported ranges, as were longitudinal and the absence of vertical gradients (Baird *et al.*, 1981; Emmerson and Erasmus, 1987; Hanekom and Baird, 1988; Cloete 1990; Baird and Pereyra-Lago, 1992). Due to repeatedly similar results derived from several studies, the assumption that the Kromme estuary is a well mixed water body is supported.

Neither longitudinal nor vertical gradients for oxygen or pH were pronounced in the well-mixed Swartkops estuary (this study; McLachlan, 1972; Emmerson, 1985). During summer the estuarine waters were slightly less oxygenated. Similarly, Emmerson (1985) reported lower s mmer readings, which were inversely related to temperature. Oxygen concentrations equivalent to this study are reported by Emmerson (1985) and McCallum (1974), whereas slightly lower concentrations as well as saturation by Hilmer (1984). Oxygen depletion in bottom waters is of rare occurrence.

Contrary to the well mixed Kromme and Swartkops estuaries, the Sundays estuary is stratified in its oxygen concentrations and saturation. Deoxygenation in bottom waters of the middle reaches is aided by deep scour holes capable of trapping water. Similar oxygen concentrations (around 7.7 $mg \cdot l^{-1}$) with a lack of a longitudinal gradient were reported by Emmerson (1989). Other recordings from the

Sundays estuary were around 9.4 $mg \cdot l^{-1}$ at 99 % saturation for the lower reaches (Scharler, 1992), slightly higher values compared to those of the present study. Unlike for oxygen, no gradients were apparent for pH, except a negative vertical gradient in the middle reaches on two sampling occasions in summer. The same pH values were recorded by Emmerson (1989), although a slight positive gradient towards the mouth was apparent, which was more prominent during summer.

The decrease in turbidity towards the head of the Kromme estuary observed during this study has also been reported previously (Hecht, 1973; Marais, 1984; Cloete, 1990,). Transparency in the Kromme and Geelhoutboom estuaries can change rapidly due to freshwater inflow follow ng heavy rains. Especially the latter carries high silt loads during freshets.

In the Swartkops estuary, both increases (this study; Marais, 1984) and decreases (McLachlan and Grindley, 1974; Daniel, 1994) in turbidity towards the upper reaches have been recorded, where the highest turbidity was often measured in its middle reaches. Polluted water from the Motherwell and /or Markman canal near Brickfields might have an influence near their confluences with the Swartkops estuary.

Unlike the Kromme and Swartkops estuary, turbidity in the Sundays estuary decreases towards the mouth of the estuary where measurements in the middle and upper reaches are similar (this study; Marais, 1984; Daniel, 1994). No relationship between turbidity and the amount of freshwater discharging into the estuary was apparent from this study, but high Secchi disk readings coincided with extremely low chlorophyll-a readings (near zero). The longitudinal gradients were greater compared to those measured in either the Kromme or Swartkops estuary, suggesting that high phytoplankton abundance might be a cause of increased turbidity in the middle and upper reaches of the Sundays estuary.

4.4.2 Nutrients:

4.4.2.1 Kromme estuary:

Phosphate:

The Kromme river was a viable source of phosphate to its estuary in the case of high rates of freshwater discharge. In June 1993 freshwater inflow on the day of sampling reached 8.75 $m^3 \cdot sec^{-1}$ which led to an elevation of phosphate concentrations in the estuary by an order of magnitude. During other occurrences of freshwater inflow, ranging from 0.1 to 1.7 $m^3 \cdot sec^{-1}$, the generally low concentrations throughout the estuary were approximately doubled, achieved through an addition of only 5 to 10 $\mu g \cdot l^{-1}$.

Judging from the lack of a longitudinal phosphate gradient, no net uptake along the length of the estuary was evident. Regeneration might take place in various parts of the estuary to compensate for eventual uptake and there is the possibility that the Geelhoutboom supplies phosphate to the middle and lower reaches of the Kromme estuary during spring low tides. An elevation of phosphate concentrations in the Geelhoutboom was evident only after heavy rains, therefore its role as a phosphate supplier to the Kromme estuary is doubtful under low flow conditions. The saltmarshes in the lower reaches, which were inundated during the spring high tide preceding the time of sampling, could be a further source of phosphate. The marshes might be responsible for the positive gradient towards the mouth at times freshwater inflow at the tidal head was absent. The Marina, situated near the mouth of the estuary, might contribute phosphate to this region on occasion. A study by Hilmer (unpub. data) conducted in 1990 reported higher phosphate concentrations in the Marina compared to the mouth region. However, data collected by Baird and Pereyra-Lago (1992) during 1989/90 indicate no differences between those two regions. The sediment as a major source for phosphate can probably be ruled out, since flow velocities during non-flood conditions are presumably too small to resuspend sediments and trigger nutrient release.

Vertical profiles did not reveal any in- or decrease towards the bottom (Fig. 4.5), again emphasising the well mixed status of the estuary. Overall lower concentrations were measured during the present study compared to previously conducted studies. Nevertheless, the homogenous distribution of phosphate in the Kromme system as well as the slight positive gradients towards the mouth and/or higher values in the middle reaches were common findings (this study; Hilmer, unpub. data; Emmerson and Erasmus, 1987; Baird and Pereyra-Lago, 1992). Values calculated from Hilmer (unpub. data) were about twice as high for the entire estuary, but similar at the tidal head. Emmerson and Erasmus (1987) reported co: centrations 5 to 10 fold higher for the period 1979 - 1981, before the completion of the Impofu dam when a longitudinal salinity gradient was always present. Similarly, higher concentrations are presented in Watling (1982). Measurements from the mouth region in Baird and Pereyra-Lago (1992) were 4 to 14 fold higher with a peak value of 1 $mg \cdot l^{-1}$.

Nitrate:

Nitrate concentrations vary, as in the case of phosphate, with the occurrence and non-occurrence of freshwater inflow. Negative gradients towards the head of the estuary during dry periods were turned to positive when freshwater discharged at the head of the estuary. In addition, concentrations were elevated. As in the case of phosphate, concentrations were high during the freshet in June 1993, approximately double to triple compared to other occasions of freshwater inflow. The negative gradient towards the tidal head during the absence of freshwater inflow might have been created by a nitrate supply stemming from either the saltmarshes in the lower reaches or the Marina situated near the mouth. Baird and Pereyra-Lago (1992) report higher nitrate concentrations in the Marina canals compared to the mouth region of the estuary, whereas values by Hilmer (unpub. data) did not show any differences. The Geelhoutboom did not seem to influence the waters of the Kromme estuary, since concentrations in the Kromme above and below their confluence were similar in most cases.

Nitrate concentrations obtained during this study were approximately 7-fold higher compared to values by Hilmer (unpub. data). Data by Emmerson and Erasmus (1987) and Watling (1982) similarly show overall lower values. Mean concentrations were higher in the Geelhoutboom compared to those of the middle reaches of the Kromme estuary (this study; Emmerson and Erasmus 1987; Watling 1982). The upper reaches did display the most pronounced sink behaviour during periods of freshwater inflow, whereas from the middle reaches towards the mouth no change in concentrations was apparent.

Vertical gradients were not measured on most sampling occasions (Fig. 4.5). The negative gradient in the upper reaches is probably due to nitrate rich freshwater being buoyant and lying above saline water. In the Geelhoutboom the coincidence of a negative vertical nitrate gradient with a positive vertical salinity gradient points to freshwater as the major source.

Nitrite:

The overall low nitrite concentrations in the Kromme and Geelhoutboom estuaries were elevated only during March 1995, and then by an order of magnitude. Otherwise no variation in the concentrations was apparent from other occasions of freshwater inflow. During the June 1993 freshet nitrite concentrations in the Geelhoutboom were higher (ca 8-fold than in the Kromme estuary. The freshwater discharging into the estuary was only slightly richer in nitrite than at the tidal head. Mean values were marginally higher as recorded by Emmerson and Erasmus (1987) and Hilmer (unpub. data) for the entire estuary and by Baird and Pereyra-Lago (1992) for the mouth region of the estuary, but considerably lower compared to data given in Watling (1982).

Ammonia:

As in the case of phosphate and nitrate, ammonia concentrations were highest in the mouth region during times no freshwater was discharging at the tidal head of the Kromme estuary. During periods of freshwater inflow the negative gradient towards the tidal head was levelled out and highest concentrations were measured just upstream of the confluence of the Kromme with the Geelhoutboom estuary, as well as at the tidal head. Concentrations were high in the Geelhoutboom during periods of freshwater inflow and could have contributed to the elevation of the concentrations in the middle reaches through tidal dispersion. The reaches downstream, on the other hand, were neither affected by the Geelhoutboom estuary nor by freshwater input at the tidal head of the Kromme estuary. During dry periods especially, the saltmarshes in the lower reaches as well as the Marina could be important sources for ammonia. Unpub. data by Hilmer reveal higher concentrations in the Marina on few sampling occasi·ıns. No definite trends are reported by Baird and Pereyra-Lago (1992), but measurements were low ($< 10\ \mu g \cdot l^{-1}$).

During periods of freshwater inflow a net uptake of ammonia is apparent towards the lower reaches of the estuary. The biggest differences in concentrations were found to be between the inflowing freshwater and the tidal head. Most of the ammonia therefore seems to be taken up in this region, whereas regeneration and possible supplements from the Geelhoutboom might be sources for ammonia further downstream. Vertical gradients were not prevalent in the Kromme estuary, although negative gradients towards the bottom were present in the Geelhoutboom estuary (Fig. 4.5).

During the present study ammonia concentrations were high compared to Watling (1982) as well as to Emmerson and Erasmus (1987), who reported a mean of only $3.4\ \mu g \cdot l^{-1}$. Measurements by Hilmer (unpub. data) were 3 to 4 times lower compared to this study.

Total particulate nitrogen:

Similar to ammonia, TPN concentrations in the lower and mouth reaches were unaffected by freshwater inflow at the tidal head, whereas concentrations in the upper and middle reaches were elevated. In the upper reaches flocculation might have taken place induced by the mixing of freshwater and estuarine water. Since concentrations were lower in the Geelhoutboom during those periods, particulate material might have been swept into the Kromme estuary and so contributed to TPN elevations in the middle reaches. Vertical gradients showed no definite trends.

4.4.2.2 Swartkops:

Main sources of nutrients for the Swartkops estuary regarding point sources of run-off include the Swartkops river, the Motherwell and Markman canal near Brickfields as well as the Chatty river, which enters the Swartkops estuary just upstream of Wylde Bridge (MacKay, 1993). It is not clear whether the saltmarshes in the middle and lower reaches contribute nutrients to the estuary. During a study in 1988/89 a net export of phosphate from certain marshes in the lower reaches was measured, whereas they were a sink for inorganic nitrogen compounds overall (Baird and Winter, 1992). Saltmarshes in estuaries and their role in the nutrient cycle have been subject to several studies, whereby both source and sink behaviour were attributed to these systems (i.e. Valiela et al., 1978; Kjerve and McKellar, 1980; Jordan et al., 1983; Baird and Winter, 1992)

Phosphate:

The Swartkops river was an important source of phosphate to its estuary. During high river flow, a dilution effect of phosphate concentrations rather than an enhancement has been reported on several occasions (this study, Hilmer, 1984; Emmerson, 1985; MacKay, 1993). Nevertheless, regarding the entire estuary, high freshwater inflow rates resulted in elevated phosphate concentrations.

The decrease of the phosphate concentrations towards the mouth show a net uptake of phosphate along the length of the estuary. Since concentrations are high in the estuary, export to the adjacent sea is likely. Winter and Baird (1991) calculated a net export of 24.4 tons p.a. for 1983/84. In the estuary, the upper reaches seem to be the biggest sink for phosphate. Similar results were obtained by Emmerson (1985), whose measurements ranged from 300 $\mu g \cdot l^{-1}$ at the mouth to 3200 $\mu g \cdot l^{-1}$ in the upper reaches. Hilmer's results (1984) show ca 100 $\mu g \cdot l^{-1}$ at Amsterdamhoek and 550 $\mu g \cdot l^{-1}$ at Redhouse. McCallum (1974), Watling (1982), MacKay (1992) and DWA&F (unpub. data) similarly report increasing concentrations upriver. Phosphate concentrations during this study were low compared to the above mentioned studies (Watling, 1982; Hilmer, 1984; Emmerson, 1985; MacKay, 1993; DWA&F, unpub. data), ranging from ca 25 $\mu g \cdot l^{-1}$ at the mouth to 120 $\mu g \cdot l^{-1}$ in the upper reaches, whereas ca 210 $\mu g \cdot l^{-1}$ was the mean concentration in the inflowing river water.

In the middle and more pronounced in the upper reaches, a tendency for negative gradients towards the bottom was apparent (Fig. 4.6). Emmerson (1985) reports a similar vertical distribution of phosphate in the upper reaches, a lack of gradients in the middle reaches and bottom waters richer in phosphate near the mouth.

Nitrate:

Nitrate concentrations in the estuary did not necessarily increase with elevated freshwater inflow rates. The freshwater entering the estuary at its tidal head therefore was not the only, albeit an important, external source for nitrate to the Swartkops estuary. Nitrate supply by the Motherwell stormwater canal, which joins the Swartkops estuary just upstream of Brickfields, is possibly responsible for high measurements in these reaches. Watling (1982) recorded higher (especially surface) measurements in this region. The role of the Motherwell canal as one of the major polluters, especially during increased flow is also pointed out by MacKay (1992, WRC report) as well as Home (1995). A further important external source is the Chatty river. Concentrations are usually low compared to the Motherwell canal (Berry and Robertson, 1996), but increase during high river flow (MacKay, 1993).

Variable trends along the longitudinal axis is shown in Watling (1982) and comparatively higher concentrations than the present study. Emmerson (1985) reports a consistent negative gradient towards the mouth, increased nitrate concentrations in the whole estuary after strong river flow and additionally steeper gradients towards the mouth of the estuary. Nitrate concentrations reported in other studies were ca 240 $\mu g \cdot l^{-1}$ at the mouth to 820 $\mu g \cdot l^{-1}$ in the upper reaches (Emmerson 1985), whereas Hilmer (1984) reports fairly constant levels below 75 $\mu g \cdot l^{-1}$ at Redhouse and Amsterdamhoek, concentrations which increased during floods.

The estuary does show a sink behaviour for nitrate, although not to the same extent as for phosphate. Again, concentrations are reduced to a bigger extent in the upper reaches. Vertical gradients show a zig-zag pattern at all three stations in the estuary (Fig. 4.6). In the lower reaches the bottom waters were richer in nitrate.

Nitrite:

Nitrite concentrations were overall low and were independent from the rate of freshwater inflow. Variations in concentrations were in the region of 5 $\mu g \cdot l^{-1}$ in the upper reaches. Since this addition often meant a doubling of concentrations, correlations with freshwater inflow were relatively strong. A negative concentration gradient towards the head of the estuary was the norm. Similar values are given by Emmerson (1984), although the upper reaches were richer in nitrite. Hilmer (1984) reports concentrations around 30 $\mu g \cdot l^{-1}$ at Redhouse and Amsterdamhoek, and states that concentrations are not extensively influenced by floods.

Ammonia:

The rate of freshwater inflow did not exert any definite influence on ammonia concentrations in the Swartkops estuary. There was no evidence of net uptake along the length of the estuary (this study; Watling, 1982; Hilmer, 1984; Emmerson, 1985; MacKay, 1993), which is probably partly due to supplements from the Motherwell canal as well as the Chatty river. Ammonia concentrations increase in both the latter systems during wet weather (MacKay, 1993; Berry and Robertson, 1996). Previous studies recorded lower ammonia concentrations, i.e. levels of generally below 30 $\mu g \cdot l^{-1}$ in Emmerson

(1985) and concentrations of < 100 $\mu g \cdot l^{-1}$ in MacKay (1992) as well as Hilmer (1984). Short lived increases due to floods are mentioned in Hilmer (1984) as well as MacKay (1992). Occasional high ammonia levels occurred in the presence of anoxic waters, an event detected and attributed by Watling (1982) to a failure in the Uitenhage sewage works.

Vertical gradients, if present, were pronounced, and concentrations increased towards the bottom (Fig. 4.6). The same zig-zag pattern was observed as for nitrate. Near Brickfields, ammonia concentrations were generally higher near the surface, which can be attributed to pollution from the Motherwell canal.

Total particulate nitrogen:

TPN concentrations did not necessarily increase with high freshwater discharge rates. There was no indication regarding gradients along the longitudinal or vertical axes.

4.4.2.3 Sundays:

Phosphate:

Freshwater discharge at the head of the estuary seemed not to have been a major source of phosphate. A few zero measurements in the lower and middle reaches are probably responsible for the significant correlations with low salinities. On the contrary, Emmerson (1989) reports a positive phosphate gradient towards the upper reaches. Concentrations were overall lower compared to previous studies by approximately an order of magnitude (Watling, 1982; Emmerson, 1989).

Nitrate:

The major source of nitrate to the estuary was the inflowing freshwater at the tidal head. The Sundays estuary acted as a sink for nitrate, particularly in the upper reaches. Considerable amounts are probably exported to adjacent coastal waters, since concentrations in the lower reaches were still fairly high (around 300 $\mu g \cdot l^{-1}$). In accordance with this study, steeper longitudinal gradients, with increasing concentrations towards the upper reaches were observed by Emmerson (1989) and Watling (1982). A similar dilution effect to phosphates in the Swartkops river during high flow rates was measured in the Sundays river for nitrates. This phenomenon was also reported by Emmerson (1989).

Negative vertical gradients were more often measured towards the upper reaches, and were a reflection of positive vertical salinity gradients (Fig. 4.7). Emmerson (1989) reports the same gradients as a fairly rare occurrence.

Nitrite:

Nitrite concentrations were generally low (around 10 $\mu g \cdot l^{-1}$) and were not influenced by varying freshwater inflow. Values measured in this study were lower compared to Emmerson (1989) and Watling (1982).

Ammonia:

The freshwater discharging into the estuary cannot be labelled as the most important source for ammonia for the Sundays estuary. Concentrations were higher in the upper reaches compared to the river water and from there on showed a decrease towards the mouth. Nevertheless, concentrations were higher on occasion when freshwater inflow had increased. It is suggested that part of the nitrate was reduced to ammonia, since nitrate was a highly abundant form of nitrogen. Oxygen concentrations seem to be lower when ammonia concentrations increased. Due to equipment failure, measurements of oxygen could unfortunately not be taken on every sampling occasion. This last assumption is therefore not suitable for any statistical investigation. Ammonia generation in the estuary itself has been reported by Horrigan et al. (1990). Variable concentrations along the length of the estuary were measured by Watling (1982), although values were higher in some cases. Emmerson (1989) gives a negative gradient towards the mouth with overall lower concentrations compared to this study.

Total particulate nitrogen:

TPN concentrations were highest in the middle and upper reaches, following the same pattern as chlorophyll-a concentrations. Due to the high phytoplantkon standing stocks, algal cells will also have contributed to the particulate matter. Vertical gradients were variable without any definite trends.

4.4.3 Chlorophyll-a:

4.4.3.1 Kromme estuary:

Chlorophyll-a concentrations were generally low in both the Kromme and Geelhoutboom estuaries, although slightly elevated during periods of freshwater inflow. It seemed that phytoplankton biomass was higher in the middle reaches, although this can be attributed to only two high measurements for the study period. In general chlorophyll-a values were similar in the middle and upper reaches. Concentrations were not elevated on all occasions freshwater was discharging into the estuary, although phytoplankton cells have the ability to respond quickly to higher nutrient loads, since cell division takes place in a matter of hours. Jerling and Wooldridge (1994) report increased numbers of mysids and copepods after a freshwater pulse in the Kromme estuary. Grazing pressure exerted on the phytoplantkon population by zooplankton could therefore be responsible for the lack of increase in chlorophyll-a concentrations apparent from most sampling occasions during periods of freshwater inflow.

In a previous study (Hilmer, unpub. data) low chlorophyll-a ($< 4\ \mu g \cdot l^{-1}$) concentrations were measured. These measurements were taken during dry periods and are similar to data from dry periods obtained during this study.

4.4.3.2 Swartkops estuary:

The most productive regions in the estuary in terms of chlorophyll-a were in the upper reaches, decreasing downstream towards the mouth. Hilmer (1984) also reports lower values in the lower reaches. The major controlling factor of chlorophyll-a in the estuary seems to be turbidity, whereas changes in freshwater inflow or salinity did not have any immediate effects. Phosphate in the Swartkops system is in high abundance, therefore phytoplankton production is assumed to be nitrogen limited. Especially ammonia levels fluctuated according to chlorophyll-a concentrations. Bacteria, standing stocks of which are high in the Swartkops estuary (Watling, 1982; Emmerson, 1985; DWA&F, unpub. data), could be viable competitors for nutrients.

4.4.3.3 Sundays estuary:

Chlorophyll-a values were highest in the middle and upper reaches, where favourable nutritional as well as hydrodynamic conditions prevailed. Not only concentrations, but also variances were higher in the middle and upper estuary (this study; Hilmer and Bate, 1990; Jerling and Wooldridge, 1995). During bloom conditions, which occur frequently in the Sundays estuary (Hilmer and Bate, 1990) concentrations of 50 to 60 $\mu g \cdot l^{-1}$ were measured in the middle and upper reaches. Hilmer and Bate (1990) measured chlorophyll-a at $< 6\ \mu g \cdot l^{-1}$ near the mouth to $> 100\ \mu g \cdot l^{-1}$ in the middle and upper reaches. Phosphate is probably the limiting nutrient for phytoplankton, an assumption which is supported by the high nitrate concentratic ıs throughout the estuary, and the significant correlation between phosphate and chlorophyll-a.

4.4.4 N:P ratios:

4.4.4.1 Kromme:

Atomic N:P ratios for the dissolved inorganic nutrients in the Kromme system exceeded the Redfield ratio of 16:1 in most cases (Fig. 4.10 A). Exceptional low ratios for the Kromme estuary were apparent during the June 1993 freshet, when an unusual high amount ($8.75\ m^3 \cdot sec^{-1}$) of freshwater and, in consequence, phosphate entered the estuary. N:P ratios then were at a low of 9:1 at the head of the estuary, but increased towards the mouth. Unfortunately there are no nutrient measurements available regarding the inflowing freshwater for this particular sampling occasion. A N:P ratio of only 0.79:1 is reported in Emmerson and Erasmus (1987). The discrepancy stems from very high phosphate concentrations (mean estuarine value: 121 $\mu g \cdot l^{-1}$) and the consideration of total Phosphorus, as well as low dissolved inorganic nitrogen concentrations (mean estuarine value: 81 $\mu g \cdot l^{-1}$) compared to this study.

Besides nutrient limitation in general, plant production in the Kromme estuary is inhibited by proportional low phosphate concentrations. Similar N:P ratios were measured during periods of occurrence and non-occurrence of freshwater inflow, although higher values overall are apparent from the freshwater. Chlorophyll-a concentrations nevertheless seem to increase when salinities are lower than the obligate seawater salinities, which can be attributed to overall higher nutrient loads brought into the estuary with the inflowing freshwater. In general, the Geelhoutboom is richer in phosphate compared to the Kromme estuary, which is apparent from the lower N:P ratios. During dry periods, a negative N:P ratio gradient towards the mouth was apparent. Proportionally more phosphate than nitrate was available when freshwater was discharging into the estuary, which levelled the ratio gradient during these periods. Emmerson and Erasmus (1987) similarly measured lower N:P ratios in the Geelhoutboom as well as a negative gradient towards the mouth.

4.4.4.2 Swartkops:

In the Swartkops estuary, N:P ratios increased towards the mouth of the estuary (Fig. 4.10 B). The biggest increase was apparent from the middle to the lower reaches, due to a proportionally bigger decrease in phosphate as compared to nitrate concentrations. N:P ratios were in general smaller than Redfield ratios, with the exception of the lower reaches. Phytoplankton was therefore limited mostly in nitrogen. Proportionally more nitrate of the inflowing river water was taken up in the upper reaches, which were the biggest sink for nutrients in the estuary.

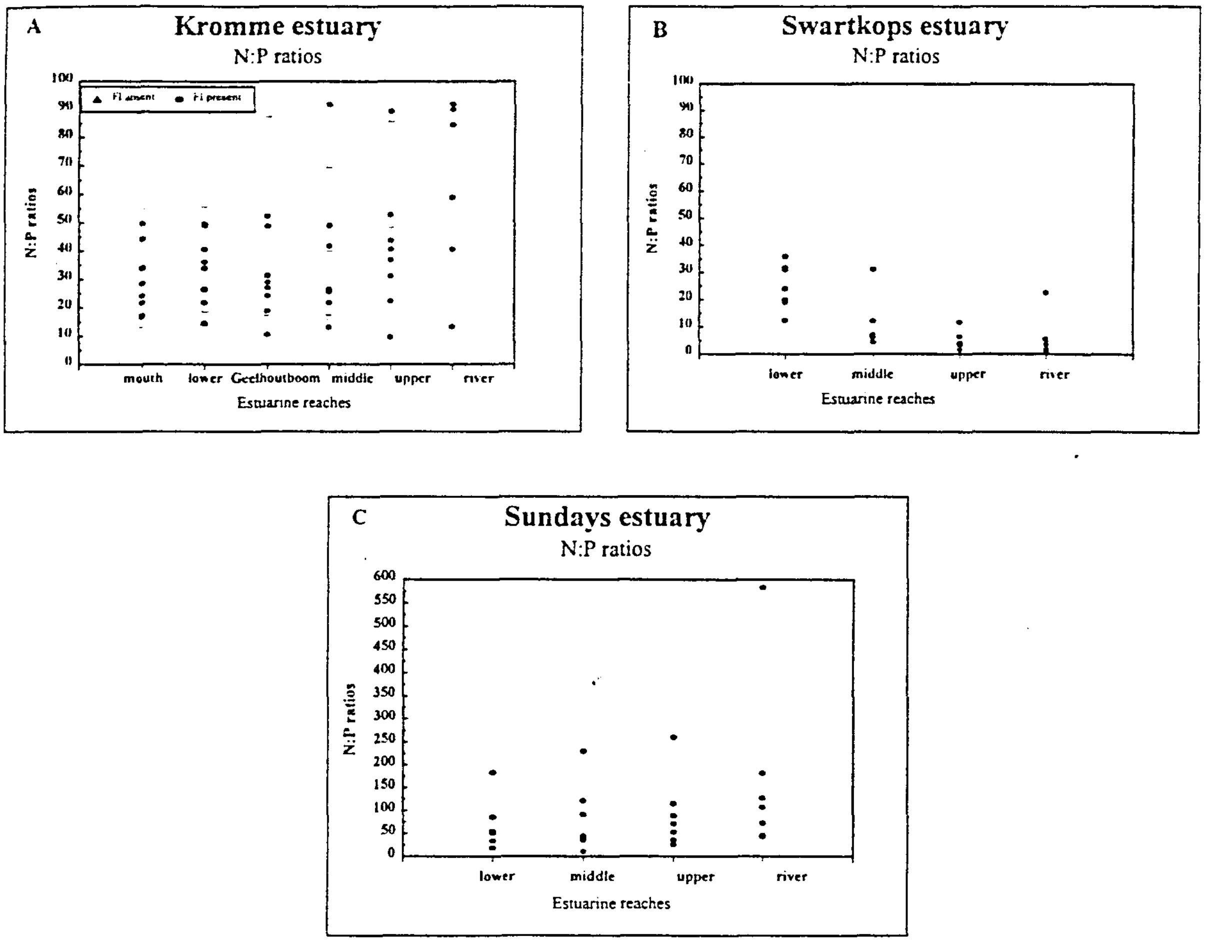


Fig. 4.10: Atomic N:P ratios along the longitudinal axes of the Kromme, Swartkops and Sundays estuaries, including the riverine station. Datapoints denote the depth averaged data of the sampling stations on individual sampling sessions. Note that on graph C (Sundays estuary) the scale is different on the y-axis. FI = Freshwater Inflow

A N:P ratio of 0.39-0.49:1 was calculated by Emmerson (1985), due to exceptionally high phosphate concentrations (mean estuarine value: 1320 $\mu g \cdot l^{-1}$) as compared to this study (mean estuarine value: 85 $\mu g \cdot l^{-1}$). The high mean phosphate concentration is partly attributable to two high measurements, when sampling coincided with the failure of the Uitenhage sewage works (Watling, 1982; Emmerson, 1985).

4.4.4.3 Sundays:

Contrary to the Swartkops estuary, the relatively high N:P ratios decreased towards the lower reaches in the Sundays estuary (Fig. 4.10 C). The high ratios in the riverine section are mainly due to the high nitrate levels, for which nitrogenous fertilisers used in the Sundays catchment area are responsible. The nitrogen compounds decreased in their concentrations more rapidly towards the mouth than phosphate. On the whole phytoplankton production is assumed to be phosphate limited, since the N:P ratios exceed Redfield ratios by far. Emmerson (1989) reports a N:P ratio of 3.25:1. The difference between the two studies lie in both contradicting phosphate as well as nitrate concentrations. Phosphate, whose levels were mentioned of being more than an order of magnitude higher compared to this study, contributed to the differences in N:P ratios between the two studies.

4.4.5 The Kromme, Swartkops and Sundays rivers as nutrient sources:

The amount of freshwater inflow into each estuary was regarded as the most critical aspect between the three systems, since it was in this region where the biggest differences lay. Naturally it is not only the quantity of water which is crucial to its loads brought into the estuary, but also its quality which in turn is determined by the condition of soil and vegetation along the river banks as well as human activities in the catchment area. The Swartkops and Sundays estuarine catchment areas are undoubtedly subject to anthropogenic influences which encompass residential areas and industrial activities in the former and nutrient enrichment resulting mainly from agriculture in the latter. Since none of these activities are found along the Kromme river, artificial elevation of nutrient contents through external sources is lacking. Additionally, the river flows through an area of well leached soils (Reddering and Esterhuysen, 1983). Water storage in dams may alter its quality (Palmer and O'Keeffe, 1990). However, keeping in mind, that water is leaving the Impofu dam mainly as overflow after heavy rains, the influence of processes taking place in the dam seem negligible, due to short residence time of water during the event of high runoff or floods. On the other hand, sluice gates are usually opened to prevent major overflows and then water may be released from various depths of the lake, but the proportion of the in this manner released water is comparatively small.

The relative importance of the rivers as an external nutrient source is furthermore supported by the increasing divergence of the estuaries in terms of nutrient concentrations towards their upper reaches. The Kromme river, once allowed to reach the estuary, contributes to an elevation in nutrient concentrations throughout the estuary. Regarding nutrient concentrations, not only the amount, but equally the timing of freshwater releases from the Impofu dam (as discussed in chapter 3) is of great importance. From a nutrient point of view, frequent releases are more important to replenish depleted nutrient pools than one or two major releases per year. The same concept is true for phytoplankton, which could thrive on nutrients supplied repeatedly in short time intervals. The Geelhoutboom is not seen as a reliable nutrient source to the Kromme estuary, an assumption supported by its relatively low nutrient concentrations during low flow conditions. Only following rains in its catchment area, where agriculture is practised on a limited scale (Emmerson and Erasmus, 1987), were nutrient concentrations elevated in the lower reaches of the Geelhoutboom estuary. Saltmarshes in the lower reaches of the Kromme estuary presumably have their place in nutrient uptake and regeneration, although nutrient contribution from this source to the watercolumn did not seem to be a major one.

The Swartkops estuary had several other run-off sources contributing nutrients besides the river itself. The Swartkops river was mainly a source for phosphate to its estuary. All nitrogen compounds had, especially after rains, additional sources in the Motherwell canal as well as the Chatty river. Contribution of nutrients from the saltmarshes was not verified.

The Sundays river was a main source for nitrate and the only run-off point source for nutrients for the estuary. Ammonia is presumably generated in the estuary, whereas the low phosphate concentrations are most probably replenished by regeneration throughout the estuary.

Average phosphate input into the Kromme, Swartkops and Sundays estuaries via their rivers amounted to 0.22, 6.51 and 1.82 tons per annum respectively. The total dissolved inorganic nitrogen (nitrate, nitrite and ammonia) contribution, on the other hand, was measured at 6.55, 22.88, and 92.91 tons per annum respectively. Higher phosphate loads (28.8 tons p.a.) in the Swartkops river are given in MacKay (1992), whereas total dissolved inorganic nitrogen amounted to 20.1 tons p.a.. The concentrations for all dissolved inorganic nutrients were higher during wet as compared to dry periods, where the Chatty river was the most important source of nitrogen to the estuary and the Swartkops river for phosphate (this study; MacKay, 1993).

Atomic N:P ratios derived from the concentrations of the dissolved inorganic phosphate and nitrogen compounds in the inflowing freshwater amounted to 63.2:1 for the Kromme, 5.8:1 for the Swartkops and 166.0:1 for the Sundays estuary. Judging from the Redfield ratio for N:P (16:1), both the Kromme and Sundays rivers are in short supply of phosphate, whereas nitrogen is a limiting factor in the lower Swartkops river. This pattern was apparent throughout their estuaries. External nutrient supplies can be important in determining the limiting nutrient in an estuary (Doering et al., 1995), which again emphasises the close connection between an estuary and its adjacent ecosystems.

4.4.6 Nutrient supply and phytoplankton production:

Phytoplankton production in terms of $mgC \cdot m^{-2} \cdot d^{-1}$ in the Kromme, Swartkops and Sundays estuaries was estimated from chlorophyll-a measurements averaged over the sampling period (see Chapter 5). Using Redfield ratios, the total dissolved inorganic nitrogen (nitrate, nitrite, ammonia) as well as phosphate requirement for phytoplankton production was calculated. Values were then expressed as N and P demand per annum and compared with the average amount of dissolved inorganic N and P supplied by the individual rivers to their estuaries over the sampling period.

In the Kromme estuary, around 10.5 tons N and 0.6 tons P p.a. were calculated to be used for primary production. The Kromme river, on the other hand, supplies annually 6.6 tons N and 0.2 tons P. Since primary production demands more of the nutrients than supplied by the Kromme river, regeneration within the estuary as well as nutrient pulses from the Geelhoutboom during high river flow are proposed as additional nutrient sources. Phosphate supply exceeded demand in the Swartkops estuary (6.5 vs 1.7 tons p.a.), due to exceptional high loads in the river. N requirements were higher compared to river supply (27.8 vs 22.9 tons p.a.). During drier periods, regeneration in the estuary is presumably more important compared to rainfall periods, since then N is flushed from the various run-off point sources along the estuary (Motherwell canal, Markman canal, Chatty river) in high concentrations. In the Sundays estuary, requirements for both N and P exceeded riverine supply by far (157.9 tons N and 9.8 tons P required vs 92.9 N and 1.8 tons P supplied). No abnormally high concentrations were measured on individual sampling sessions, which suggests that contamination with phosphates from anthropogenic influences would not play a major role. Standing stocks of the fauna in the Sundays estuary are relatively high (Marais, 1981; Wooldridge and Bailey, 1982; Whitfield, 1994, Jerling and Wooldridge, 1995). Rapid recycling of the nutrients as well as a quick response of the phytoplankton to the newly available food resources could be one explanation of the big discrepancy between nutrient requirements and supply.

Besides species composition, which will be discussed in chapter 5, chlorophyll-a concentrations portray nutrient and hydrodynamic conditions prevailing in an estuary (Joint and Pomroy, 1981; Malone et al., 1988; Mallin et al., 1991). Stratification is an important feature to increase phytoplankton standing stock and chlorophyll-a levels as well as the formation of blooms (Ingram et al., 1985; Radach and Moll, 1990; Monbet, 1992). In the Sundays estuary, the importance of the hydrodynamics for chlorophyll-a were emphasised by the local resemblance of different hydrodynamic regimes within the estuary and the sections based on chlorophyll-a characteristics (Hilmer and Bate, 1990). Light availability in this shallow estuary presumably is not a limiting factor to phytoplankton (Hilmer and Bate, 1990).

The low variation in chlorophyll-a as well as the lack of extensive blooms to in the Swartkops estuary can be attributed to the well mixed status of the watercolumn (Hilmer, 1990). Nutrient concentrations are relatively high in the estuary, but regarding primary producers, macrophyte dominance is favoured in the Swartkops estuary (Hilmer, 1990). In the Kromme estuary, releases of freshwater from the Impofu dam (see Chapter 3) would not only aid as a source of nutrient, but would equally provide stratification in some parts of the estuary. Again, from this point of view, frequent releases are favoured over major freshwater pulses, which are separated by long timespans.

4.5 CONCLUSION:

The nutrient supply of the Kromme, Swartkops and Sundays rivers to their estuaries was largely dependent on the rate of riverflow. Some nutrient species were artificially elevated in the Swartkops and Sundays estuaries, a result of anthropogenic influences. The Kromme estuary, on the other hand, was nutrient depleted due to reduced freshwater inflow caused by impoundments in its catchment area. Chlorophyll-a was mostly a reflection of the nutrient concentrations in the estuaries, although hydrodynamics seem to be equally important in governing concentrations. The biggest differences between the three estuaries lay in their upper reaches, which seemed to be the most active (in terms of a sourceand/or sink behaviour) in the Swartkops and Sundays estuaries.

Nutrient regeneration seems to be an important feature in all three estuaries investigated. Therefore it is important that the headwaters of an estuary are sampled additionally to the estuary to be able to draw conclusions as to how important the riverine source is to the estuary regarding the various nutrients.

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CHAPTER 5

BIOMASS, PRODUCTIVITY AND DIVERSITY OF VARIOUS BIOTA IN THE KROMME, SWARTKOPS AND SUNDAYS ESTUARIES IN RELATION TO FRESHWATER INFLOW

5.1 INTRODUCTION:

Estuaries, which are transition zones between the sea and rivers, derive organic and inorganic material from both the sea- and landward boundary. These systems usually support a high biomass and their productivity has been found to be comparable with other highly productive ecosystems such as tropical rain forests and coral reefs (Boaden and Seed, 1985). In general, the river's importance as a contributor of new material to the estuary is ranked higher than that of the sea, and the magnitude of freshwater inflow is therefore critical to the living biota in the estuary (Funicelli, 1984). Although the recycling of materials is a vital part in the ecology of estuaries, the replenishment of the estuarine material pool via freshwater input is crucial to avoid decreases in productivity (Flint, 1985).

Consequences of river impoundment for the physical environment in estuaries include *inter alia* increased sediment accumulation due to the reduction of floods. Estuaries tend to become shallower and might be temporarily closed off from the sea. A disruption in freshwater inflow will consequently not only affect residents, but equally those numerous species migrating between the estuary and the sea to spend part of their lives in either environment (Wooldridge, in press).

Estuaries are dynamic ecosystems, where abiotic and biotic conditions change continually (Heydorn, 1979; Whitfield and Bruton, 1989; Allanson and Read, 1995). It is therefore not unusual, that the ecological state of an estuary can change over years, or similarly be disrupted by episodic events such as floods (Whitfield and Bruton, 1989). Abstraction of river water in the catchment area alters these natural patterns and is one of the biggest threats to estuaries. Not surprisingly, this issue has been given considerable attention by scientists (e.g. Flint, 1985; Skreslet, 1986; Whitfield and Bruton, 1989; Montagna and Kalke, 1992; Schlacher and Wooldridge, submitted; Allanson and Baird, in press).

In this study the influence of freshwater inflow on various biota in the Kromme, Swartkops and Sundays estuaries was investigated. It was hypothesised that an estuary with a fairly regular freshwater inflow and a longitudinal salinity gradient, such as the Sundays and Swartkops estuaries, can support a higher biomass, productivity and species diversity relatively to a system which receives little freshwater, such as the Kromme estuary.

5.2 MATERIALS AND METHODS:

Datasets of abundance and density were extracted from the literature, converted to estimates of biomass ($mg \cdot m^{-2}$) and production ($mg \cdot m^{-2} \cdot d^{-1}$) and used to compute diversity indices for various biota in the Kromme, Swartkops and Sundays estuaries. All datasets included in this study had to feature certain criteria, which w re equivalent mesh sizes of plankton nets and sieves used for the extraction of invertebrate macrozoobenthos from the sediment, as well as the size and mesh for seine and gill-nets. The references referred to for various datasets and computations are listed in Table 5.1A (Kromme estuary), 5.1B (Swartkops estuary) and 5.1C (Sundays estuary).

Units per volume were transformed to areal units by integration over depth, where the average depth was assumed to be 2.75 m in the Kromme estuary (Bickerton and Pierce, 1988), 3 m in the Swartkops estuary (Baird et al., 1986) and 2 m in the Sundays estuary (Hilmer and Bate, 1990). The surface areas, which constitute a factor in calculating total standing stock and annual production for the entire estuary, are ca 275 ha and 268 ha for the Kromme and Sundays estuaries respectively (Jezewski and Roberts, 1986), whereas the Swartkops estuary covers an area of approximately 502 ha (Baird et al., 1986). These values represent both the inter- and subtidal areas.

5.2.1 Biomass and Productivity

Density, biomass (in $mg \cdot m^{-2}$) and productivity (in $mg \cdot m^{-2} \cdot d^{-1}$) were calculated for the individual species from various datasets (Appendix: Table 5.2, 5.3, 5.4). A total value for the various biota is presented in Tables 5.2 (Density), 5.3 (Biomass) and 5.4 (Productivity). In the case more than one set of information on a particular species was available (see Appendix: Table 5.2, 5.3, 5.4), an average value for this species was used in the derivation of the total value.

5.2.1.1 Phytoplankton:

Chlorophyll-a measurements served as an estimate of phytoplankton biomass. Its productivity was estimated referring to P/B ratios of 0.0685 (Heymans and Baird, 1995), 0.0855 (Baird and Ulanowicz, 1993) and 0.4960 (Hilmer, 1990) for the Kromme, Swartkops and Sundays estuaries respectively (see Table 5.1A, 5.1B, 5.1C; Appendix: Table 5.1).

5.2.1.2 Benthic microalgae:

Alike to the pelagic microalgae component, the chorophyll-a content of benthic microalgae was used as an equivalent for its biomass. Chlorophyll-a measurements (Snow, 1994; Rodriguez, 1993) were converted to productivity using a P/B ratio of 0.99 (Baird and Ulanowicz, 1993). This P/B ratio had been calculated for the Kromme estuary, and - due to a lack of information on this particular feature for the Swartkops and Sundays estuaries - was assumed to be the identical in the latter two systems (Table 5.1A, 5.1B, 5.1C).

5.2.1.3 Macrophytes:

Submerged Macrophytes:

Information on submerged macrophytes was restricted to *Zostera capensis* and *Caulerpa filiformis*. Dry mass was converted to productivity via a P/B ratio of 0.0063 for *Z. capensis* (Baird, 1988) and 0.0130 for *C. filiformis* (Wooldridge et al., 1989) (Table 5.1A, 5.1B, 5.1C; Appendix: Table 5.1).

Saltmarsh Macrophytes:

Saltmarshes *per se* are not part of the Sundays estuarine system, although the fringing vegetation, which covers part of the narrow intertidal area in the middle and upper reaches, features typical saltmarsh plants. A survey has yet to be conducted on this part of the flora. Dry mass per unit area in the Kromme and Swartkops estuaries are listed in Adams (1991) and in Baird et al. (1986) respectively (Table 5.1A, 5.1B, 5.1C). A P/B ratio of 0.003 (Pierce, 1983, 150) was applied to all species in both the Swartkops and Kromme estuaries (Appendix: Table 5.1).

5.2.1.4 Zooplankton:

Microzooplankton:

The microzooplankton dealt with in this study comprised zooplankton species smaller than 200 µm (after Sieburth et al., 1978). A dataset for the microzooplankton was available for the Sundays estuary (Jerling, 1993). In the case of the Swartkops estuary, the microzooplankton component was only represented by a dataset on nauplii larvae (Wooldridge, 1979), whereas for the Kromme estuary no information was existent in the literature (Table 5.1 A, B, C).

The dry mass for flagellates was derived by the conversion of volume (in Jerling, 1995) to carbon biomass values with the formula: Log C = -0.460+0.866(logV) (after Strathmann, 1967). C is the carbon content in pg and V the cell volume in μm^3. The carbon content of zooplankton was assumed to be 40 % of the dry mass (Gifford and Dagg, 1988). Density and volume of rotifers and ciliates (in

Jerling, 1993; Jerling, 1995) were converted to dry mass after Bottrell et al. (1976) and Laybourn and Finlay (1976) respectively. The dry mass of rotifers was calculated as 10 % of their wet mass, whereas 0.17 pg·µm^{-3} was assumed to be the dry mass of ciliates. The dry weight of nauplii larvae is given in Wooldridge and Bailey (1982). A P/B ratio of 0.6667 estimated originally for the Swartkops estuary (Baird and Ulanowicz, 1993) was assumed to be alike in the Sundays estuary (Table 5.1 A, B, C; Appendix, Table 5.1).

Mesozooplankton:

The mesozooplankton studied in the three estuaries was restricted to three copepod species (*Acartia natalensis*, *Acartia longipatella*, *Pseudodiaptomus hessei*) and three species of Mysidacea (*Gastrosaccus brevifissura*, *Mesopodopsis wooldridgei*, *Rhopalophthalmus terranatalis*).

Dry mass measurements for the individual mesozooplankton species in the Swartkops and Sundays estuaries (Wooldridge, 1979) were used to calculate biomass from densities in the Kromme (Jerling and Wooldridge, 1994), Swartkops and Sundays estuaries (Wooldridge, 1979). The dry weight of *Rhopalophthalmus terranatalis* was derived from a length-dry weight regression (Wooldridge and Bailey, 1982) (Table 5.1A, 5.1B, 5.1C).

The biomass of the copepod species in all three estuaries was converted into productivity with a P/B ratio of 0.2433, a factor originally derived for *P. hessei* from the Sundays estuary (Jerling and Wooldridge, 1991). Similarly, the P/B ratio of 0.0228 for *R. terranatalis* (Wooldridge, 1986, 164) was applied to *G. brevifissura* and *M. wooldridgei* (Appendix: Table 5.1).

5.2.1.5 Meiofauna:

The meiofaunal biomass and density in the Kromme estuary was recalculated from carbon biomass values given in Heymans and Baird (1995). The carbon content of the meiofauna was assumed to be 50 % of the ash free dry weight (McLusky, 1981). Densities were deducted via various AFDWs for Nematoda, Harpacticoida and 'Others', which include Oligochaeta, Polychaeta, Plathelminthes, Gastrotricha, Amphipoda and Ostracoda (in Dye and Furstenberg, 1978). In addition, data obtained during a singular study on the meiofauna density in the Kromme estuary are available from 1976 (Dye, 1977), where biomass (as AFDW) was calculated with the information given in Dye and Furstenberg (1978) (Table 5.1A, 5.1B, 5.1C). Density values from the Swartkops estuary (Dye and Furstenberg, 1978; Gyedu-Ababio, unpub. data) were treated alike. Available data on meiofauna in the Sundays estuary were restricted to Nematoda (Furstenberg, pers. comm.).

A P/B ratio of 0.0219 (Dye, 1977) was used for the meiofauna in all three estuaries (Appendix: Table 5.1).

5.2.1.6 Invertebrate Macrozoobenthos:

The various macrobenthic species were assigned to different feeding types: 1.) carnivores, which comprise predators and scavengers, 2.) detritivores, 3.) deposit feeders, 4.) grazers and 5.) suspension feeders. Information on the feeding guild of the individual species was acquired from Fauchald and Jumars (1979), Griffis and Suchanek (1991) and Branch et al. (1994).

Data extracted from the literature (see Table 5.1A, 5.1B, 5.1C) predominantly featured density data only, whereas biomass measurements were seldom available. Biomass values for various density data (i.e. Baird et al., 1981; Scharler, 1992; Forbes, 1994) were derived via average ash free dry weights calculated from density and weight values for individual species (in Hanekom, 1982; Bally, 1994). In case the biomass was expressed as dry weight (Winter and Baird, 1988) or carbon (Heymans and Baird, 1995), these values were recalculated into AFDW with the aid of conversion factors given in McLusky (1981).

Productivity was estimated using P/B ratios given for various species listed in Heymans and Baird (1995) and Emmerson (1986). These P/B ratios were furthermore assigned to those species, which do not feature in Heymans and Baird (1995). Guidelines to choose a certain ratio for a certain species were firstly an affiliation with the same family or order, secondly feeding guild and thirdly size (Appendix, Table 5.1).

5.2.1.7 Ichthyofauna:

Ichthyoplankton:

The density and biomass of the ichthyoplankton in the Kromme, Swartkops and Sundays estuaries are given in Melville-Smith (1981) and Strydom (1995), in Melville-Smith and Baird (1980) and in Harrison and Whitfield (1990) respectively (Table 5.1A, 5.1B, 5.1C). To derive an estimate of productivity, a P/B ratio of 0.0005 (Baird, 1988) was used for all three estuaries (Appendix, Table 5.1).

Ichthyonekton:

The ichthyonekton was divided into two categories, accordingly to the catch methods employed. Seine net catches are referred to as the 'Smaller component', whereas the 'Larger component' comprises catches by the means of gill nets. The ichthyonekton was divided into three feeding groups, i.e. zooplanktivores, piscivores, which is constituted be the pelagic predators, and benthic feeders. The family Mugilidae was treated as a separate group, since it features prominently in all three estuaries.

A. Smaller component:

Various studies have been covering the entire estuary, i.e. the Kromme estuary by Cloete (1990) and Strydom (1995), the Swartkops estuary by Winter (1979) and the Sundays estuary by Beckley (1994). In addition, data representative of exclusively the lower (Marais, in prep; Whitfield, 1994) and middle reaches (Hanekom and Baird, 1984) were included in this study (Table 5.1A, 5.1B, 5.1C).

Dividing the CPUE (in mass) of each species caught by the volume of water sampled by one haul yielded the mass in $mg \cdot m^{-3}$. A unit of effort was equivalent to one haul. The mass was expressed as $mg \cdot m^{-2}$ by integrating the former value over depth. The P/B ratios for the various groups represented in the Kromme estuary were 0.0065 for zooplanktivores (Ratte, 1989), 0.00068, 0.00109 and 0.00055 for piscivores, benthic feeders and *Mugilidae* respectively (Baird and Ulanowicz, 1993). In the case of zooplanktivorous fish, the same P/B ratio was applied to all three estuaries. P/B ratios given for the Swartkops estuary were used for the ichthyonekton of the Sundays estuary, i.e. 0.00075 for piscivores and 0.00068 for benthic feeders (Baird and Ulanowicz, 1993). The P/B ratio of 0.00055 for Mugilidae (Baird and Ulanowicz, 1993) was used for both the Swartkops and Sundays estuaries (Table 5.1A, 5.1B, 5.1C; Appendix: Table 5.1).

B. Larger component:

A gill net samples effectively 44000 m^3 of water (Hay, 1985). The CPUE (in mass) for the individual species was divided by 44000, yielding the results in mass per m^3. A unit of effort was equivalent to one gill net (50 x 3m) set from dusk until dawn (approximately 12 hours),

P/B ratios used for the various categories are equivalent to those for the smaller fish component.

Table 5.1A: Reference list for various parameters (abundance, density, biomass and P/B ratios) used in the calculations to derive estimates of biomass and productivity of all biotic components in the Kromme estuary.

BIOTA	PARAMETER	REFERENCE
Phytoplankton	Chlorophyll-a	this study Hilmer, 1990
	NPP/B ratio	Baird and Ulanowicz, 1993
Benthic Microalgae	Chlorophyll-a	Snow, 1994
	NPP/B ratio	Baird and Ulanowicz, 1993
Macrophytes		
Submerged:	Biomass	Emmerson, 1986 Hanekom and Baird, 1988 Adams, 1991
	NPP/B	Wooldridge et al., 1989
Saltmarsh:	Biomass	Adams, 1991
	NPP/B	Hanekom, 1982 Baird, 1988 Wooldridge et al., 1989
Zooplankton		
Microzooplankton:	No data	
Mesozooplankton:	Density	Jerling and Wooldridge, 1994
	Biomass	Wooldridge, 1979
	Length-dry mass relationship	Wooldridge and Bailey, 1982
	P/B ratio	Jerling and Wooldridge, 1991 Wooldridge, 1986
Meiofauna	Biomass	Dye, 1977 Heymans and Baird, 1995
	Ash-free dry weight	Dye and Furstenberg, 1978
	P/B ratio	Dye, 1977
Invertebrate Macrozoobenthos	Density	Baird et al., 1981 Emmerson, 1986 Winter and Baird, 1988 Matthewson, 1989 Heymans and Baird, 1995
	Ash-free dry weight	Hanekom, 1982
	P/B	Emmerson, 1986 Heymans and Baird, 1995
Ichthyoplankton	Density, Biomass	Melville-Smith, 1981 Strydom, 1995
	P/B ratio	Baird, 1988

ıble 5.1 A cont.

BIOTA	PARAMETER	REFERENCE
Ichthyonekton (Smaller component)	Abundance, Biomass	Hanekom, 1982 Hanekom and Baird, 1984 Cloete, 1990 Strydom, 1995 Marais, in prep.
	P/B ratio	Ratte, 1989 Baird and Ulanowicz, 1993 Heymans and Baird, 1995
Ichthyonekton (Larger component)	Catch per unit effort	Marais, 1983 Cloete, 1990 Strydom, 1995
	Biomass	Marais, 1983 Cloete, 1990 Strydom, 1995
	P/B	Baird and Ulanowicz, 1993

Table 5.1B: Reference list for various parameters (abundance, density, biomass and P/B ratios) used in the calculations to derive estimates of biomass and productivity of all biotic components in the Swartkops estuary.

BIOTA	PARAMETER	REFERENCE
Phytoplankton	Chlorophyll-a	This study (see Chapter 4) Hilmer, 1984
	NPP/B ratio	Baird and Ulanowicz, 1993
Benthic microalgae	Chlorophyll-a	Dye, 1977 Rodriguez, 1993
	NPP/B ratio	Baird and Ulanowicz, 1993
Macrophytes		
Submerged:	Biomass	Emmerson, 1986 Talbot and Bate, 1987
	NPP/B	Baird et al., 1988
Saltmarsh:	Biomass	Baird et al., 1986 Pierce, 1983 Talbot, 1982
	NPP/B	Pierce, 1983
Zooplankton		
Microzooplankton:	Density	Wooldridge, 1979
Mesozooplankton:	Density	Wooldridge, 1979
	Biomass	Wooldridge, 1979
	Length-dry mass relationship	Wooldridge and Bailey, 1982
	P/B ratio	Baird and Ulanowicz, 1993
Meiofauna	Density	Gyedu-Ababio, unpub. data
	Biomass	Dye and Furstenberg, 1978
	Ash-free dry weight	Dye and Furstenberg, 1978
	P/B	Dye, 1977
Invertebrate Macrozoobenthos	Density, Biomass	Emmerson, 1986 Winter and Baird, 1988 Hanekom, 1988
	Ash-free dry weight	Hanekom, 1982
	P/B ratio	Emmerson, 1986 Baird, 1988
Ichthyoplankton	Abundance	Melville-Smith and Baird, 1980
	P/B ratio	Heymans and Baird, 1995
Ichthyonekton - Smaller component	Abundance, Biomass	Winter, 1979; Marais, in prep.
	P/B ratio	Ratte, 1989 Baird and Ulanowicz, 1993
Ichthyonekton - Larger component	Abundance, Biomass	Marais, 1980 Daniel, 1994
	P/B	Baird and Ulanowicz, 1993

Table 5.1C: Reference list for various parameters (abundance, density, biomass and P/B ratios) used in the calculations to derive estimates of biomass and productivity of all biotic components in the Sundays estuary.

BIOTA	PARAMETER	REFERENCE
Phytoplankton	Chlorophyll-a	This study (see Chapter 4) Hilmer, 1990 Adams, 1994 Rodriguez, 1993
	NPP/B ratio	Hilmer, 1990
Benthic microalgae	Chlorophyll-a	Rodriguez, 1993
	NPP/B ratio	Baird and Ulanowicz, 1993
Macrophytes		
Submerged:	Biomass	Emmerson, 1986 Wooldridge et al., 1989
	NPP/B	Wooldridge et al., 1989
Saltmarsh:	No data	
Zooplankton		
Microzooplankton:	Density	Wooldridge, 1979 Jerling, 1993
	Dry mass	Bottrell et al., 1976 Laybourn and Finlay, 1976
	P/B	Baird and Ulanowicz, 1993
Mesozooplankton:	Density	Wooldridge, 1979 Jerling, 1993 Jerling and Wooldridge, 1995
	Biomass	Wooldridge, 1979
	Length-dry mass relationship	Wooldridge and Bailey, 1982
	P/B ratio	Jerling and Wooldridge, 1991 Wooldridge, 1986
Meiofauna	Density	Furstenberg, pers.comm.
Invertebrate Macrozoobenthos	Abundance	Emmerson, 1986 Winter and Baird, 1988 Scharler, 1992 Forbes, 1994
	Ash-free dry weight	Hanekom, 1982 Bally, 1994
	P/B	Emmerson, 1986 Heymans and Baird, 1995
Ichthyoplankton	Abundance	Harrison and Whitfield, 1990
	P/B ratio	Baird, 1988
Ichthyonekton - Smaller component	Abundance, Biomass	Beckley, 1984 Whitfield, 1994 Marais, in prep.

BIOTA	PARAMETER	REFERENCE
	Biomass	Marais, in prep.
	P/B ratio	Ratte, 1989 Baird and Ulanowicz, 1993
Ichthyonekton - Larger component	Abundance, Biomass	Marais, 1981 Daniel, 1994
	P/B	Baird and Ulanowicz, 1993

5.2.2 Diversity Indices:

Richness (Hill's N0), Diversity (Hill's N1) and Evenness (Pielou's J') Indices were calculated for various datasets of the 3 components of the Ichthyofauna as well as the invertebrate macrozoobenthos. Hill's N0 (N0 = S) is the total number of species, Hill's N1 the number of abundant species (N1 = $e^{H'}$; Shannon function: $H' = -\sum_{i=1}^{S}\left[\left(\frac{n_i}{n}\right)\ln\left(\frac{n_i}{n}\right)\right]$) and evenness is given as $\frac{H'}{\ln(S)}$ or $\frac{\ln(N1)}{\ln(N0)}$ (Ludwig and Reynolds, 1988). The input data for the calculations of these indices were densities (no·m^{-3} or no·m^{-2}) in the case of the ichthyoplankton, the smaller fish component and the macrozoobenthos, but catch per unit effort (CPUE) for the larger fish component. The type of input data, which were taken directly from the literature, is assumed to be adequate, since only a intercomparison between the Kromme, Swartkops and Sundays estuaries was attempted. It is clear, that these findings cannot be put into perspective with indices computed for other estuaries.

5.3 RESULTS:

5.3.1 Biomass and Productivity:

One feature in the calculations of the overall standing stocks and annual productions was the aerial cover of the individual estuaries, values of which include both the inter- and subtidal. Since the intertidal area of the Swartkops estuary is huge compared to the total area (approximately 360 out of 502 ha (Baird et al., 1986), the estimated standing stocks and annual productions of those biota confined mainly to the subtidal will be an overestimate and are to be treated with caution. The biomass and productivity per area or volume (Table 5.3, 5.4) are therefore far better suited for interestuarine comparisons.

5.3.1.1 Phytoplankton and Benthic Microalgae:

The pelagic algal biomass constituted approximately a fourth of the benthic microalgal biomass in the three estuaries (Table 5.2). The Kromme and Swartkops estuaries supported a low biomass in comparison to the Sundays estuary, which maintained distinctly higher values (approximately three times those of the Swartkops estuary; see Table 5.2). Productivity follows a similar pattern (Table 5.4, Fig. 5.2).

5.3.1.2 Macrophytes:

Zostera beds had the highest biomass per area in the Sundays estuary, followed by those in the Kromme estuary, whereas it was lowest in the Swartkops estuary. Nevertheless, due to the size of the

Zostera beds, the Sundays estuary supports the lowest standing stock and the Kromme estuary the highest (Table 5.2, 5.3; Fig: 5.1).

In both the Kromme and Swartkops estuaries saltmarsh macrophytes cover a bigger area and have bigger standing stocks than there submerged counterparts (Table 5.2, 5.3). The Swartkops estuary features the more extensive saltmarshes covering its vast intertidal area (Table 5.1). Although the overall standing stock of saltmarsh plants in the Swartkops estuary is about an order of magnitude higher relative to the Kromme estuary, the biomass in $mg \cdot m^{-2}$ was approximately one and a half times lower in the Swartkops (Table 5.3; Fig: 5.1). As mentioned before, no data are available on the fringing vegetation in the Sundays estuary. Their contribution to the whole system in terms of both biomass and productivity are assumed to be low, judging from to the narrow intertidal areas and consequently small aerial coverage.

Production in the three systems follows a similar pattern to that of biomass (Table 5.4), since the same P/B ratio was applied to all species in both the Kromme and Swartkops estuaries (see 5.2.1.3). The annual production of the whole estuary was biggest for both the submerged and saltmarsh macrophytes in the Swartkops estuary (Fig. 5.2).

5.3.1.3 Zooplankton:

Zooplankton standing stocks reflect a similar pattern observed for phytoplankton (Table 5.3, Fig. 5.1). In the Sundays estuary, 1.1 tons (dry wt) of mesozooplankton was measured, where 0.75 tons in the Kromme estuary seem comparatively low (Fig. 5.1). *P hessei* was the most abundant copepod in all three estuaries, followed by *A. longipatella* in the Kromme and Sundays estuaries and *A. natalensis* in the Swartkops estuary (Appendix Table 5.1). *M. wooldridgei* is the most abundant of the Mysidacea in the Kromme and Swartkops estuaries, whereas in the Sundays estuary *R. terranatalis* was more prominent (Appendix Table 5.1).

Nauplii larvae, the only microzooplankton component investigated in both the Swartkops and Sundays estuaries have a similar standing stock of 0.007 and 0.005 tons dry weight respectively.

Productivity of the mesozooplankton was approximately one and a half times higher in the Sundays estuary compared to the Kromme as well as Swartkops estuaries (Table 5.4). Overall annual production of the whole estuary, on the other hand, is again higher in the Swartkops estuary, where the vast intertidal areas were included in the calculations probably leading to an overestimate, and lowest in the Kromme estuary (Fig. 5.2).

5.3.1.4 Meiofauna:

The density, biomass and productivity of the meiofauna was higher in the Kromme compared to the Swartkops estuary (Table 5.2, 5.3, 5.4). Information on numbers and biomass of the meiofauna in the Sundays estuary was only available for the Nematoda. Relative to the Kromme and Swartkops estuaries, their numbers and biomass were the highest (Appendix: Table 5.2, 5.3, 5.4).

5.3.1.5 Invertebrate Macrozoobenthos:

The Sundays estuary sustained the overall lowest biomass and productivity of the macrozoobenthos, with 65 tons standing stock and 121 tons of production per annum (Fig. 5.1, 5.2). The overall highest biomass was estimated for the Swartkops estuary and the highest production per annum in the Kromme estuary (Fig. 5.1, 5.2).

The production to biomass ratio was lowest in the Swartkops estuary, where biomass almost equalled productivity (145 t and 157 t p.a. respectively). The Sundays estuary, on the other hand, seems the most productive - the annual production almost doubles the standing stock in the estuary. The macrobenthic productivity of the Kromme estuary takes a place in between the former two estuaries, with productivity (173 t p.a.) being approximately one and a half times bigger than the estimated standing stock (112 t) (Fig. 5.1, 5.2).

Suspension feeders were the most prominent group in terms of both biomass and productivity in all three estuaries (Table 5.3, 5.4; Fig: 5.1, 5.2). Grazers, which included the molluscs *Haminoea alfredensis*, *Assimenia ovata* and *A. globulus*, as well as the polychaete *Marphysa sanguinea*, featured as the least important contributors to the overall macrozoobenthic biomass and productivity (Table 5.3, 5.4; Fig. 5.1, 5.2; Appendix: Table 5.3, 5.4). Crustacea were the main component of the carnivores, deposit feeders as well as detritus feeders, whereas molluscs dominated grazers and suspension feeders (Table 5.3, 5.4).

The most prominent species in terms of biomass in the Kromme estuary were *Sesarma catenata*, *Paratylodiplax algoense* and *Upogebia africana*, in the Swartkops estuary *Upogebia africana*, *Assimenia ovata* and *Callianassa kraussi* and *Solen capensis*, *Upogebia africana* as well as *Nassarius kraussianus* in the Sundays estuary (Appendix, Table 5.3).

5.3.1.6 Ichthyofauna:

Ichthyoplankton:

The contribution of the ichthyoplankton to the overall biomass (Standing stock: 0.01 to 0.02 tons) and productivity (Annual production: 0.01 to 0.04 tons) in the three estuaries was minor (Fig. 5.1, 5.2). Both parameters were lowest in the Sundays estuary, but highest in the Kromme estuary.

Ichthyonekton:

A. Smaller Component:

Densities of zooplanktivores followed a similar pattern to that of phytoplankton and zooplankton in the three estuaries. The numbers were highest in the Sundays estuary (Table 5.2). The benthic feeders and mullets were most numerous in the Kromme estuary. Overall densities (measured in no per haul) were lowest in the Kromme estuary and highest in the Sundays estuary, which was mainly due to the high zooplanktivore numbers (Table 5.2). The biomass (in mg per m^2) of the smaller fish component was lowest in the Swartkops estuary (Table 5.3). In all three estuaries, the benthic feeders and mullets were the major component in terms of biomass and productivity (Table 5.3, 5.4). Zooplanktivores and piscivores reached highest values in the Sundays estuary relative to the Kromme and Swartkops estuaries (Table 5.3, 5.4)

The combined standing stock of the 4 components of the smaller ichtyhyonekton were similar in the Kromme (225 t), Swartkops (268 t) and Sundays (259 t) estuaries (Fig. 5.1). The family Mugilidae dominated in all three estuaries, and achieved particularly high biomass in the Swartkops estuary with 170 tons (Fig. 5.1), a feature which might again be attributed to the big intertidal areas in the calculations. Benthic feeders formed the second dominant group of the smaller ichthyonekton in terms of biomass, whereas the zooplanktivorous and piscivorous biomass was distinctly lower in all three estuaries (Fig. 5.1).

The comparatively high productivity (in $mg \cdot m^{-2} \cdot d^{-1}$) and annual production (in tons p.a.) in the Kromme estuary was due mostly to benthic feeders, which constituted a major proportion of the ichthyonekton production (Table 5.4). Lowest productivity (in $mg \cdot m^{-2} \cdot d^{-1}$) was estimated for the Swartkops estuary, although the calculated total annual production for the whole estuary was alike to the Kromme and Sundays estuary (Table 5.4, Fig. 5.2).

The zooplanktivorous category in the Kromme and Swartkops estuaries was best represented by *Gilchristella aestuaria* and *Atherina breviceps* (Appendix: Table 5.2). In the Sundays estuary *Ambassis gymnocephalus* took second place after *A. breviceps* (Appendix: Table 5.2). The dominant piscivores in all three estuaries were *Lichia amia* and *Argyrosomus hololepidotus* (Appendix: Table 5.2). *Rhabdosargus holubi*, *Lithognathus lithognathus* and certain species of the family Gobiidae overall dominated the biomass and productivity of benthic feeders in the Kromme estuary (Appendix: Table 5.2). The most prominent species of the benthic feeding fish in the Swartkops estuary were *R. holubi*, *Pomadasys commersonni* as well as *Galeichthys feliceps* (Appendix: Table 5.2). In the Sundays estuary, *R. holubi*, *P. commersonni* and *Monodactylus falciformis* were the three principal benthic feeders in terms of biomass and productivity (Appendix: Table 5.2). The family Mugilidae was dominated by *Liza dumerilii* in the Kromme and Swartkops estuaries and by *Mugil cephalus* in the Sundays estuary (Appendix: Table 5.2).

B. Larger Component:

The highest CPUE concerning the larger fish component was reached in the Sundays estuary (Table 5.2). In the Swartkops estuary it was the lowest, where the piscivores reached the lowest numbers. The benthic feeders were the most prominent group in terms of numbers in all three estuaries, reaching only slightly higher numbers than the mullets (Table 5.2).

Biomass (in $mg \cdot m^{-2}$) was highest in the Sundays estuary and lowest in the Swartkops estuary (Table 5.3). Piscivores contributed the major part to the biomass in the Kromme and Sundays estuaries. In the Swartkops estuary the benthic feeders achieve values similar to the piscivorous component (Table 5.3). The overall highest standing stocks were estimated for the Swartkops estuary, which again is presumed to be an overestimate (Fig 5.1).

Piscivores contributed by far the biggest part to both biomass and productivity in the Sundays estuary (Fig. 5.1, 5.2), where *Argyrosomus hololepidotus* was the most prominent piscivorous species (Appendix: Table 5.2). In the Swartkops estuary piscivores and benthic feeders reached similar values in terms of standing stock as well as production (Fig. 5.1, 5.2). *Elops machnata* dominated the piscivores, whereas *Galeichthys feliceps* and *Pomadasys commersonni* contributed the major part to both biomass and productivity for the benthic feeding component, likewise to the Sundays and Kromme estuaries (Appendix: Table 5.3, 5.4). In the Kromme estuary, benthic feeders contributed more to the annual production, although piscivores had the highest standing stock (Fig. 5.1, 5.2). *Liza richardsonii*, *L. tricuspidens* as well as *Mugil cephalus* were the most prominent species of the *Mugilidae* in the three estuaries (Appendix: Table 5.2). The highest estimates of daily production per square meter was calculated for the Sundays and Kromme estuaries (Table 5.4).

Table 5.2: Densities of various biota in the Kromme, Swartkops and Sundays estuaries. Data are mean values calculated from various surveys on the entire estuary (see 5.2: Materials and Methods). In addition, densities for the invertebrate macrozoobenthos and ichthyonekton obtained from studies conducted exclusively in the lower reaches are listed.

	Density			
BIOTA	Kromme	Swartkops	Sundays	
MACROPHYTES	Areal cover (ha)	Areal cover (ha)	Areal cover (ha)	
Submerged	20.0	15.0	8.0	
Saltmarsh	70.4	731.1	No data	
ZOOPLANKTON	no·m^3	no·m^3	no·m^3	
Microzooplankton	no data	1792 (Nauplii only)	1.2×10^7	
Mesozooplankton	4919.7	7530.0	8622.6	
MEIOFAUNA	no·m^2	no·m^2	no·m^2	
	816713.0	236090.1	1018083 (Nematoda only)	
INVERTEBRATE MACROZOOBENTHOS	no·m^2	no·m^2	no·m^2	lower reaches no·m^2
Carnivores:				
Crustacea	193.3	126.0	100.9	194.8
Mollusca	48.7		11.1	0.8
Polychaeta	3.6		5.2	6.2
Detritivores:				
Crustacea	155.9	14.4	12.6	1008.5
Mollusca	8.7			
Polychaeta	2.8		0.7	
Deposit feeders:				
Crustacea	4.3	29.3	4.5	1.4
Polychaeta			41.2	18.4
Grazers:				
Mollusca	49.4		0.1	18.6
Polychaeta	0.1			
Suspension feeders:				
Crustacea	23.7	148.2	60.6	52.6
Mollusca	1414.1	10.6	12.0	9.9

	Density					
BIOTA	Kromme		Swartkops		Sundays	
Polychaeta					283.6	
Feeding guild not identified:						
Unident. *Polychaeta*, *Oligochaeta*, Tongue worm	49.2		1.9		260.2	
ICHTHYOFAUNA						
Ichthyoplankton	no·m^3		no·m^3		no·m^3	
	3.6		3.3		2.7	
Ichthyonekton - Smaller component	CPUE (no/haul)		CPUE (no/haul)		CPUE (no/haul)	
		lower reaches		lower reaches		lower reaches
Zooplanktivores	187.8	948.3	857.3	752.0	1455.2	756.2
Piscivores	0.5	0.1	1.1	1.1	2.0	0.6
Benthic feeders	356.0	73.4	139.8	134.9	215.6	109.8
Mugilidae	437.7	85.3	87.1	196.8	115.6	140.7
Ichthyonekton - Larger component	CPUE (no/net)		CPUE (no/net)		CPUE (no/net)	
Piscivores	5.5		4.3		9.4	
Benthic feeders	11.0		9.6		11.1	
Mugilidae	10.6		8.5		9.6	

Table 5.3: Biomass of various biota in the Kromme, Swartkops and Sundays estuaries. Data are mean values calculated from various surveys on the entire estuary (see 5.2: Materials and Methods). In addition, the biomass for the invertebrate macrozoobenthos and ichthyonekton obtained from studies conducted exclusively in the lower reaches are listed.

	Biomass			
BIOTA	Kromme	Swartkops	Sundays	
	mg Chl-a·m^{-2}	mg Chl-a·m^{-2}	mg Chl-a·m^{-2}	
PHYTOPLANKTON	10.4	14.0	45.3	
BENTHIC MICROALGAE	47.7	50.8	166.2	
MACROPHYTES	mg dry wt·m^{-2} areal cover	mg dry wt·m^{-2} areal cover	mg dry wt·m^{-2} areal cover	
Submerged	229.0	80.6	131.5	
Saltmarsh	5531.5	3501.0	No data	
ZOOPLANKTON	mg dry wt·m^{-2}	mg dry wt·m^{-2}	mg dry wt·m^{-2}	
Microzooplankton	No data	1.29 (Nauplii only)	61.4	
Mesozooplankton	160.8	178.3	426.6	
MEIOFAUNA	mg AFDW·m^{-2}	mg AFDW·m^{-2}	mg AFDW·m^{-2}	
	405.4	216.2	197.6 (Nematoda only)	
INVERTEBRATE MACROBENTHOS	mg AFDW·m^{-2}	mg AFDW·m^{-2}	mg AFDW·m^{-2}	lower reaches
Carnivores				
Crustacea	7934.2	2727.8	3211.3	1343.3
Mollusca	696.6	22.4	2405.9	11.0
Polychaeta	40.4		98.4	61.6
Detritivores				
Crustacea	4828.9	551.2	127.7	104.5
Mollusca	18.2			
Polychaeta	28.0			5.0
Deposit feeders				
Crustacea	766.7	2615.2	549.0	486.0
Polychaeta			174.4	203.0

	Biomass					
BIOTA	Kromme		Swartkops		Sundays	
Grazers						
Mollusca		160.0				1.9
Polychaeta		16.0	2487.5			
Suspension feeders						
Crustacea		5067.0	19884.1		5450.3	7015.6
Mollusca		18950.0	1291.5		8121.5	333.4
Polychaeta					1417.8	
Feeding guild not identified						
Unident. Polychaeta, Oligochaeta, Tongue worm		1912.0	130.0		2634.0	
ICHTHYOFAUNA	$mg \cdot m^{-2}$		$mg \cdot m^{-2}$		$mg \cdot m^{-2}$	
Ichthyoplankton	4.7		4.7		2.5	
Ichthyonekton - Smaller component		lower reaches		lower reaches		lower reaches
Zooplanktivores	3219.6	3663.5	3174.0	1042.5	6973.8	1267.5
Piscivores	489.7	1028.5	987.2	26.0	1183.0	436.0
Benthic feeders	37657.1	23076.5	15526.3	7504.0	42135.3	9043.7
Mugilidae	40522.8	62372.9	33702.0	58.3	46223.0	26505.5
Ichthyonekton - Larger component						
Piscivores	447.7		322.7		731.1	
Benthic feeders	360.8		324.0		278.2	
Mugilidae	229.1		188.0		238.5	

Table 5.4: Producitivity of various biota in the Kromme, Swartkops and Sundays estuaries. Data are mean values calculated from various surveys on the entire estuary (see 5.2: Materials and Methods). In addition, the productivity for the invertebrate macrozoobenthos and ichthyonekton obtained from studies conducted exclusively in the lower reaches are listed.

	Productivity			
BIOTA	Kromme	Swartkops	Sundays	
	mg Chl-a·m^{-2}·d^{-1}	mg Chl-a·m^{-2}·d^{-1}	mg Chl-a·m^{-2}·d^{-1}	
PHYTOPLANKTON	0.28	1.20	22.44	
BENTHIC MICROALGAE	47.22	50.29	164.88	
MACROPHYTES	mg dry wt·m^{-2} areal cover·d^{-1}	mg dry wt·m^{-2} areal cover·d^{-1}	mg dry wt·m^{-2} areal cover·d^{-1}	
Submerged	2.26	1.15	0.88	
Saltmarsh	16.60	10.50	no data	
ZOOPLANKTON	mg dry wt·m^{-2}·d^{-1}	mg dry wt·m^{-2}·d^{-1}	mg dry wt·m^{-2}·d^{-1}	
Microzooplankton	ND	0.3139 (Nauplii only)	14.93	
Mesozooplankton	26.85	27.93	44.00	
MEIOFAUNA	mg AFDW·m^{-2}·d^{-1}	mg AFDW·m^{-2}·d^{-1}	mg AFDW·m^{-2}·d^{-1}	
	7.65	4.75	4.33	
INVERTEBRATE MACROZOOBENTHOS	mg AFDW·m^{-2}·d^{-1}	mg AFDW·m^{-2}·d^{-1}	mg AFDW ·m^{-2}·d^{-1}	lower reaches
Carnivores				
Crustacea	50.12	20.30	27.44	17.13
Mollusca	2.73	0.06	6.02	0.05
Polychaeta	1.54		1.32	0.83
Detritivores				
Crustacea	13.11	0.83	0.10	0.35
Mollusca	0.08			
Polychaeta	0.38			0.07
Deposit feeders				
Crustacea	2.46	8.38	2.77	0.55

	Productivity					
BIOTA	Kromme		Swartkops		Sundays	
Polychaeta					2.33	2.72
Grazers						
Mollusca	0.51		7.71		0.01	0.01
Polychaeta	0.21					
Suspension feeders						
Crustacea	13.69		53.69		14.72	18.94
Mollusca	77.72		5.35		34.11	1.38
Polychaeta					19.00	
Feeding guild not identified						
Unident. Polychaeta, Oligochaeta, Tongue worm	18.93		1.74		35.30	
ICHTHYONEKTON	$mg \cdot m^{-2} \cdot d^{-1}$		$mg \cdot m^{-2} \cdot d^{-1}$		$mg \cdot m^{-2} \cdot d^{-1}$	
Ichthyoplankton	0.0024		0.0001		0.0001	
Ichthyonekton - Smaller component		lower reaches		lower reaches		lower reaches
Zooplanktivores	20.93	23.81	19.71	6.48	43.32	7.87
Piscivores	0.33	0.70	0.74	0.02	0.89	0.33
Benthic feeders	41.05	25.15	10.56	5.10	28.65	6.15
Mugilidae	22.29	34.31	18.54	32.07	25.42	14.58
Ichthyonekton - Larger component						
Piscivores	0.31		0.25		0.55	
Benthic feeders	0.39		0.21		0.19	
Mugilidae	0.13		0.11		0.13	

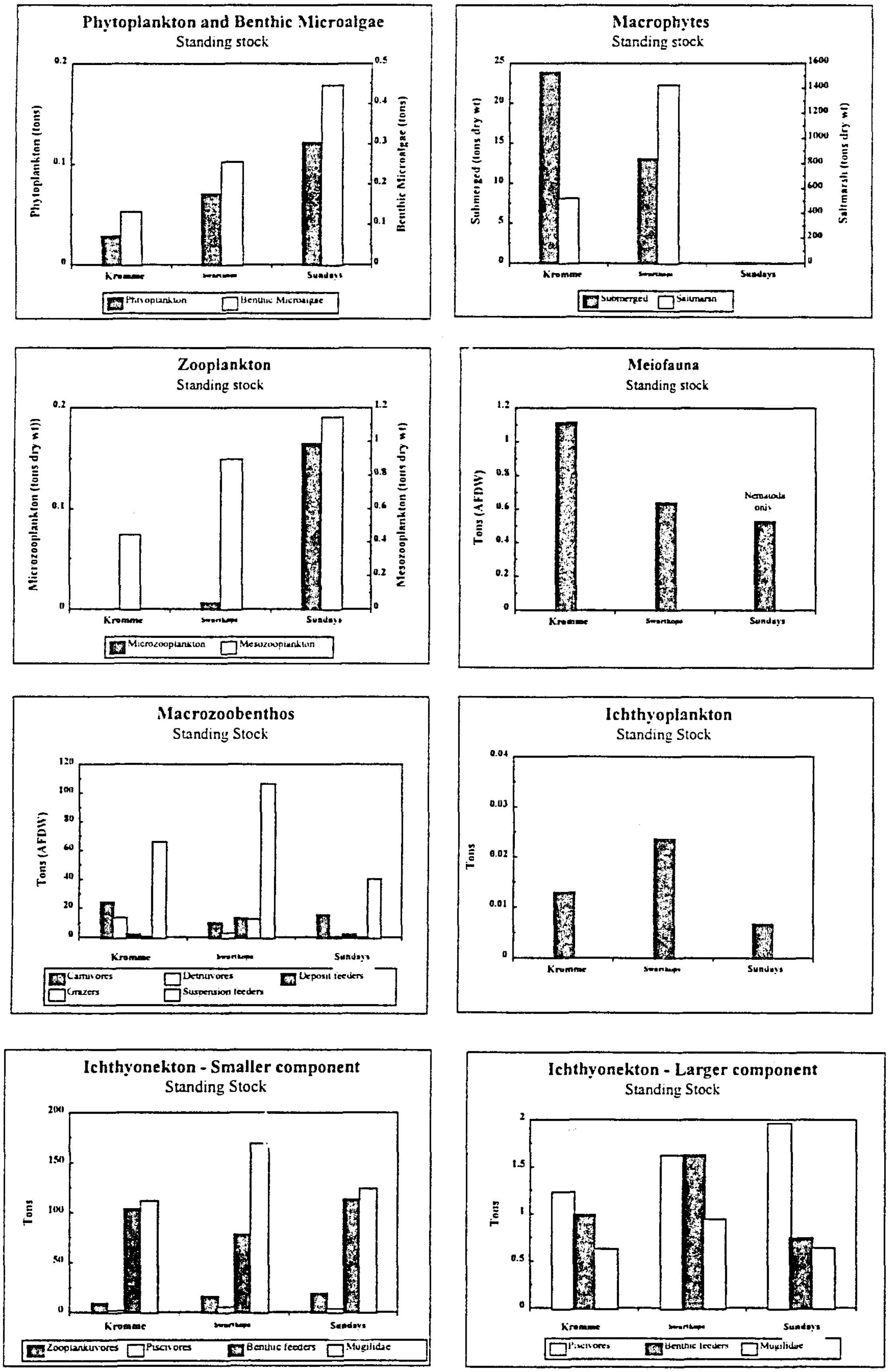

Fig. 5.1: Standing stocks of the flora and fauna in the Kromme, Swartkops and Sundays estuaries. Units are tons per estuary.

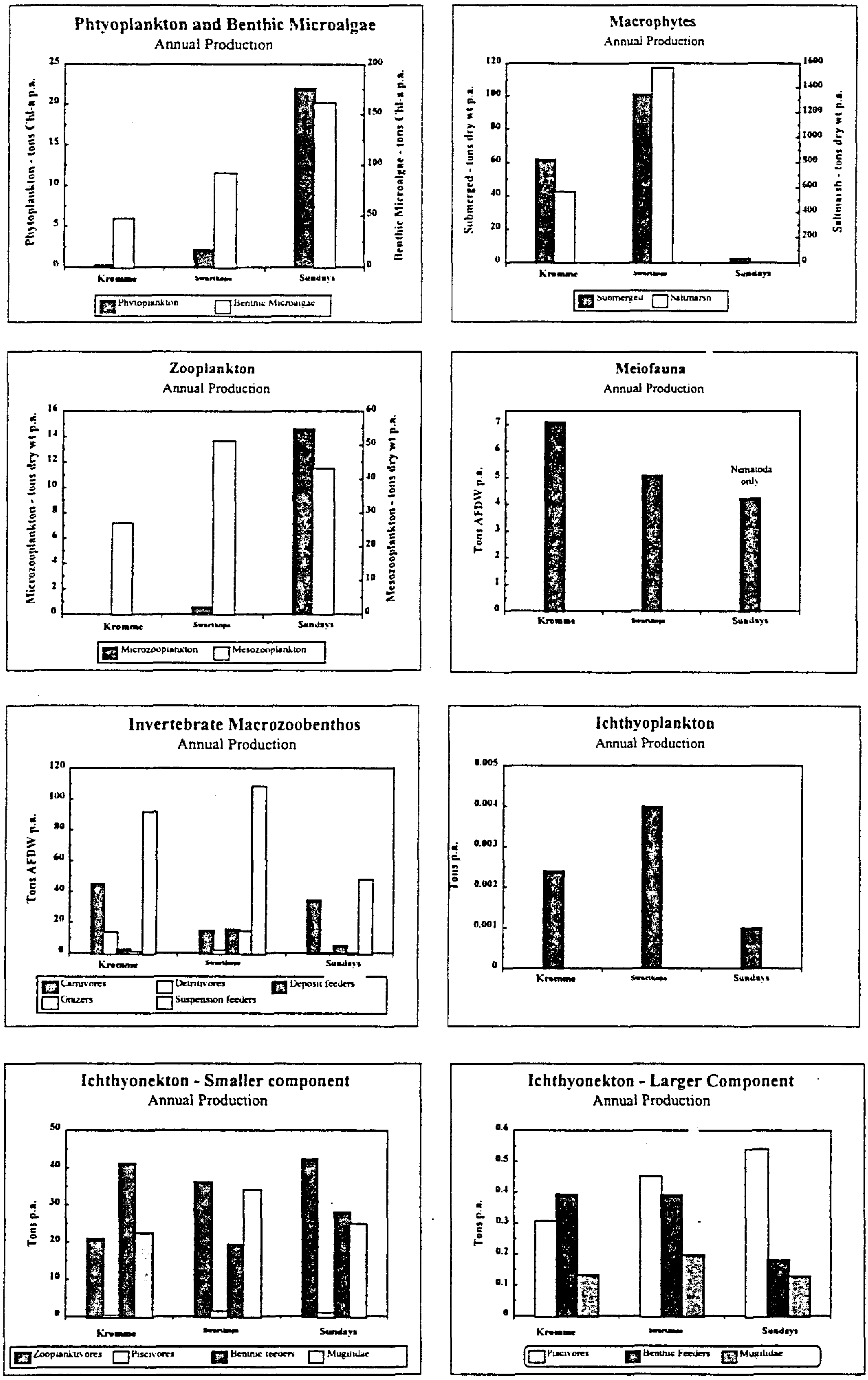

Fig. 5.2: The annual production of the flora and fauna in the Kromme, Swartkops and Sundays estuary. Units are tons per annum in the entire estuary.

5.3.2 Diversity Indices:

An acceptable set of data to calculate Richness (Hill's N0), Diversity (Hill's N1) and Evenness (Pielou) was only available for some of the biota treated so far, i.e. the invertebrate macrozoobenthos and the various components of the ichthyofauna (ichthyoplankton, the smaller and larger component of the ichthyonekton). Both densities for the various reaches in the estuaries as well as mean estuarine values were included. Furthermore, no complete dataset for the macrozoobenthos of the Swartkops estuary was available and it was therefore excluded from the analysis.

5.3.2.1 Invertebrate Macrozoobenthos:

Surveys of the entire length of the estuary indicate a decrease in the total number of species (N0) towards the upper reaches in both the Kromme and the Sundays estuaries. In the lower reaches the Sundays estuary was comparatively richer in species (Fig. 5.3A). To the contrary, the species diversity - here presented by Hill's N1, the number of abundant species - is higher in the Kromme estuary. Regarding the datasets for the entire estuary, fewer species dominate towards the upper reaches, i.e. the macrozoobenthic community becomes less diverse (Fig. 5.3B). Regarding evenness, no great fluctuations along the length of the Kromme and Sundays estuaries were prominent, and in general, the abundances of the various macrobenthic species in the Sundays estuary were less evenly distributed compared to the Kromme estuary (Fig. 5.3C).

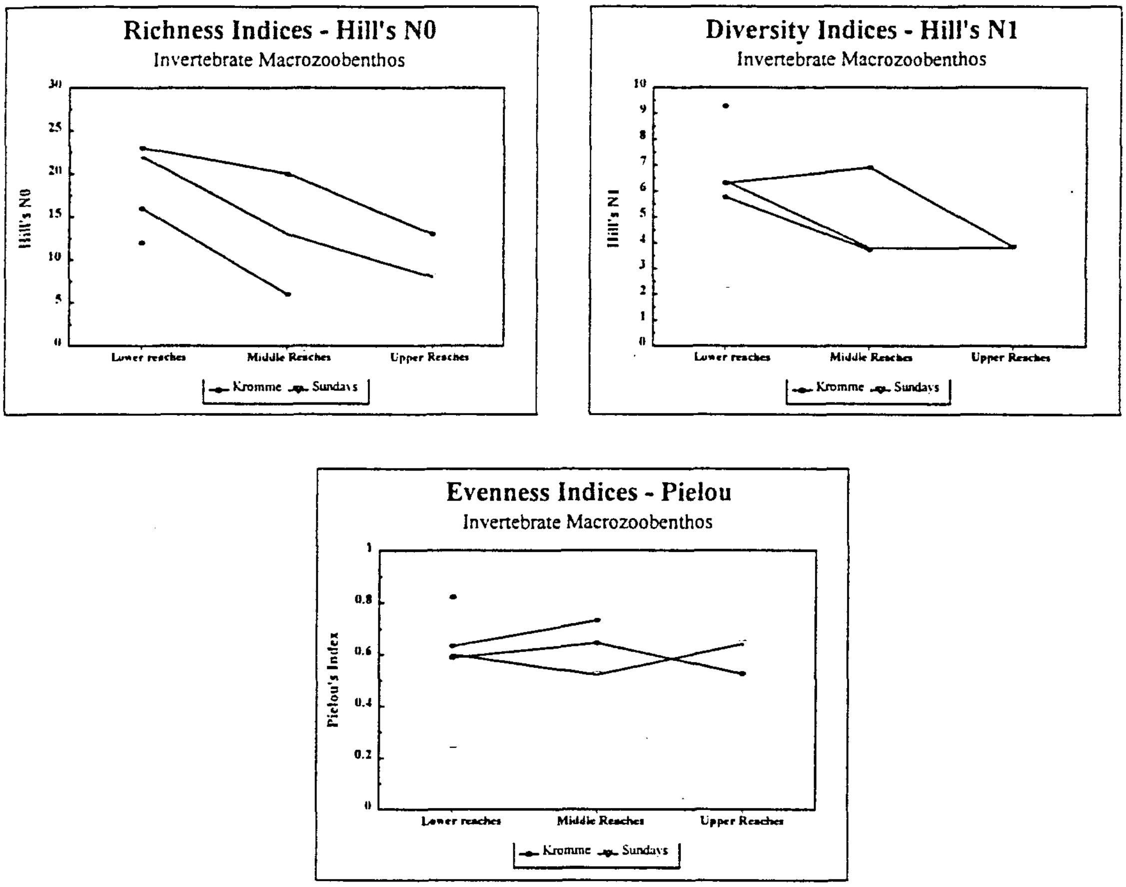

Fig. 5.3: Richness (Hill's N0 = S)), diversity (Hill's N1 = $e^{H'}$; Shannon function: $H' = -\sum_{i=1}^{S}\left[\left(\frac{n_i}{n}\right)\ln\left(\frac{n_i}{n}\right)\right]$) and evenness ($\frac{H'}{\ln(S)}$ or $\frac{\ln(N1)}{\ln(N0)}$) indices(Ludwig and Reynolds, 1988) calculated for the invertebrate macrozoobenthos in the Kromme and Sundays estuaries.

5.3.2.2 Ichthyofauna:

Ichthyoplankton:

Ichthyoplankton data for the various reaches of the estuary were available only in the case of the Sundays estuary. The straight lines in Figs. 5.4 for the Kromme and Swartkops estuaries denote a mean estuarine value. The ichthyoplankton in the Swartkops estuary was the species richest, the most diverse and showed the highest evenness. Regarding the Sundays estuary, its middle reaches were the species richest, but in the lower reaches the number of abundant species was higher (Fig. 5.4 A,B,C).

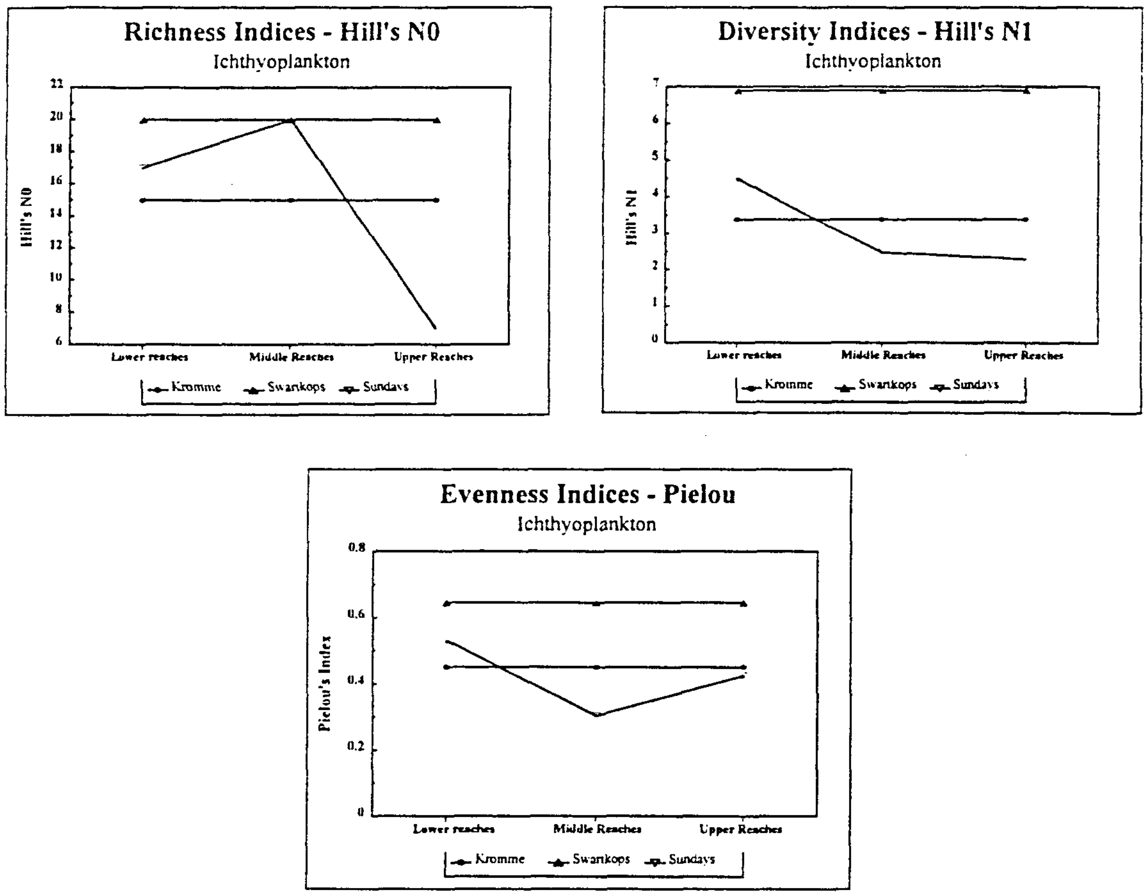

Fig. 5.4: Richness (Hill's N0 = S), diversity (Hill's N1 = $e^{H'}$; Shannon function: $H' = -\sum_{i=1}^{S}\left[\left(\frac{n_i}{n}\right)\ln\left(\frac{n_i}{n}\right)\right]$), and evenness ($\frac{H'}{\ln(S)}$ or $\frac{\ln(N1)}{\ln(N0)}$) indices (Ludwig and Reynolds, 1988) calculated for the ichthyoplankton in the Kromme, Swartkops and Sundays estuaries. Datapoints connected via a straight line between the lower and upper reaches denote one mean value for the entire estuary.

Ichthyonekton:

A. Smaller Component:

The smaller component of the ichthyonekton in the Kromme estuary was the poorest in species richness compared to the Swartkops and Sundays estuaries (Fig. 5.5 A). The straight lines for the indices for the Sundays estuary in Figs. 5.5 indicate a mean estuarine value. The diversity indices show no definite trends between the reaches of the estuaries. The Kromme estuary featured the highest numbers of abundant species, as well as the highest evenness compared to the Swartkops and

Sundays estuaries (Fig. 5.5). The Sundays estuary features lowest concerning the latter two parameters.

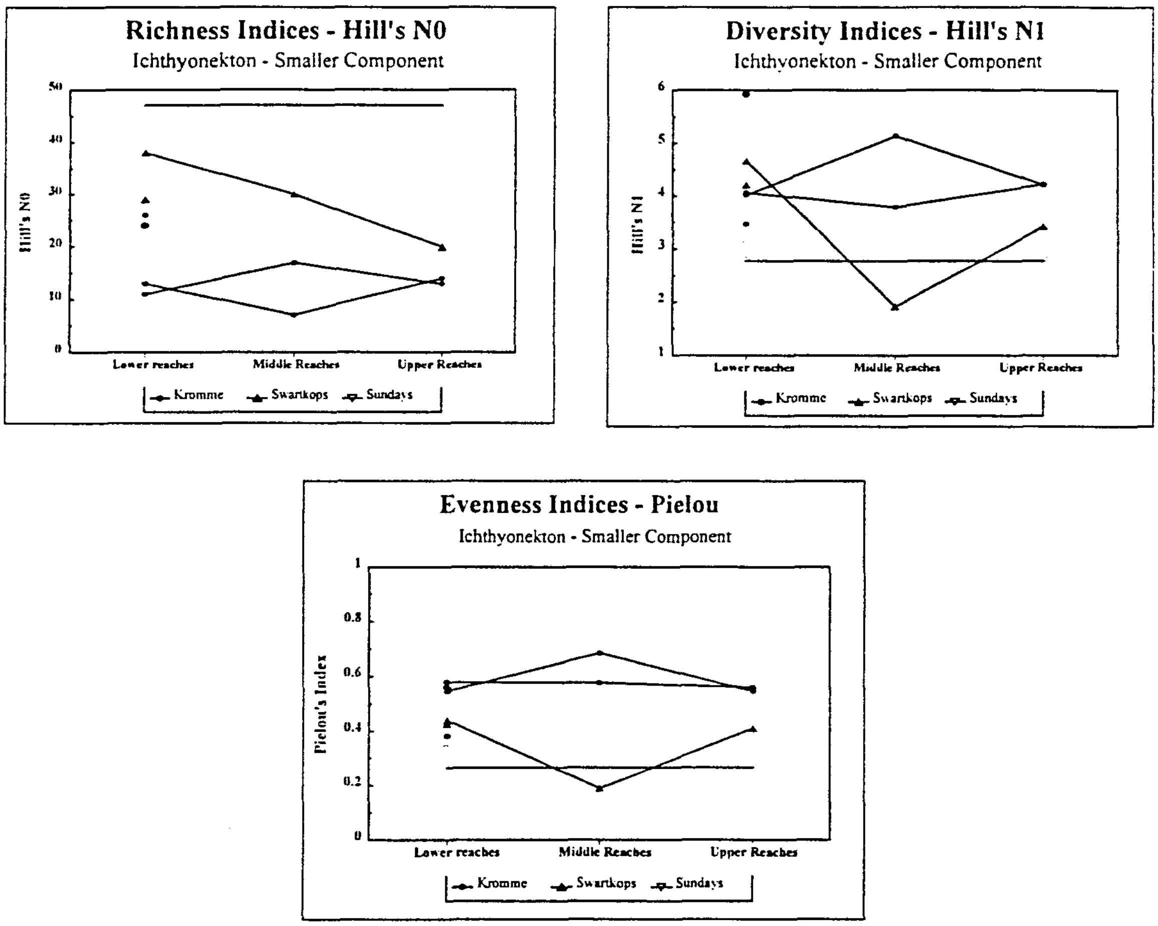

Fig. 5.5: Richness (Hill's N0 = S), diversity (Hill's N1 = $e^{H'}$; Shannon function: $H' = -\sum_{i=1}^{S}\left[\left(\frac{n_i}{n}\right)\ln\left(\frac{n_i}{n}\right)\right]$), and evenness ($\frac{H'}{\ln(S)}$ or $\frac{\ln(\mathrm{N1})}{\ln(\mathrm{N0})}$) indices (Ludwig and Reynolds, 1988) calculated for the smaller component of the ichthyonekton in the Kromme, Swartkops and Sundays estuaries. Datapoints connected via a straight line between the lower and upper reaches denote one mean value for the entire estuary.

B. Larger Component:

The upper estuarine reaches of all three estuaries seem to support a slightly smaller number of species than the lower regions. The number of abundant species shows a similar pattern in most cases. Taking all reaches into account, differences between the lower and middle reaches seem to be the biggest. Evenness shows in general little variation between the reaches. No definite trend can be seen between the three estuaries, none exhibits either highest or lowest values overall (Fig. 5.6 A,B,C).

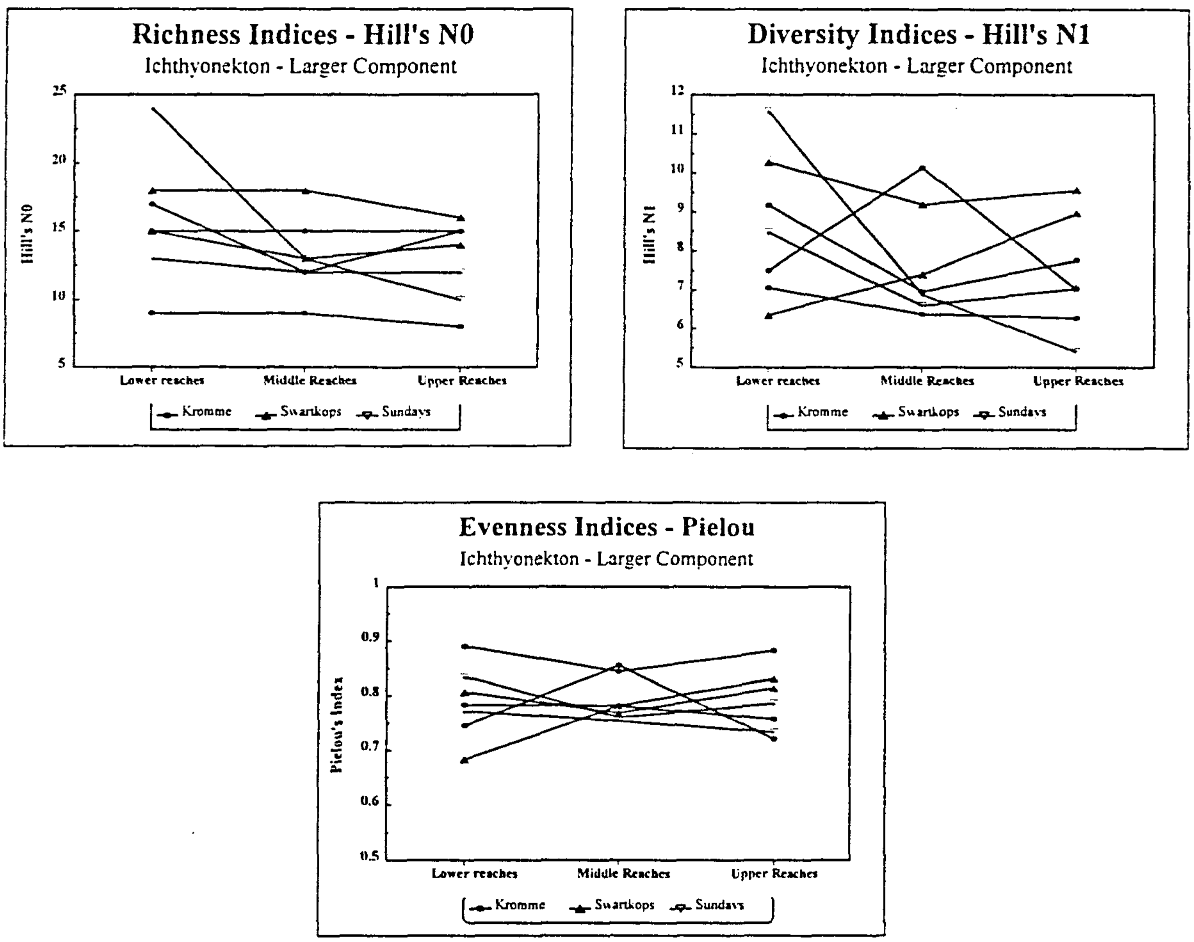

Fig. 5.6: Richness (Hill's N0 = S), diversity (Hill's N1 = $e^{H'}$; Shannon function: $H' = -\sum_{i=1}^{S}\left[\left(\frac{n_i}{n}\right)\ln\left(\frac{n_i}{n}\right)\right]$), and evenness ($\frac{H'}{\ln(S)}$ or $\frac{\ln(N1)}{\ln(N0)}$) indices (Ludwig and Reynolds, 1988) calculated for the larger component of the ichthyonekton in the Kromme, Swartkops and Sundays estuaries.

5.4 DISCUSSION:

The purpose of this study was initially to relate biomass and productivity in the Kromme, Swartkops and Sundays estuaries to freshwater supplies and the resulting salinity regime in the individual system. With the exception of those biota directly subjected to variations in 'new' nutrient supplies via the freshwater inflow, i.e. microalgae and zooplankton, the various biota do not seem to be influenced by variable freshwater input in a direct cause and effect relationship. It is rather the indirect effect of variable freshwater inflow on the hydrodynamics and sedimentation patterns in the estuary, which affects the flora and fauna. Different current velocities as well as changes in sediment composition (i.e. mud or sand) might favour or disfavour the encroachment of macrophytes, and in turn build new or destroy habitats for various macrobenthic and fish species. The nature of habitats in the Kromme, Swartkops and Sundays estuaries therefore seem more important in structuring certain biotic communities than the presence/absence of a salinity gradient along the longitudinal axis of the respective estuary. These habitat changes are brought about by the amount of freshwater received by the individual estuary, measured on a time scale of hours or days, e.g. floods, to several years or decades, e.g. a continuous in- or decreased freshwater supply to the system overall.

5.4.1 Salinity, nutrients and microalgae:

The salinity regime and freshwater supply to the Kromme, Swartkops and Sundays estuaries are described in detail in chapter 3. In a brief summary: the Sundays estuary has a fairly steady freshwater inflow of approximately 1 $m^3 \cdot sec^{-1}$ and experiences floods on a regular basis. To the contrary, the Kromme estuary has a fairly high chance of developing hypersalinities in the upper reaches during dry years, a situation developed as a cause of increased water abstraction along the Kromme river. The dams on the river decrease any flood smaller than 1 in 30 years and freshwater supply at the head of the estuary is an occurrence combined with overspills at the Impofu dam situated 4 km from the tidal head. Salinity regimes in the Swartkops estuary vary from occasional hypersalinities in the upper reaches under drought conditions to floods on a regular basis and is not considered to be in any danger of becoming a marine dominated system throughout. These varying freshwater supply and flood regimes caused different habitat structures in the Kromme, Swartkops and Sundays estuaries.

The direct influence of freshwater inflow on the concentrations of various inorganic nutrients and phytoplankton in the estuaries is dealt with in chapter 4. Results mirrored freshwater supply situations in all three estuaries as well as their pollution status. A situation, which leaves the Kromme estuary as the comparatively poorest system in terms of nutrients as well as chlorophyll-a, for both the pelagic and benthic microalgae. The Sundays estuary supports a high biomass of pelagic microalgae and occasional blooms, due to a continuous nutrient supply and favourable hydrodynamic conditions in the estuary, i.e. a stratified water column combined with a long enough residence time to enable the development of blooms. Systems like the Kromme and Swartkops estuary are probably not able to develop similar standing stocks of phytoplankton to the Sundays estuary even if the nutrient supply would be sufficient, due to the lack of aforementioned hydrodynamic conditions.

5.4.2 Macrophytes:

In the Kromme estuary reduced current velocities and clear waters brought about by reduced freshwater inflow favoured the growth of existing macrophyte populations and in addition the establishment of new populations (Adams et al., 1992). Since the nutrient pool is hardly ever renewed in the Kromme estuary, nutrient recycling in the sediment apparently suffices the growth of macrophytes. A similar situation is found in the Kariega estuary, where increased water abstraction in the catchment area lead *Zostera* to colonise the entire length of the estuary (Hogdson, 1987). Saltmarshes now extend into the upper reaches of the Kromme estuary, whereas brackish macrophyte communities are absent (Adams et al., 1992), a direct result of reduced freshwater inflow and high salinities. The Swartkops estuary meanders through extensive saltmarshes. Submerged macrophytes, on the other hand, formed small patches in the estuary, but not to an extent as in the Kromme estuary. In the Sundays estuary, the colonisation of submerged macrophytes has not taken place to a great extent (Emmerson, 1986; Wooldridge, 1989), despite a continuos 'new' nutrient input. Current velocities, relatively low salinities as well as turbidity most probably deny submerged macrophytes to take root in the river bed. Only *Caulerpa filiformis* colonised a small patch near the mouth (Wooldridge et al., 1989), where the crossectional area increases and sheltered areas are present. Saltmarsh plants, on the other hand, are restricted by the lack of space to build up sizeable populations in the Sundays estuary.

5.4.3 Zooplankton:

The zooplankton populations in the three estuaries are a reflection of the salinity regimes, nutrient status and phytoplankton standing stocks - the Sundays estuary once more supports the highest biomass of mesozooplankton, whereas in the Kromme estuary it was the lowest. There is no difference in the species composition between the three estuaries, although the Kromme estuary can only support an impoverished fauna. Especially densities of species preferring less saline waters (e.g. *Acartia natalensis*, *Rhophalophthalmus terranatalis*) continually subside in a system with inadequate freshwater inflow (Jerling and Wooldridge, 1994).

The quality of available food will be better in freshwater dominated estuaries, since phytoplankton dominates the seston in systems with adequate freshwater input, but detritus in freshwater starved estuaries (Grange, 1992). Directly affected are mysids in subadult stages as well as copepods, which feed mainly on detritus as well as phytoplankton. In turn, adult mysids will be influenced by the standing stock of copepods, which substantiate the diet of adult mysids (Wooldridge and Bailey, 1982; Jerling and Wooldridge, 1995). Comparisons of the Great Fish and the Kariega estuary (which are similar systems to the Sundays and Kromme estuaries respectively), showed that an increase in freshwater inflow will result in higher zooplankton standing stocks (Grange, 1992). After a freshwater pulse into the Kromme estuary a similar increase of copepods, followed by mysids with a delay of one month was noted (Jerling and Wooldridge, 1994, 429). The food availability, which increases with freshwater inflow, seems more effective for an increase in zooplankton biomass, than mere alterations of the physical environment (i.e. salinity) suitable to zooplankton species. But continuous alterations thereof can eventually affect species composition, due to inadequate breeding conditions for certain species within the zooplankton community (Jerling and Wooldridge, 1994; Grange, 1992). In the Sundays estuary, where phytoplankton standing stocks are high (Hilmer and Bate, 1990; Jerling and Wooldridge, 1995; Chapter 4, this thesis), no grazing impact of the zooplankters was detected (Jerling and Wooldridge, 1995). Food availability therefore does not seem to be a limiting factor for zooplankters, and standing stocks remain high. The zooplankton density in turn is probably controlled by the abundant zooplanktivorous fish, circumstances which might also secure high phytoplankton densities in the Sundays estuary (see also Table 5.2, 5.3).

5.4.4 Invertebrate Macrozoobenthos:

Similar to the macrophyte population, the densities as well as biomass of the intertidal invertebrate macrozoobenthos was lowest in the Sundays estuary. A feature, which is, similar to macrophyte populations, subscribed to a lack of available areas for colonisation. Direct comparisons of the entire macrozoobenthic community between the Kromme, Swartkops and Sundays estuaries were not possible, due a lack of a complete dataset regarding the Swartkops estuary. The one available dataset of a complete survey of the entire estuary featured the ten most prominent species only (Hanekom et al., 1988). The biggest difference of the macrobenthic communities in the Kromme and Sundays estuaries can be seen in terms of detritivores, which rank more prominently in terms of numbers in the Kromme compared to the Sundays estuary. This might be a result of increased detritus production by the macrophyte populations of the Kromme estuary. Grazers as well as suspension feeders reach higher numbers in the Kromme compared to the Sundays estuary, but deposit feeders were more numerous in the Sundays estuary. Suspensoid feeding invertebrates are known to increase in marine dominated systems through increased detritus production (Boaden and Seed, 1985; Hodgson, 1987).

The biomass of certain species was higher for carnivores, detritivores and suspension feeders in the Kromme estuary, especially when associated with saltmarshes or *Zostera* beds, whereas deposit feeders and grazers were the more prominent in the Swartkops estuary (Appendix: Table 5.3).
In terms of densities of the macrozoobenthos, space availability or habitat structure seems to overrule the influence of a particular salinity regime in at least the Kromme and Sundays estuaries. The *Zostera* beds and saltmarsh areas in the intertidal seem to favour macrozoobenthic densities in the Kromme estuary through increased food supply (especially for detritus feeders) as well as shelter from predators and water currents. In the Kariega estuary, similar conditions prevail which favour high macrobenthic standing stocks, highest ones which were found in the *Zostera* beds themselves (Hodgson, 1987). In the case of the Kromme, Swartkops and Sundays estuaries, positive correlations between *Palaemon pacificus* and *Zostera* proved highly significant (Emmerson, 1986).

Stable conditions in an estuary also contribute to higher standing stocks, and they might exert a positive impact on species diversity, which conforms with results from this study (see Fig. 5.3). In estuaries in general, few species dominate the community (Hanekom et al., 1988; Whitfield, 1989), which is due to variable environmental conditions. If conditions are stable, i.e. a continuous low freshwater input into the Kromme estuary, macrophytes are able to encroach and therefore increase macrozoobenthic biomass on the whole (e.g. de Decker and Bally, 1985; Montague and Ley, 1993), a phenomenon which seems to support the relatively high macrozoobenthic biomass in the Kromme estuary. Macrophyte cover might, of course, limit the distribution of species preferring sandy or muddy habitats, but in general seems to enhance standing stocks (e.g. Whitfield, 1989; Kaletja and Hockey, 1991).

Habitat structure overall seems to be at least an equally important factor next to salinity controlling invertebrate macrozoobenthic communities in the relatively small South African estuaries. The reason why the Kromme estuary can support a fairly high macrobenthic density and biomass is mainly due to the macrophyte beds . On the other hand, freshwater inflow has a positive influence on the productivity, which is apparent from the higher production per m^{-2} estimated in the Sundays relative to the Kromme estuary. In fairly big estuaries with a continuous freshwater inflow, which creates different physical environments for various species from the lower to the upper reaches, the macrobenthic community will be negatively influenced, once the freshwater supply ceases, due to a loss of habitats directly dependent on freshwater. A study on two estuaries with differing freshwater input (Montague and Kalke, 1992) revealed that in a system with continuous supply of freshwater (Guadalupe), macrobenthic density and biomass increased with decreasing salinity, whereas in the Nueces, which is freshwater starved, density and diversity increased with increasing salinity due to marine species inhabiting the lower reaches of the estuary. In the Kromme estuary, marine species even migrated and inhabited the region right near the tidal head, such as species of the genus Balanus and Aurelia (pers. obs.; Bentley, 1989). Overall, density and biomass were higher in the estuary exhibiting a salinity gradient along its longitudinal axis (Montague and Kalke, 1992), which might be due to the variety of habitats created along the salinity gradient.

5.4.5 Ichthyofauna:

5.4.5.1 Ichthyoplankton:

In all three estuaries only a few species dominated the ichthyoplankton community in the Kromme, Swartkops and Sundays estuaries (Melville-Smith, 1981; Melville-Smith and Baird, 1980; Harrison and Whitfield, 1990). The number of species was higher in the Sundays and Swartkops estuary than in the Kromme estuary (Melville-Smith, 1981; Melville-Smith and Baird, 1980; Harrison and Whitfield, 1990). The high abundance encountered in the Kromme estuary is probably a result of the sampling strategy, since most of the data gathering (in January, June and November) was concurrent with highest ichthyoplankton densities of the year. The yearly average for the Kromme estuary seems therefore an overestimate.

Fishlarvae seem mainly distributed according to food resources. Harrison and Whitfield (1990) recorded higher numbers in the middle and upper reaches of the Sundays estuary, which coincided with high zooplankton stocks in these reaches. The fishlarvae may even follow vertical zooplankton migration patterns during the night (Whitfield, 1989). Since zooplankton is the major prey of fishlarvae (Whitfield, 1985; Harrison and Whitfield, 1990), freshwater inflow exerts an influence on ichthyoplankton densities and biomass via the nutrient input and phytoplankton production.

5.4.5.2 Ichthyonekton:

Not only the invertebrate macrozoobenthos but also the ichthyonekton is seemingly affected by macrophyte communities in an estuary. Despite the lack of a longitudinal salinity gradient in the Kromme estuary, the density and biomass of the benthic feeding ichthyonekton is high. Although the larger component of piscivorous fish have a higher standing stock, the benthic feeders are more productive. Eelgrass beds can draw the fish fauna through increased food supply (epibenthic algae, detritus, epifauna) and increased shelter from predators, similar to the invertebrate macrozoobenthos.

Habitat structure exerts an influence on the fish fauna, be it substrate (muddy vs. sandy), the presence of intertidal flats, or macrophyte communities (Beckley, 1983; Whitfield, 1993). Although fish can adapt to a changing environment in terms of feeding habits and deviate from their normal diet (Hecht and van der Lingen, 1992; Whitfield, 1980; Whitfield, 1988), the density of the fish fauna has often be found to be in accordance with food supply. Higher densities can be expected in areas which increased detrital input from surrounding macrophyte stands (Whitfield, 1980; Beckley, 1983; Plumstead et al., 1991), around eelgrass beds (Marais and Baird, 1980; Whitfield, 1980; Hanekom and Baird, 1984), or simply in accordance with the distribution and density of the preferred prey (Marais and Baird, 1980 Marais, 1981; Marais, 1982).

Mullets incorporate detritus and microalgae in different proportions into their diet, according to availability (Whitfield, 1988). The Sundays estuary, where benthic microalgal stocks are high, can therefore support high densities and biomass of Mugilidae (Table 5.3), despite the lack of extensive eelgrass beds. The distribution of mullet seems especially closely linked to food supply, becoming apparent from different behaviour of the various species after floods (Marais, 1982). Increasing numbers were encountered in the Swartkops estuary, where food supply increased due to the deposition of mud and silt, whereas in the Sundays estuary the rich sediment surface layer was swept out of the estuary and the abundance of mullets increased only after a couple of months.

Several authors found positive relationships between fish abundance and longitudinal salinity gradients (e.g. Marais, 1983; Marais, 1988; Whitfield, 1994), but a salinity gradient does not exclusively determine fish densities in an estuary (see Table 5.2). Notable though are the higher abundance of zooplanktivores in the Sundays estuary, a direct result of higher zooplankton biomass supported by a highly productive phytoplankton community. In this respect, freshwater inflow clearly dictates the abundance of part of the fish fauna. The number of benthic feeders on the other hand, is reduced in the Sundays estuary by most probably diminished food resources, i.e. the lower standing stocks of macrozoobenthos, eelgrass beds as well as lower detritus production from primary producers. To the contrary, catchment size and regular freshwater input influence the large pelagic predators (Marais, 1988; Marais, 1996), which can explain the high abundance and biomass in the Sundays estuary. In the Swartkops estuary angling pressure does influence the densities of targeted species, abundances of which have decreased over the years for certain species (Daniel, 1994).

5.4.6 General considerations:

Several biotic communities in estuaries are directly related to freshwater inflow and nutrient input, including phyto- and zooplankton as well as small fish preying on the former. Indirect effects of freshwater inflow are apparent from macrophyte communities, macrozoobenthos and the ichthyonekton, especially the benthic feeders (including mullets). The variable freshwater inflow in the Kromme, Swartkops and Sundays estuaries has both positive and negative effects on the various biota. A continuous freshwater inflow had positive effects on those biota under direct influence through a sustained nutrient supply and an established longitudinal salinity gradient, whereas a decreased or absent freshwater inflow indirectly influenced the biota. The Kromme estuary was still able to harbour a rich fish fauna despite the increased marine influence on the system, although phyto- and zooplankton stocks might be depleted and salinity gradients greatly reduced or absent. Since the completion of the Impofu dam in 1983 the energy pathways in the Kromme estuary have most probably shifted towards a more detritus based system, due to the reduced phytoplankton production and encroachment of macrophytes into the system.

Overall, it seems that nutrient input via freshwater inflow at the tidal head of the Kromme, Swartkops and Sundays estuaries was of greater importance for the density and biomass of certain biota than the actual establishment and maintenance of a longitudinal salinity gradient. Shifts in species composition as a direct result of a reduced longitudinal salinity gradient was apparent for the smaller planktonic communities (e.g. Jerling and Wooldridge, 1994).

In terms of macrozoobenthos and the ichthyofauna, on the other hand, a longitudinal salinity gradient does not seem to have a major influence on community structure. Species are tolerant of salinity fluctuations, therefore sediment structures as well as food resources are probably equally important than physical environmental factors. Salinity could not be identified as the exclusive determinant of macrozoobenthic community structure in several studies, e.g. McLachlan and Grindley, 1974; Whitfield, 1989; Forbes, 1994, Schlacher, in press. Bulger et al. (1993) identified various salinity zones preferred by certain fishes and invertebrates. But a species, even when being more abundant in a certain salinity zone, is not necessarily limited to that one zone, but might well be part of a community of a different salinity zone (Bulger et al., 1993). Fish species are usually tolerant to salinity variations, especially of low salinities (Whitfield, et al., 1981), and are therefore not limited to a particular salinity zone in the estuary. Food resources have probably an even greater influence on fish abundance and biomass than on the invertebrate macrozoobenthos.

Another crucial difference between the Kromme, Swartkops and Sundays estuaries is the stability of the systems in terms of freshwater input and hydrodynamic conditions. Ecosystem stability favours diversity and abundance of biological communities. The species are not required to be able to adapt to frequent changes in their physical environment, and control over certain populations due to these changes will simply be lost in stable environments. Several authors make reference to the effect of the stability of the estuarine environment on various biotic communities (Whitfield, 1980; de Decker and Bally, 1985; Hodgson, 1987; Marais, 1988; Adams and Talbot, 1992; Grange, 1992; Montague and Ley, 1993). Estuaries are usually very dynamic ecosystems, which go through various succession states, which in turn can be reset by certain environmental influences (e.g. floods) (Whitfield and Bruton, 1989). The Swartkops and Sundays estuaries are subject to floods on a regular basis as well as variations in freshwater inflow (see chapter 3), whereas the dams on the Kromme river inhibit freshwater inflow at most times and in addition the regular floods large enough to reset the whole system to an earlier successional state. Therefore the Kromme estuary as a whole is a much more stable environment than both the Swartkops and Sundays estuaries, which might also favour its relatively high biomass. In resetting the estuarine systems, floods reduce biomass and diversity for a short period of time, since most of the fauna and flora will be swept out to sea.

Results from this study showed, that freshwater inflow (present or absent) is a great determinant in the structuring as well as the production rate of the various communities in an estuary. These findings are in accordance with Allanson and Read (1995), who investigated three similar estuaries (Kariega, Keiskamma and Great Fish) and also observed a switch from a pelagic food chain in a freshwater dominated system (Great Fish) to a detritus based system (Kariega). Human influences, which nowadays form a major part in determining certain ecosystem structures, might not necessarily destroy estuarine habitats through river impoundment, as is apparent from the Kromme estuary. Up to this date, the system is well functioning and productive, and only certain species, especially in the pelagic food chain are thus far affected to a certain extent. Long term effects (10 years and more) of man induced changes (i.e. a continuous water abstraction) will probably include species loss as well as a further shift in species composition, with the system becoming more and more marine dominated. Especially temporarily closed estuaries will be affected by the loss of the scouring effect of floods, since many species migrating between estuaries and the sea will be interrupted in their developmental stages (Wooldridge, in press; Whitfield and Wooldridge, 1994), which in turn can result in an impoverished estuarine fauna. Freshwater input into estuaries is not only of importance to the estuary itself, but equally for onshore regions, which can benefit in various ways, such as higher nutrient input, clues for various species to migrate in and out of the estuary in various developmental stages. Especially commercial fisheries are subject to the recruitment patterns of the targeted species (e.g. Gammelsrød, 1992). The riverflow therefore creates unique environmental conditions not only in river ecosystems, but also in estuaries and nearshore oceanic regions. A disruption of riverflow through dams, weirs and other obstructions, therefore disturbs the functioning of all these ecosystems.

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CHAPTER 6

RECOMMENDATIONS FOR FUTURE RESEARCH

Chapters 1 to 5 of this report presented comprehensive data and results on a comparative study between the Kromme, Swartkops and Sundays estuaries in respect to their physico-chemical variables, nutrient input and concentrations, as well as the productivity, diversity and biomass of their biota. During the course of this study it also became clear, however, that there is a lack of data for certain biotic components, and on some of the physical and chemical properties of each of the three systems. The details thereof will be discussed in this chapter.

Research on the above mentioned estuaries is of considerable range and extent, and data on these systems have been collected by the University of Port Elizabeth since the 1970's. Datasets for certain biotic communities therefore are available, although some datasets are inadequate and on certain biota information has yet to be collected. Furthermore, some biota have been sampled too many years ago to be representative for the present times. For comparative purposes as well as to ascertain the ecological and conservational status of the estuary, further studies on various biota in the three estuaries are of future interest. During the present study, we found inadequate datasets, or only historic data (more than 10 or 15 years old) for the communities listed below. The particular feature of the data missing on certain biota are given in brackets (i.e. areal cover, abundance, biomass, productivity, etc.):

- Benthic microalgae (productivity) in the Kromme, Swartkops and Sundays estuaries.
- Submerged macrophytes (areal cover, biomass, productivity) in the Swartkops and Sundays estuaries.
- Saltmarsh macrophytes/fringing vegetation (areal cover, biomass, productivity) in the Sundays estuary, as well as the productivity for various species in all three estuaries.
- Microplankton, i.e. planktonic organisms smaller than 200 µm in size (abundance, biomass, productivity) in the Kromme and Swartkops estuaries.
- Mesoplankton, mainly zooplankton > 200 µm in size (abundance, biomass for certain species, productivity) in the Swartkops estuary.
- Meiofauna (biomass, productivity) in the Sundays estuary.
- Inter- and subtidal macrobenthos (abundance, biomass and productivity of certain species) in the Swartkops estuary.

- Ichthyoplankton (abundance for all seasons, biomass, productivity) in the Kromme and Swartkops estuaries.
- The smaller component of the ichthyonekton (abundance, biomass, productivity) in the Sundays estuary.

For further detail on the availability of information of certain biota in the Kromme, Swartkops and Sundays estuaries, see Chapter 5.

A good knowledge of the biota at the present time is of cardinal importance from both scientific and management points of view. The intercomparison of ecosystems is most effective if datasets of biotic and abiotic variables are available for the same period of time for those systems under study. Secondly, changes (or the lack thereof) over a certain period of time in each individual system can be monitored only in the case where data are available for comparison (i.e. datasets obtained in different years). Therefore it is not adequate to survey an ecosystem only once, but to continue monitoring it during the following years. Monitoring ecosystems to detect changes brought about by reduced freshwater input, increased pollution, angling pressure, bait collection and other anthropogenic influences plays obviously an important part in the management of such a system. The recent report by Baird and Heymans (1996) on changes in the Kromme estuarine ecosystem attributed to freshwater input patterns highlights the importance of adequate data in comparative ecosystem ecology. In addition, changes of ecosystems over time could be compared with changes brought about by anthropogenic influences and their impacts assessed from a holistic, ecosystem perspective. No effective management strategy can be employed to a systems where adequate knowledge does not exist. Therefore the status of the estuaries must be evaluated through continuous monitoring.

Another part of the biotic environment so far completely ignored are the planktonic and sediment microbiota (bacteria, protozoa). Microbiota play an important role in two ways. Firstly, bacteria and protozoa are major components of the the microbial loop and the remineralization of essential elements (N, P, Si, etc.) in a system. Little effort has been directed to these communities and their role in South African estuaries. Secondly, these microbiota are good indicators of the pollution status of a system due to their high nutrient throughput and high turnover rates. They also constitute important components of the foodweb for many zooplankters, filter- and deposit feeders. Studies of the microbiota as pollution and water quality indicators go hand in hand with research on the behaviour of aquatic ecosystems on a global basis conducted in other zoological fields. Pollution studies are an integral part of estuarine research in many countries, but intensive research in this particular field is lacking to a great part in South Africa.

Lack of data on abiotic and biotic variables not only provide difficulties when ecosystems are viewed on a comparative basis. A common problem arrives from 'point sampling', i.e. where data are only available for certain dates with no knowledge whatsoever of any events in between sampling dates. Studies centered around the freshwater input into estuaries are obviously restricted by the lack of data on freshwater inflow rates. Gauging stations just above the tidal head of estuaries monitoring river flow would give an overall picture of the flow conditions concerning a particular estuary. 'Point sampling' of this variable could then be avoided, and research results viewed in a wider context. For most studies conducted in estuaries, the amount of freshwater inflow into an estuary is of importance. A continuous database on that particular variable therefore would provide a very valuable source not only for a particular research goal, but also for an overall picture of the status of the system. In addition, knowledge of the rate of freshwater inflow rates provide the basis of flux studies (abiotic and biotic), since the hydraulics of the systems can only be understood providing basic data such as those of freshwater inflow are available.

In summary, we recommend that the following aspects of estuaries should receive attention, with particular reference to the influence and effect of the quantity and quality of freshwater input into estuaries:

1. An assessment of the importance of planktonic and sediment microbiota in estuaries and freshwater (a) as food sources for larger organisms, (b) their sensitivity to water quality (i.e. nutrient concentrations, salinity, temperature, pH, etc.), and (c) as potential rapid assessment indicators in water quality essays.

2. An assessment of fish and invertebrate larvae in estuaries and the adjacent freshwater system (riverine waters), and the potential intermixing of these organisms.

3. A study on the benthic-pelagic coupling in fresh and estuarine waters of selected systems, with particular reference to the flux of nutrients (N, P, Si) between the sediment and the overlying watercolumn. Very little research has been done in South African aquatic systems investigating the flux rates of nitrogen and phosphorus between bottom sediments and the overlying watercolumn. The regeneration of nutrients within aquatic systems are essential processes which are probably influenced by water quality and other physical and chemical parameters of which we have scant evidence in South Africa.

4. We furthermore recommend that these studies be done on a comparative basis to include estuaries on which considerable information presently exists. The three systems (Kromme, Swartkops, Sundays) mentioned in this report represent the ideal range of estuaries for the studies mentioned above.

5. We also recommend that existing 'old' datasets should be updated to provide the basis for the future management of these systems.

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APPENDIX

Table 5.1: P/B ratios for the various floral and faunal biota in the Kromme, Swartkops and Sundays estuary. The star (*) denotes original P/B ratios listed in various publications. All other P/B ratios were assigned after certain taxonomic and /or biological criteria (see 5.2: Materials and Methods).

	P/B ratio		
BIOTA	Kromme	Swartkops	Sundays
PHYTOPLANKTON	0.0685	0.0855	0.4960
BENTHIC MICROALGAE	0.99*	0.99	0.99
MACROPHYTES			
Submerged:			
Caulerpa filiformis	0.0130	--	0.0130*
Zostera capensis	0.0063	0.0063*	---
Saltmarsh:	0.003	0.003*	---
ZOOPLANKTON			
Microzooplankton:	---	0.6667*	0.6667
Mesozooplankton:			
Copepoda:	0.2443	0.2443	0.2443*
Mysidacea:	0.0228	0.0228	0.0228*
MEIOFAUNA:	0.0219	0.0219 *	0.0219
INVERTEBRATE MACROZOOBENTHOS			
CARNIVORES (PREDATORES AND SCAVENGERS):			
Crustacea:			
Cirolana fluviatilis	0.0025	0.0025	0.0025
Cyathura carrinata	0.0025	0.0025	0.0025
Diogenes brevirostris	0.0040*	0.0040	0.0040
Eurydice longicornis	0.0025	0.0025	0.0025
Excirolana natalensis	0.0025	0.0025	0.0025
Exosphaeroma hylocoetes	0.0025	0.0025	0.0025
Hermit crabs	0.0040	0.0040	0.0040
Hymenosoma orbiculare	0.0032*	0.0032	0.0032
Ligia sp.	0.0025	0.0025	0.0025
Palaemon pacificus	0.008*	0.016*	0.016*
Penaeus canaliculatus	0.0025	0.0025	0.0025
Penaeus japonicus	0.0025*	0.0025	0.0025
Pontogeloides latipes	0.0025	0.0025	0.0025
Rhynchoplax bovis	0.0032	0.0032	0.0032

	P/B ratio		
BIOTA	Kromme	Swartkops	Sundays
Sesarma catenata	0.0060	0.0060	0.0060
DETRITIVORES:			
Crustacea:			
Amphipod (Unident.)	0.0025	0.0025	0.0025
Paratylodiplax algoense	0.0032*	0.0032	0.0032
Paratylodiplax edwardsii	0.0008*	0.0008	0.0008
Thaumastoplax spiralis	0.0020	0.0020	0.0020
Urothoe serrulidactylus	0.0025	0.0025	0.0025
Mollusca:			
Psammotellina capensis	0.0041	0.0041	0.0041
Tellina gilchristi	0.0041	0.0041	0.0041
DEPOSIT FEEDERS:			
Crustacea:			
Alpheus crassimanus	0.0032	0.0032	0.0032
Alpheus frontalis	0.0032	0.0032	0.0032
Betaeus jucundus	0.0032	0.0032	0.0032
Callianassa kraussi	0.0032*	0.0032	0.0032
GRAZERS:			
Mollusca:			
Haminoea alfredensis	0.0031	0.0031	0.0031
Assimenia ovata (=bifasciata)	0.0031*	0.0031	0.0031
Assimenia globulus	0.0031*	0.0031	0.0031
SUSPENSION FEEDERS:			
Crustacea:			
Upogebia africana	0.0027*	0.0027	0.0027
Mollusca:			
Arcuatula (=Lamya) capensis	0.0041*	0.0041	0.0041
Donax serra	0.0041	0.0041	0.0041
Donax sordidus	0.0041	0.0041	0.0041
Dosinia hepatica	0.0028*	0.0028	0.0028
Eumarcia paupercula	0.0028	0.0028	0.0028
Loripes clausus	0.0041	0.0041	0.0041
Macoma litoralis	0.0041	0.0041	0.0041

	P/B ratio		
BIOTA	Kromme	Swartkops	Sundays
Macoma ordinaria	0.0041	0.0041	0.0041
Solen capensis	0.0042*	0.0042	0.0042
Solen cylindraceus	0.0042	0.0042	0.0042
Solen sp.	0.0042	0.0042	0.0042
All *Polychaeta*	0.0134*	0.0134	0.0134
Oligochaeta, Ochaetostoma capensis	0.0134	0.0134	0.0134
ICHTHYOPLANKTON	0.0005	0.0005*	0.0005
ICHTHYONEKTON			
Zooplanktivores	0.0065*	0.0065*	0.0065*
Piscivores	0.0007*	0.0008*	0.0008
Benthic Feeders	0.0011*	0.0007*	0.0007
Mugilidae	0.0006*	0.0006	0.0006

Table 5.2: Densities of various species recorded in the Kromme, Swartkops and Sundays estuaries. The year, in which samples were obtained, is given next to each value. In case this information was not available, the year of publication is given in brackets. Densities of 0.0 denote values below 0.04. (M): species associated with Saltmarshes. (Z): species associated with *Zostera capensis* beds

	Kromme		Swartkops		Sundays	
Species	Density	Year	Density	Year	Density	Year
MACROPHYTES	Areal cover (ha)		Areal cover (ha)		Areal cover (ha)	
Submerged:						
Caulerpa filiformis	2.3	1989/90	No data		8.0	[1988]
Zostera capensis	13.8 21.7	1979-81 1989/90	15.0	1981	no data	
Saltmarsh:					no data	
Chenolea diffusa	14.7	1989/90	27.9	[1982]		
Limonium linifolium	5.7	1989/90	< 1	[1982]		
Sarcocornia decumbens	19.2	1989/90				
Sarcocornia perennis	8.2	1989/90	55.9	[1982]		
Sarcocornia pillansiae	6.8	1989/90				
Spartina maritima	12.0	1989/90	82.8	1977		
Triglochin bulbosa	3.4	1989/90	1.5	[1982]		
Phragmites australis	0.4	1989/90				
ZOOPLANKTON	no·m^{-3}		no·m^{-3}		no·m^{-3}	
Microzooplankton:	No data		No data			
Rotifers					1171500	1989/90
Loricated Ciliates					1544400	1989/90
Microciliates					1835500	1989/90
Nanociliates					2089300	1989/90
Microzooflagellates					4901400	1989/90
Nauplii larvae			1792	1976-78	3854 18693	1976-78 1986-90
Mesozooplankton:						
Copepoda:						
Acartia natalensis	79.5	1988-91	4240.0	1976-78	1.3 2892.8	1976-78 1986-90
Acartia longipatella	2409.2	1988-91	907.7	1976-78	958.0 6588.7	1976-78 1986-90
Pseudodiaptomus hessei	2321.7	1988-91	2230.5	1976-78	1357.1 5052.6	1976-78 1986-90
Mysidacea:						
Rhopalophthalmus terranatalis	5.6	1988-91	1.5	1976-78	51.7 112.5	1976-78 1986-90

	Kromme		Swartkops		Sundays	
Species	Density	Year	Density	Year	Density	Year
Mesopodopsis wooldridgei	83.0	1988-91	97.1	1976-78	69.9	1976-78
					155.5	1986-90
Gastrosaccus brevifissura	20.7	1988-91	53.2	1976-78	1.3	1976-78
					3.8	1986/87
MEIOFAUNA:	no·m^{-2}		no·m^{-2}		no·m^{-2}	
Nematoda	572500	1976	321130	1975/76	1018083	[1996]
	66667 (M)	1991	47290	1995/96		
	333333	1991				
Harpacticoida	110000	1976	40250	1975/76		
	35849 (M)	1991				
	56603.8	1991				
Others*	126250	1976	11630	1975/76		
	370212.8 (M)	1991				
	778723.4					
		1991				
INVERTEBRATE MACROBENTHOS	no·m^{-2}		no·m^{-2}		no·m^{-2}	
CARNIVORES (PREDATORES AND SCAVENGERS):						
Crustacea:						
Cirolana fluviatilis					67.7	1994
Cyathura carrinata	2.6 (Z)	1979/80				
	0.4	1979/80				
Diogenes brevirostris	5.8 (Z)	1979/80			1.0	1992
	1.6	1979/80				
	20	1978				
	6.5	[1995]				
Eurydice longicornis					11.5	1992
					0.6	1994
Excirolana natalensis					0.1	1992
Exosphaeroma hylocoetes	0.6 (Z)	1979/80				
Hermit crabs					8.9	1994
Hymenosoma orbiculare	10.2 (Z)	1979/80				
	1.2	1979/80				
	17.9	[1995]				
Ligia sp.					0.6	1994
Palaemon pacificus	156.5	1980/82	126.0	1980/82	163.0	1980/82
Penaeus canaliculatus					0.3	1992
Penaeus japonicus	0.1	[1995]				
Pontogeloides latipes					18.9	1992
					1.2	1994
Rhynchoplax bovis	0.3 (Z)	1979/80				
Sesarma catenata	5.0	1978			11.0	1994
	27.2 (M)	1989				
Mollusca:						
Bullia rhodostoma					0.4	1992

	Kromme		Swartkops		Sundays	
Species	Density	Year	Density	Year	Density	Year
Hydatina physis	17.7	[1995]				
Nassarius kraussianus	28.7 (Z) 4.4 6.1	1979/80 1979/80 [1995]				
Nassarius sp.					11.1	1994
Natica genuana	1.9 (Z) 33.9	1979/80 [1995]				
Natica tecta					0.4	1992
Polychaeta:						
Glycera tridactyla	3.5 (Z) 1.8	1979/80 1978				
Glycinde capensis					3.21 0.57	1992 1994
Lumbrineris sp.					4.0	1994
Nephtys capensis					3.0	1992
Nephtys sp.					0.6	1994
Nemertea:						
Polybrachiorhynchus dayi	2 0.1 (Z) 0.8	1978 1979/80 1979/80				
DETRITIVORES:						
***Crustacea*:**						
Amphipod (Unident.)					0.6	1994
Paratylodiplax algoense	13.2 (Z) 141.8 (M)	1979/80 1989	10.5	1975/76		
Paratylodiplax edwardsii	94.6 (Z) 5.6 163 (M) 43.9	1979/80 1979/80 1989 [1995]	3.9	1975/76	11.0	1992
Thaumastoplax spiralis	0.8 (Z) 2.4	1979/80 1979/80			1.0	1992
Urothoe serrulidactylus					996.5	1992
Mollusca:						
Psammotellina capensis	2.3 6.7 (Z) 2	1978 1979/80 1979/80				
Tellina gilchristi	5.0	1978				
Polychaeta:						
Arenicola loveni	2.8	1978				
Nereidae sp.					0.7	1992

	Kromme		Swartkops		Sundays	
Species	Density	Year	Density	Year	Density	Year
DEPOSIT FEEDERS:						
Crustacea:						
Alpheus crassimanus	0.3 (Z)	1979/80	1.6	1975/76		
Alpheus frontalis					0.8	1992
Betaeus jucundus	0.1 (Z) 1.6	1979/80 1979/80				
Callianassa kraussi	5.5 0.8	1978 [1995]	27.7	1975/76	1.28 4.53	1992 1994
Polychaeta:						
Armandia leptocirrus					0.1	1992
Capitella capitata					8.9 24.7	1992 1994
Cirratulidae sp.					0.1 0.6	1992 1994
Cossura coasta					0.6	1994
Lumbrineris tetraura					9.1	1992
Magelona cincta					0.1 0.6	1992 1994
Prinospio sexoculata					3.4	1994
Scolelepsis squamata					3.6	1992
Spionidae sp.					7.8	1992
GRAZERS:						
Mollusca:						
Haminoea alfredensis	8.6 (Z)	1979/80				
Assimenia ovata (=bifasciata)	40.8 (M)	1989				
Assimenia globulus					18.6	1992
Gastropod (Unident.)					0.1	1994
Polychaeta:						
Marphysa sanguinea	0.1 (Z)	1979/80				
SUSPENSION FEEDERS:						
Crustacea:						
Upogebia africana	21 (Z) 38 20.3 (M) 15.4	1979/80 1979/80 1989 [1995]	148.2	1975/76	52.6 60.6	1992 1994
Mollusca:						
Arcuatula (=Lamya) capensis	79.4 (Z) 2604.3	1979/80 [1995]				
Donax serra					5.3 0.6	1992 1994
Donax sordidus					1.0	1992

	Kromme		Swartkops		Sundays	
Species	Density	Year	Density	Year	Density	Year
Dosinia hepatica	6.0 (Z) 12 10.03	1979/80 1979/80 [1995]	3.1	1975/76		
Eumarcia paupercula	0.6 (Z) 1.6	1979/80 1979/80				
Loripes clausus	12 9 (Z) 8.8 14.1	1978 1979/80 1979/80 [1995]				
Macoma litoralis	70.6 (Z) 6.4 45.4	1979/80 1979/80 [1995]	1.8	1975/76	3.5	1992
Macoma ordinaria	3.0	1978				
Solen capensis	8 0.8 (Z) 0.8 0.6	1978 1979/80 1979/80 [1995]	0.7	1975/76	0.13 7.6	1992 1994
Solen cylindraceus	13.1 (Z) 2	1979/80 1979/80	5.0	1975/76		
Solen sp.						
Polychaeta:						
Desdemona ornata					283.6	1994
FEEDING TYPE NOT IDENTIFIED						
Ceratonereis erythraensis	3.2 (Z) 3.2	1979/80 1979/80				
Ceratonereis keiskama					218.3	1994
Paralocydonia sp.					3.4	1994
Polychaeta, unident.	45.9	[1995]			0.6	1994
Ochaetostoma capensis	0.1 (Z)	1979/80	1.9	1975/76		
Oligochaeta, unident.					38.5	1994
ICHTHYOPLANKTON	no·m^{-3}		no·m^{-3}		no·m^{-3}	
	5.5 1.7	1978 1994/95	3.3	1976-78	2.7	1986/87
ICHTHYONEKTON - SMALLER COMPONENT	CPUE (no per haul)		CPUE (no per haul)		CPUE (no per haul)	
ZOOPLANKTIVORES						
Ambassis gymnocephalus			1.0 0.1	1977-79 1987-89	1.5 0.1	1980/81 1987-89
Atherina breviceps	15.2 720.5 362.4 67.3	1981 1987-89 1990 1994/95	207.8 8.6	1977-79 1987-89	11.8 5.4	1980/81 1987-89
Engraulis japonicus	0.0	1987-89				

	Kromme		Swartkops		Sundays	
Species	Density	Year	Density	Year	Density	Year
Etrumeus teres					0.0	1980/81
Gilchristella aestuaria	21.2	1981	584.3	1977-79	1441.8	1980/81
	212.0	1987-89	710.5	1987-89	732.0	1987-89
	5.7	1990				
	65.9	1994/95				
Hemiramphus far	8.6	1994/95	0.5	1977-79		
Hyporamphus capensis	15.8	1987-89	0.7	1977-79	0.0	1980/81
			32.8	1987-89	18.7	1987-89
Sardinella gibbosa					0.0	1980/81
Stolephorus commersonni			63.0	1977-79		
Stolephorus holo lon					0.1	1980/81
PISCIVORES:						
Argyrosomus hololepidotus	0.1	1994/95	0.5	1977-79	1.2	1980/81
					0.2	1987-89
Caranx sexfasciatus			0.0	1987-89	0.1	1980/81
					0.0	1987-89
Caranx spp.			0.1	1977-79		
Elops machnata			0.1	1977-79	0.6	1980/81
Fistularia petimba			0.0	1977-79		
			0.1	1987-89		
Lichia amia	0.1	1981	0.2	1977-79	0.1	1980/81
	0.1	1987-89			0.4	1987-89
	0.4	1990				
Pomatomus saltatrix	0.1	1990	0.2	1977-79	0.0	1987-89
			0.9	1987-89		
Scomberomorus commerson			0.0	1977-79		
BENTHIC FEEDERS:						
Acanthopagrus berda			0.1	1977-79	0.2	1980/81
					0.0	1987-89
Amblyrhyncotes honckenii	0.6	1987-89	0.2	1977-79	0.0	1980/81
			0.0	1987-89		
Arothron hispidus			0.0	1977-79		
Caffrogobius multifasciatus	10.8	1981	0.4	1987-89	16.1	1980/81
	5.7	1987-89			1.0	1987-89
Caffrogobius nudiceps	1.4	1987-89	7.6	1987-89		
Chirodactylus brachydactylus	0.1	1987-89	0.1	1987-89	0.1	1987-89
Chrysoblephus laticeps			0.1	1977-79		
Clinidae	1.4	1994/95				
Clinus superciliosus	0.3	1981				
	2.9	1987-89				
Cyprinus carpio					3.3	1980/81
Diplodus cervinus hottentotus	0.0	1981	0.2	1977-79		
	0.7	1987-89				
	1.4	1990				
	0.1	1994/95				

	Kromme		Swartkops		Sundays	
Species	Density	Year	Density	Year	Density	Year
Diplodus sargus capensis	0.3	1981	31.7	1977-79	2.7	1980/81
	12.9	1987-89	15.0	1987-89	14.8	1989/90
	0.7	1994/95			2.3	1987-89
Galeichthys feliceps	0.3	1981	1.7	1977-79	0.5	1980/81
	1.9	1994/95				
Glossogobius giurus	76.4	1981			2.1	1980/81
Gobiidae	53	1990	16.6	1977-79		
	160.4	1994/95				
Heteromycteris capensis	1.8	1981	0.3	1987-89	19.3	1980/81
	0.1	1987-89			0.0	1989/90
Hippichthys spicifer	0.1	1987-89			0.0	1987-89
Lacornia fornasini			0.0	1987-89		
Lagocephalus scleratus					0.0	1980/81
Lithognathus lithognathus	0.0	1981	5.2	1977-79	11.0	1980/81
	0.9	1987-89			1.0	1989/90
	8.6	1990			0.3	1987-89
	2.9	1994/95			0.6	
Lithognathus mormyrus	2.9	1987-89	1.1	1977-79	0.3	1980/81
			21.5	1987-89	0.7	1987-89
Monodactylus falciformis	2.7	1981	0.0	1977-79	42.0	1980/81
	20.1	1994/95			0.7	1987-89
Myliobatus aquila	0.1	1994/95	0.0	1977-79	0.0	1980/81
Oligolepsis keiensis					0.3	1980/81
Omobranchus woodi					0.1	1980/81
Oreochromis mossambicus					0.2	1980/81
Paramonacanthus cingalensis			0.0	1977-79		
Pavoclinus pavo	0.0	1987-89				
Platycephalus indicus			0.9	1977-79	0.1	1980/81
			0.4	1987-89	0.3	1987-89
Pomadasys commersonni	0.1	1981	1.7	1977-79	9.6	1980/81
	0.1	1994/95	3.0	1987-89	1.6	1987-89
Pomadasys olivaceum	0.4	1981	6.1	1977-79	5.9	1980/81
	0.3	1987-89	7.4	1987-89	0.3	1989/90
					2.7	1987-89
Psammogobius knysnaensis	12.1	1981	47.5	1987-89	32.7	1980/81
	10.0	1987-89			43.4	1987-89
Rhabdosargus globiceps	5.7	1990			0.3	1980/81
					4.6	1989/90
Rhabdosargus holubi	20.3	1981	69.0	1977-79	66.0	1980/81
	30.1	1987-89	30.8	1987-89	2.42	1989/90
	141.7	1990			25.7	1987-89
	144.7	1994/95				
Rhabdosargus sarba			0.0	1977-79		
Sarpa salpa	4.3	1987-89	0.2	1977-79	0.0	1980/81
	1.4	1990			0.1	1989/90
Scomberoides sp.			0.0	1977-79		
Solea bleekeri	0.6	1981	0.5	1987-89	20.7	1980/81
					0.0	1989/90
					3.9	1987-89
Soleidae sp.	24.5	1990	4.9	1977-79		
	27.2	1994/95				

Table 5.3: Biomass of various species recorded in the Kromme, Swartkops and Sundays estuaries. The year in which samples (density and/or biomass data) were obtained is given next to each value. In case this information was not available, the year of publication is given in brackets. (M): species sampled in saltmarshes. (Z): species sampled in *Zostera capensis* beds.

	Kromme		Swartkops		Sundays	
Species	Biomass	Year	Biomass	Year	Biomass	Year
PHYTOPLANKTON	mg Chl-a·m^{-2}		mg Chl-a·m^{-2}		mg Chl-a·m^{-2}	
	6.9	1990	8.5	1983	30.2	1986-89
	13.8	1993/94/95	19.5	1993/94	58	1992
					57	1992
					35.8	1993/94
BENTHIC MICROALGAE	47.7	1994	50.8	1992	166.2	1992
MACROPHYTES	g dry wt·m^{-2} areal cover		g dry wt·m^{-2} areal cover		g dry wt·m^{-2} areal cover	
Submerged:						
Caulerpa filiformis	122	1989/90	No data		7	[1988]
Zostera capensis	52 84 185	1979-81 1980/82 1989/90	73.9 87.3	1980/82 1981	124.5	1980/82
Saltmarsh:					no data	
Chenolea diffusa	782	1989/90	889	[1979]		
Limonium linifolium			563	[1979]		
Sarcocornia decumbens	1124	1989/90				
Sarcocornia perennis			1290	[1979]		
Sarcocornia pillansiae						
Spartina maritima	1500	1989/90	549	1977		
Triglochin bulbosa			210	[1979]		
Phragmites australis	2125	1989/90				
ZOOPLANKTON			mg·m^{-2} dry wt		mg·m^{-2} dry wt	
Microzooplankton:	no data					
Rotifers					15.4	1989/90
Loricated Ciliates					22.6	1989/90
Microciliates					4.8	1989/90
Nanociliates					0.6	1989/90
Microzooflagellates					7.2	1989/90
Nauplii larvae			1.3	1976-78	1.8 9.0	1976-78 1986-90

	Kromme		Swartkops		Sundays	
Species	Density	Year	Density	Year	Density	Year
Spondyliosoma emarginatum	0.1	1981			0.3	1980/81
Syngnathidae	2.9	1990				
Syngnathus acus	0.7	1981	0.1	1977-79	0.2	1980/81
	0.4	1987-89	0.3	1987-89		
	1.2	1994/95				
Terapon jarbua			0.0	1977-79	0.1	1980/81
					0.3	1989/90
Torpedo fuscomaculata						1980/81
Torpedo nobiliana			0.0	1987-89		
Torpedo sinuspersici			0.1	1987-89		
MUGILIDAE:						
Liza dumerilii	103.6	1981	61.7	1977-79	62.1	1980/81
	36.0	1987-89	60.3	1987-89	43.8	1989/90
	27.7	1990			94.2	1987-89
	18.6	1994/95				
Liza richardsonii	0.5	1981	23.4	1977-79	18.6	1980/81
	28.8	1987-89	27.0	1987-89	9.1	1989/90
	35.0	1990			4.8	1987-89
	21.5	1994/95				
Liza tricuspidens	0.5	1981	1.4	1977-79	2.9	1980/81
	0.3	1987-89	18.6	1987-89	0.4	1989/90
	8.6	1990			0.2	1987-89
Mugil cephalus	3.5	1981	0.6	1977-79	29.2	1980/81
	22.9	1990	0.1	1987-89	3.0	1989/90
					0.2	1987-89
Myxus capensis	0.1	1981	0.0	1977-79	1.3	1980/81
					0.0	1987-89
Valamugil buchanani					1.5	1980/81
					0.1	1989/90
Valamugil cunnesius					0.0	1980/81
Mugilidae sp.	20.2	1987-89	90.8	1987-89	32.0	1989/90
	350.9	1994/95			89.1	1987-89
Crenimugil crenilabis					2.2	1989/90
ICHTHYONEKTON - LARGER COMPONENT	CPUE (no per net)		CPUE (no per net)		CPUE (no per net)	
ZOOPLANKTIVORES:						
Thryssa vitirostris					0.0	1976-79
PISCIVORES:						
Argyrosomus hololepidotus	1.8	1977-80	1.03	1975-79	4.8	1976-79
	1.3	1990	0.6	1992/93	6.7	1992/93
	1.4	1994/95				
Caranx spp.			0.0	1975-79	0.1	1976-79
Chanos chanos			0.2	1975-79		
Elops machnata	0.1	1977-80	1.2	1975-79	0.8	1976-79
	0.2	1990	1.2	1992/93	4.5	1992/93
	0.9	1994/95				

	Kromme		Swartkops		Sundays	
Species	Density	Year	Density	Year	Density	Year
Lichia amia	6.9	1977-80	1.6	1975-79	1.0	1976-79
	0.3	1990	2.1	1992/93	0.3	1992/93
	2.2	1994/95				
Megalops cyprinoides					0.0	1976-79
Pomatomus saltatrix	0.9	1977-80	0.3	1975-79	0.2	1976-79
	0.0	1994/95	0.2	1992/93		
BENTHIC FEEDERS:						
Acanthopagrus berda	0.0	1977-80	0.0	1975-79		
Cyprinus carpio					0.6	1976-79
Dasyatus brevicaudatus	0.1	1977-80				
Diplodus cervinus hottentotus					0.1	1976-79
Diplodus sargus capensis	0.9	1977-80			0.0	1976-79
Galeichthys feliceps	5.6	1977-80	1.97	1975-79	3.7	1976-79
	2.5	1990	3.2	1992/93	7.5	1992/93
	4.4	1994/95				
L. annulatus					0.1	1976-79
L. umbratus					0.0	1976-79
Lithognathus lithognathus	0.0	1977-80	0.2	1975-79	0.1	1976-79
	0.2	1994/95			0.1	1992/93
Monodactylus falciformis	3.1	1977-80	1.37	1975-79	0.2	1976-79
	2.2	1990	0.3	1992/93	1.6	1992/93
	0.8	1994/95				
Myliobatus aquila	1.0	1977-80	0.4	1975-79	1.1	1976-79
	0.3	1994/95	0.4	1992/93		
Oreochromis mossambicus					0.2	1992/93
Pachymetopon aeneum			0.0	1992/93		
Platycephalus indicus			0.6	1975-79	0.1	1976-79
			0.1	1992/93	0.3	1992/93
Pomadasys commersonni	1.1	1977-80	5.1	1975-79	1.9	1976-79
	1.3	1990	1.7	1992/93	1.4	1992/93
	0.8	1994/95				
Pomadasys olivaceum	0.0	1977-80				
Rhabdosargus holubi	2.0	1977-80	2	1975-79	0.4	1976-79
	1.7	1990	1.3	1992/93	0.6	1992/93
	1.7	1994/95				
Rhinobatus annulatus	0.0	1977-80				
Sarpa salpa	0.1	1977-80	0.2	1975-79		
	0.2	1994/95				
Torpedo fuscomaculata			0.0	1992/93		
Torpedo sinuspersici			0.0	1975-79		
MUGILIDAE:						
Liza dumerilii	0.1	1977-80	0.5	1975-79	0.4	1976-79
	2.2	1990	1.3	1992/93	1.3	1992/93
	0.4	1994/95				
Liza richardsonii	1.7	1977-80	3.9	1975-79	2.8	1976-79
	2.5	1990	5.3	1992/93	4.2	1992/93
	3.9	1994/95				

	Kromme		Swartkops		Sundays	
Species	Density	Year	Density	Year	Density	Year
Liza tricuspidens	0.9	1977-80	2.1	1975-79	2.0	1976-79
	1.3	1990	0.8	1992/93	3.3	1992/93
	0.8	1994/95				
Mugil cephalus	0.4	1977-80	2.7	1975-79	3.8	1976-79
	8.2	1990	0.2	1992/93	0.9	1992/93
	0.0	1994/95				
Myxus capensis					0.1	1976-79
Valamugil buchanani	0.0	1977-80	0.1	1975-79	0.1	1976-79
			0.1	1992/93		
Mugilidae spp.	3.1	1977-80				

Species	Kromme Biomass	Kromme Year	Swartkops Biomass	Swartkops Year	Sundays Biomass	Sundays Year
Mesozooplankton:	$mg \cdot m^{-2}$ dry wt		$mg \cdot m^{-2}$ dry wt		$mg \cdot m^{-2}$ dry wt	
Copepoda:						
Acartia natalensis	0.3	1988-91	15.7	1976-78	0.016 3.838	1976-78 1986-90
Acartia longipatella	22.9	1988-91	6.6	1976-78	9.0 15.02	1976-78 1986-90
Pseudodiaptomus hessei	81.9	1988-91	85.9	1976-78	21.84 32.345	1976-78 1986-90
Mysidacea:						
Rhopalophthalmus terranatalis	16.3	1988-91	4.8	1976-78	248.45 270.47	1976-78 1986-90
Mesopodopsis wooldridgei	29.7	1988-91	38	1976-78	119.36 132.18	1976-78 1986-90
Gastrosaccus brevifissura	9.6	1988-91	27.4	1976-78	0.38 0.57	1976-78 1986/87
MEIOFAUNA	mg $AFDW \cdot m^{-2}$		mg $AFDW \cdot m^{-2}$		mg $AFDW \cdot m^{-2}$	
Nematoda	240.5 28 (M) 140	1976 1991 1991	134.9 200.1	1975/76 1995/96	197.6	[1996]
Harpacticoida	116.6 38 (M) 60	1976 1991 1991	44.3	1975/76		
Others*	53 174 (M) 366	1976 1991 1991	4.9	1975/76		
INVERTEBRATE MACROOBENTHOS	mg $AFDW \cdot m^{-2}$		mg $AFDW \cdot m^{-2}$		mg $AFDW \cdot m^{-2}$	
CARNIVORES (PREDATORES AND SCAVENGERS):						
Crustacea:						
Cirolana fluviatilis					399.6	1994
Cyathura carrinata	14 (Z) 1.4	1979/80 1979/80				
Diogenes brevirostris	1544 448.0 (Z) 191.4 498.0	1978 1979/80 1979/80 [1995]			79.5	1992
Eurydice longicornis					8.1 0.4	1992 1994
Excirolana natalensis					0.7	1992
Exosphaeroma hylocoetes	6 (Z)	1979/80				
Hermit crabs					687.4	1994
Hymenosoma orbiculare	154 (Z) 71.6 141.3 270	1979/80 1979/80 [1988] [1995]	636	[1988]	8	[1988]
Ligia sp.					3.4	1994
Palaemon pacificus	1632.4 1950.4	1980/82 [1988]	1533.5 35.3	1980/82 [1988]	1900.9 190	1980/82 [1988]

	Kromme		Swartkops		Sundays	
Species	Biomass	Year	Biomass	Year	Biomass	Year
Penaeus canaliculatus					98.8	1992
Penaeus japonicus	40	[1995]				
Pontogeloides latipes					111.2 6.8	1992 1994
Rhynchoplax bovis	1.2 (Z)	1979/80				
Sesarma catenata	1286.1 873.2 18850 (M) 24	[1988] 1978 1989 [1995]	1307.3	[1988]	1915.7	1994
Mollusca:						
Bullia rhodostoma					1.6	1992
Hydatina physis	148	[1995]				
Nassarius kraussianus	228 (Z) 45 141.3 48	1979/80 1979/80 [1988] [1995]	22.4	[1988]	2318	[1988]
Nassarius sp.					87.9	1994
Natica genuana	46 (Z) 820	1979/80 [1995]				
Natica tecta					9.4	1992
Polychaeta:						
Glycera tridactyla	35 18 (Z)	1978 1979/80				
Glycinde capensis					32.1 57.0	1992 1994
Lumbrineris sp.					40.2	1994
Nephtys capensis					29.5	1992
Nephtys sp.					1.2	1994
Nemertea:						
Polybrachiorhynchus dayi	12 0.6 (Z) 29.2	1978 1979/80 1979/80				
DETRITIVORES:						
Crustacea:						
Amphipod. unident.					0.1	1994
Paratylodiplax algoense	338 (Z) 777.3 10600 (M)	1979/80 [1988] 1989	350 141.3	1975/76 [1988]		

	Kromme		Swartkops		Sundays	
Species	Biomass	Year	Biomass	Year	Biomass	Year
Paratylodiplax edwardsii	970 (Z)	1979/80	180	1975/76	142	[1988]
	161	1979/80	431.1	[1988]	113.1	1992
	282.7	[1988]				
	2700 (M)	1989				
	450	[1995]				
Thaumastoplax spiralis	4 (Z)	1979/80			4.8	1992
	18	1979/80				
Urothoe serrulidactylus					99.7	1992
Mollusca:						
Psammotellina capensis	4.1	1978				
	12 (Z)	1979/80				
	11.6	1979/80				
Tellina gilchristi	9	1978				
Polychaeta:						
Arenicola loveni	28	1978				
Nereidae sp.					5	1992
DEPOSIT FEEDERS:						
Crustacea:						
Alpheus crassimanus	114 (Z)	1979/80	300	1975/76		
Alpheus frontalis					315.4	1992
Betaeus jucundus	0.2 (Z)	1979/80				
	14.2	1979/80				
Callianassa kraussi	733.2	1978	3740	1975/76	494	[1988]
	1095.3	[1988]	890.4	[1988]	170.6	1992
	108	[1995]			604.0	1994
Polychaeta:						
Armandia leptocirrus					0.7	1992
Capitella capitata					44.6	1992
					123.4	1994
Cirratulidae sp.					0.9	1992
					4	1994
Cossura coasta					25.8	1994
Lumbrineris tetraura					91	1992
Magelona cincta					0.7	1992
					4	1994
Prinospio sexoculata					17.2	1994
Scolelepsis squamata					10.8	1992
Spionidae sp.					54.3	1992

	Kromme		Swartkops		Sundays	
Species	Biomass	Year	Biomass	Year	Biomass	Year
GRAZERS:						
Mollusca:						
Haminoea alfredensis	36 (Z)	1979/80				
Assimenia ovata (=bifasciata)	124 (M)	1989	2487.5	[1988]		
Assimenia globulus					1.9	1992
Polychaeta:						
Marphysa sanguinea	16 (Z)	1979/80				
SUSPENSION FEEDERS:						
Crustacea:						
Upogebia africana	2800 (Z) 8991.6 2685.3 8800 (M) 2058	1979/80 1979/80 [1988] 1989 [1995]	32850 6918.2	1975/76 [1988]	2826 7015.6 8074.5	[1988] 1992 1994
Mollusca:						
Arcuatula (=Lamya) capensis	742.0 (Z) 24350	1979/80 [1995]				
Donax serra					34.7 3.7	1992 1994
Donax sordidus					9.6	1992
Dosinia hepatica	164.0 (Z) 128.4 141.3 274	1979/80 1979/80 [1988] [1995]	90 70.7	1975/76 [1988]		
Eumarcia paupercula	8 (Z) 118	1979/80 1979/80				
Loripes clausus	1276.8 958.0 (Z) 356.6 1502	1978 1979/80 1979/80 [1995]				
Macoma litoralis	3100 (Z) 294.6 1837.3 1992	1979/80 1979/80 [1988] [1995]	50 7.1	1975/76 [1988]	151.9	1992
Macoma ordinaria	131.7	1978				
Solen capensis	8440 844 (Z) 735.2 622	1978 1979/80 1979/80 [1995]	490	1975/76	137.2 7975.8	1992 1994
Solen cylindraceus	300 (Z) 200.8	1979/80 1979/80	410	1975/76		
Solen spp.	424	[1988]	282.7	[1988]	142	[1988]
Polychaeta:						
Desdemona ornata					1417.8	1994

	Kromme		Swartkops		Sundays	
Species	Biomass	Year	Biomass	Year	Biomass	Year
FEEDING TYPE NOT IDENTIFIED:						
Ceratonereis erythraensis	16 (Z) 41	1979/80 1979/80				
Ceratonereis keiskama					1406.4	1994
Paralocydonia sp.					24.1	1994
Polychaeta, unident.	45.5 3678	1978 [1995]			4	1994
Ochaetostoma capensis	22 (Z)	1979/80	130	1975/76		
Oligochaeta, unident.					1203.8	1994
ICHTHYOPLANKTON	$mg \cdot m^{-2}$		$mg \cdot m^{-2}$		$mg \cdot m^{-2}$	
	7.2 2.2	1978 1994/95	4.7	1976-78	2.5	1986/87
ICHTHYONEKTON - SMALLER COMPONENT	$mg \cdot m^{-2}$		$mg \cdot m^{-2}$		$mg \cdot m^{-2}$	
ZOOPLANKTIVORES:						
Ambassis gymnocephalus			3 8	1977-79 1987-89	517 43	1980/81 1987-89
Atherina breviceps	672.4 12240.3 6287.6 1403.0	1981 1987-89 1990 1994/95	435 176	1977-79 1987-89	126.7 83	1980/81 1987-89
Engraulis japonicus	1.7	1987-89				
Etrumeus teres					0.1	1980/81
Gilchristella aestuaria	527.0 2205.5 26.9 734.3	1981 1987-89 1990 1994/95	2385 3602	1977-7919 87-89	6329 4641	1980/81 1987-89
Hemiramphus far	2.5	1994/95	15	1977-79		
Hyporamphus capensis	206.3	1987-89	15 384	1977-79 1987-89	0.3 303	1980/81 1987-89
Sardinella gibbosa					0.1	1980/81
Stolephorus commersonni			321	1977-79		
Stolephorus holodon					0.6	1980/81
PISCIVORES:						
Argyrosomus hololepidotus	43.4	1994/95	393	1977-79	1049 253	1980/81 1987-89
Caranx sexfasciatus			4	1987-89	8 9	1980/81 1987-89
Caranx spp.			12	1977-79		
Elops machnata			333	1977-79	85	1980/81
Fistularia petimba			3 18	1977-7919 87-89		
Lichia amia	3.5 1028.5 455.1	1981 1987-89 1990	162	1977-79	37 145	1980/81 1987-89

	Kromme		Swartkops		Sundays	
Species	Biomass	Year	Biomass	Year	Biomass	Year
Pomatomus saltatrix	217	1990	84 4	1977-79 1987-89	29	1987-89
Scomberomorus commerson			0.2	1977-79		
BENTHIC FEEDERS:						
Acanthopagrus berda			105	1977-79	644 175	1980/81 1987-89
Amblyrhyncotes honckenii	387.8	1987-89	66 3	1977-79 1987-89	15	1980/81
Arothron hispidus			24	1977-79		
Caffrogobius multifasciatus	3107.9 646.3	1981 1987-89	7	1987-89	130 11	1980/81 1987-89
Caffrogobius nudiceps	192.5	1987-89	78	1987-89		
Chirodactylus brachydactylus	1.7	1987-89	4	1987-89	1	1987-89
Chrysoblephus laticeps			6	1977-79		
Clinidae	183.2	1994/95				
Clinus superciliosus	385 253.0	1981 1987-89				
Cyprinus carpio						1980/81
Diplodus cervinus hottentotus	8.6 742.5 468.4 3.7	1981 1987-89 1990 1994/95	3	1977-79		
Diplodus sargus capensis	137.2 462.0 39.6	1981 1987-89 1994/95	963 620	1977-7919 87-89	36 513 44	1980/81 1989/90 1987-89
Galeichthys feliceps	32.5 54.3	1981 1994/95	3663	1977-79	1876	1980/81
Glossogobius giurus	6078.5	1981			14	1980/81
Gobiidae	4692.1 2616.6	1990 1994/95	48	1977-79		
Heteromycteris capensis	78.3 5.5	1981 1987-89	11	1987-89	216 1	1980/81 1989/90
Hippichthys spicifer	2.8	1987-89			3	1987-89
Lacornia fornasini			5	1987-89		
Lagocephalus sclerat's					8	1980/81
Lithognathus lithognathus	0.1 2895.8 2361.4 2033.1	1981 1987-89 1990 1994/95	573	1977-79	3606 230 296	1980/81 1989/90 1987-89
Lithognathus mormyrus	198	1987-89	84 648	1977-7919 87-89	2 8	1980/81 1987-89
Monodactylus falciformis	121.0 235.8	1981 1994/95	0.6	1977-79	14326 329	1980/81 1987-89
Myliobatus aquila	428.1	1994/95	27	1977-79	49	1980/81
Oligolepsis keiensis					2	1980/81
Omobranchus woodi					0.8	1980/81
Oreochromis mossambicus					25	1980/81
Paramonacanthus cingalensis			0.6	1977-79		

	Kromme		Swartkops		Sundays	
Species	Biomass	Year	Biomass	Year	Biomass	Year
Pavoclinus pavo	1.7	1987-89				
Platycephalus indicus			234	1977-79	15	1980/81
			275	1987-89	131	1987-89
Pomadasys commersonni	93.6	1981	3366	1977-79	11096	1980/81
	17.3	1994/95	306	1987-89	2664	1987-89
Pomadasys olivaceum	324.6	1981	102	1977-79	19	1980/81
		1987-89	324	1987-89	20	1989/90
					111	1987-89
Psammogobius knysnaensis	709.7	1981	672	1987-89	161	1980/81
	151.3	1987-89			308	1987-89
Rhabdosargus globiceps	1313.1	1990			47	1980/81
					1790	1989/90
Rhabdosargus holubi	4950.6	1981	6105	1977-7919	9778	1980/81
	15394.5	1987-89	3985	87-89	944	1989/9019
	17774.1	1990			5501	87-89
	28212.3	1994/95				
Rhabdosargus sarba			3	1977-79		
Sarpa salpa	1991.0	1987-89	3	1977-79	0.5	1980/81
	353.4	1990			11	1989/90
Scomberoides sp.			0	1977-79		
Solea bleekeri	173.8	1981	21	1987-89	194	1980/81
					0.4	1989/9019
					52	87-89
Soleidae sp.	341.8	1990	39	1977-79		
	409.2	1994/95				
Spondyliosoma emarginatum	0.5	1981			43	1980/81
Syngnathidae	67.1	1990				
Syngnathus acus	88.8	1981	3	1977-7919	13	1980/81
	13.8	1987-89	27	87-89		
	28.6	1994/95				
Terapon jarbua			0.1	1977-79	1	1980/81
					8	1989/90
Torpedo fuscomaculata					16	1980/81
Torpedo nobiliana			53	1987-89		
Torpedo sinuspersici			465	1987-89		
MUGILIDAE:						
Liza dumerilii	22046.7	1981	25479	1977-7919	7418	1980/81
	29172.0	1987-89	47778	87-89	13760	1989/90
	13383.4	1990			16236	1987-89
	10466.1	1994/95				
Liza richardsonii	15452.2	1981	7266	1977-7919	3029	1980/81
	32760.8	1987-89	7567	87-89	4020	1989/90
	6423.7	1990			1125	1987-89
	14518.9	1994/95				
Liza tricuspidens	229.5	1981	573	1977-7919	2612	1980/81
	101.8	1987-89	1938	87-89	870	1989/90
	662.5	1990			273	1987-89
Mugil cephalus	759.4	1981	330	1977-7919	31436	1980/81
	7761.9	1990	31	87-89	8440	1989/90
					260	1987-89

	Kromme		Swartkops		Sundays	
Species	Biomass	Year	Biomass	Year	Biomass	Year
Myxus capensis	10.2	1981	54	1977-79	126 6	1980/81 1987-89
Valamugil buchanani					1587 223	1980/81 1989/90
Valamugil cunnesius					15	1980/81
Mugilidae sp.	338.3 8375.6	1987-89 1994/95	1004	1987-89	795 1214	1989/90 1987-89
Crenimugil crenilabis					2780	1989/90
ICHTHYONEKTON - LARGER COMPONENT	$mg \cdot m^{-2}$		$mg \cdot m^{-2}$		$mg \cdot m^{-2}$	
ZOOPLANKTIVORES:						
Thryssa vitirostris					0.1	1976-79
PISCIVORES:						
Argyrosomus hololepidotus	112 132 203	1977-80 1990 1994/95	45 24	1975-79 1992/93	291 551	1976-79 1992/93
Caranx spp.			0.5	1975-79	0.1	1976-79
Chanos chanos			49	1975-79		
Elops machnata	24 17 141	1977-80 1990 1994/95	136 179	1975-79 1992/93	86 434	1976-79 1992/93
Lichia amia	401 4 247	1977-80 1990 1994/95	50 94	1975-79 1992/93	63 15	1976-79 1992/93
Megalops cyprinoides					1	1976-79
Pomatomus saltatrix	41 0.4	1977-80 1994/95	8.4 10	1975-79 1992/93	10	1976-79
BENTHIC FEEDERS:						
Acanthopagrus berda	0.6	1977-80	1	1975-79		
Cyprinus carpio					18	1976-79
Dasyatus brevicaudatus	46	1977-80				
Diplodus cervinus hottentotus					0.1	1976-79
Diplodus sargus capensis	20	1977-80			0.3	1976-79
Galeichthys feliceps	175 73 60	1977-80 1990 1994/95	54 107	1975-79 1992/93	83 148	1976-79 1992/93
L. annulatus					1	1976-79
L. umbratus					0.3	1976-79
Lithognathus lithognathus	0.2 1	1977-80 1994/95	4	1975-79	2 15	1976-79 1992/93
Monodactylus falciformis	45 26 9	1977-80 1990 1994/95	5 2	1975-79 1992/93	1 5	1976-79 1992/93
Myliobatus aquila	48 108	1977-80 1994/95	15 18	1975-79 1992/93	17	1976-79

	Kromme		Swartkops		Sundays	
Species	Biomass	Year	Biomass	Year	Biomass	Year
Oreochromis mossambicus					6	1992/93
Pachymetopon aeneum			2	1992/93		
Platycephalus indicus			18	1975-79	4	1976-79
			10	1992/93	15	1992/93
Pomadasys commersonni	99	1977-80	263	1975-79	136	1976-79
	77	1990	106	1992/93	60	1992/93
	41	1994/95				
Pomadasys olivaceum	0.2	1977-80				
Rhabdosargus holubi	12	1977-80	13	1975-79	1	1976-79
	12	1990	5	1992/93	1	1992/93
	7	1994/95				
Rhinobatus annulatus	2	1977-80				
Sarpa salpa	0.7	1977-80	5	1975-79		
	2	1994/95				
Torpedo fuscomaculata			2	1992/93		
Torpedo sinuspersici			2	1975-79		
MUGILIDAE:						
Liza dumerilii	2	1977-80	4	1975-79	3	1976-79
	23	1990	7	1992/93	9	1992/93
	6	1994/95				
Liza richardsonii	29	1977-80	84	1975-79	53	1976-79
	47	1990	94	1992/93	75	1992/93
	73	1994/95				
Liza tricuspidens	22	1977-80	46	1975-79	10	1976-79
	50	1990	34	1992/93	198	1992/93
	27	1994/95				
Mugil cephalus	11	1977-80	85	1975-79	61	1976-79
	193	1990	7	1992/93	58	1992/93
	0.2	1994/95				
Myxus capensis					1	1976-79
Valamugil buchanani	3	1977-80	4	1975-79	4	1976-79
			11	1992/93		
Mugilidae spp.	65	1977-80				

Table 5.4: Productivity of various species recorded in the Kromme, Swartkops and Sundays estuaries. The year, in which samples (density and/or biomass data) were obtained, is given next to each value. In case this information was not available, the year of publication is given in brackets (see also 5.2: Materials and Methods). (M): species sampled in saltmarsh areas. (Z): species sampled in *Zostera capensis* beds.

	Kromme		Swartkops		Sundays	
Species	Productivity	Year	Productivity	Year	Productivity	Year
PHYTOPLANKTON	mg Chl-a·m^{-2}·d^{-1}		mg Chl-a·m^{-2}·d^{-1}		mg Chl-a·m^{-2}·d^{-1}	
	0.5	1990	0.727	1983	14.979	1986-89
	0.1	1993-95	1.667	1993/94	28.768	1992
					28.272	1992
					17.757	1993/94
BENTHIC MICROALGAE	47.2	1994	50.292	1992	164.540	1992
MACROPHYTES	g dry wt·m^{-2}areal cover·d^{-1}		g dry wt·m^{-2}areal cover·d^{-1}		g dry wt·m^{-2}areal cover·d^{-1}	
Submerged:						
Caulerpa filiformis	1.586	1989/90	No data		0.091	[1988]
Zostera capensis	0.328	1979-81	0.466	1980/82	0.785	1980/82
	0.529	1980/82	1.842	1981		
	1.166	1989/90				
Saltmarsh:					no data	
Chenolea diffusa	2.300	1989/90	2.667	[1979]		
Limonium linifolium			1.689	[1979]		
Sarcocornia decumbens	3.372	1989/90				
Sarcocornia perennis			3.870	[1979]		
Sarcocornia pillansiae						
Spartina maritima	4.500	1989/90	1.647	1977		
Triglochin bulbosa			0.630	[1979]		
Phragmites australis	6.375	1989/90				
ZOOPLANKTON	mg dry wt·m^{-2}·d^{-1}		mg dry wt·m^{-2}·d^{-1}		mg dry wt·m^{-2}·d^{-1}	
Microzooplankton:						
Rotifers					20.534	1989/90
Loricated Ciliates					15.380	1989/90
Microciliates					3.134	1989/90
Nanociliates					0.378	1989/90
Microzooflagellates					14.490	1989/90

	Kromme		Swartkops		Sundays	
Species	Productivity	Year	Productivity	Year	Productivity	Year
Nauplii larvae			0.314	1976-78	0.662 2.930	1976-78 1986-90
Copepoda:						
Acartia natalensis	0.088	1988-91	3.825	1976-78	0.004 0.1868	1976-78 1986-90
Acartia longipatella	5.561	1988-91	1.605	1976-78	2.190 7.309	1976-78 1986-90
Pseudodiaptomus hessei	19.936	1988-91	13.065	1976-78	5.314 55.403	1976-78 1986-90
Mysidacea:						
Rhopalophthalmus terranatalis	0.372	1988-91	0.089	1976-78	5.667 6.167	1976-78 1986-90
Mesopodopsis wooldridgei	0.677	1988-91	0.865	1976-78	2.721 3.014	1976-78 1986-90
Gastrosaccus brevifissura	0.220	1988-91	0.624	1976-78	0.009 0.013	1976-78 1986/87
MEIOFAUNA	mg AFDW·m^{-2}·d^{-1}		mg AFDW·m^{-2}·d^{-1}		mg AFDW·m^{-2}·d^{-1}	
Nematoda	3.102 0.613 (M) 3.066	1976 1991 1991	2.954 4.382	1975/76 1995/96	4.327	[1996]
Harpacticoida	1.504 0.832 (M) 1.314	1976 1991 1991	0.971	1975/76		
Others*	0.684 3.811 (M) 8.015	1976 1991 1991	0.107	1975/76		
INVERTEBRATE MACROBENTHOS	mg AFDW·m^{-2}·d^{-1}		mg AFDW·m^{-2}·d^{-1}		mg AFDW·m^{-2}·d^{-1}	
CARNIVORES (PREDATORES AND SCAVENGERS):						
Crustacea:						
Cirolana fluviatilis					1.000	1994
Cyathura carrinata	0.040 (Z) 0.004	1979/80 1979/80				
Diogenes brevirostris	9.264 1.790 (Z) 0.77 1.992	1978 1979/80 1979/80 [1995]			0.320	1992
Eurydice longicornis					0.020 0.001	1992 1994
Excirolana natalensis					0.002	1992
Exosphaeroma hylocoetes	0.02 (Z)	1979/80				
Hermit crabs					2.750	1994
Hymenosoma orbiculare	0.49 (Z) 0.23 0.452 0.864	1979/80 1979/80 [1988] [1995]	2.880	[1988]	0.032	[1988]
Ligia sp.					0.010	1994

	Kromme		Swartkops		Sundays	
Species	Productivity	Year	Productivity	Year	Productivity	Year
Palaemon pacificus	13.059	1980/82	24.536	1980/82	30.414	1980/82
	15.603	[1988]	0.565	[1988]	3.053	[1988]
Penaeus canaliculatus					0.247	1992
Penaeus japonicus	0.100	[1995]				
Pontogeloides latipes					0.280	1992
					0.020	1994
Rhynchoplax bovis	0.004 (Z)	1979/80				
Sesarma catenata	7.717	[1988]	7.844	[1988]	11.494	1994
	5.239	1978				
	113.6 (M)	1989				
	0.144	[1995]				
Mollusca:						
Bullia rhodostoma					0.010	1992
Hydatina physis	0.622	[1995]				
Nassarius kraussianus	0.570 (Z)	1979/80	0.056	[1988]	5.795	[1988]
	0.110	1979/80				
	0.353	[1988]				
	0.120	[1995]				
Nassarius sp.					0.220	1994
Natica genuana	0.190 (Z)	1979/80				
	3.444	[1995]				
Natica tecta					0.040	1992
Polychaeta:						
Glycera tridactyla	0.469	1978				
	2.240 (Z)	1979/80				
Glycinde capensis					0.43	1992
					0.76	1994
Lumbrineris sp.					0.540	1994
Nephtys capensis					0.400	1992
Nephtys sp.					0.020	1994
Nemertea:						
Polybrachiorhynchus dayi	0.161	1978				
	0.010 (Z)	1979/80				
	0.390	1979/80				
DETRITIVORES:						
***Crustacea*:**						
Amphipod, unident.					0.100	1994
Paratylodiplax algoense	1.080 (Z)	1979/80	1.1	1975/76		
	2.488	[1988]	0.452	[1988]		
	33.400 (M)	1989				
Paratylodiplax edwardsii	0.780 (Z)	1979/80	0.1	1975/76	0.001	[1988]
	0.130	1979/80	0.0023	[1988]	0.09	1992
	0.226	[1988]				
	2.3 (M)	1989				
	0.36	[1995]				

	Kromme		Swartkops		Sundays	
Species	Productivity	Year	Productivity	Year	Productivity	Year
Thaumastoplax spiralis	0.01 (Z) 0.04	1979/80 1979/80			0.0100	1992
Urothoe serrulidactylus					0.2500	1992
Mollusca:						
Psammotellina capensis	0.0168 0.05 (Z) 0.05	1978 1979/80 1979/80				
Tellina gilchristi	0.037	1978				
Polychaeta:						
Arenicola loveni	0.375	1978				
Nereidae sp.					0.070	1992
DEPOSIT FEEDERS:						
Crustacea:						
Alpheus crassimanus	0.37 (Z)	1979/80	0.960	1975/76		
Alpheus frontalis					1.010	1992
Betaeus jucundus	0.001 (Z) 0.05	1979/80 1979/80				
Callianassa kraussi	3.505 2.346 0.346	[1988] 1978 [1995]	12.0 2.849	1975/76 [1988]	1.581 0.55 1.93	[1988] 1992 1994
Polychaeta:						
Armandia leptocirrus					0.010	1992
Capitella capitata					0.60 1.65	1992 1994
Cirratulidae sp.					0.01 0.05	1992 1994
Cossura coasta					0.350	1994
Lumbrineris tetraura					1.220	1992
Magelona cincta					0.01 0.05	1992 1994
Prinospio sexoculata					0.230	1994
Scolelepsis squamata					0.140	1992
Spionidae sp.					0.730	1992
GRAZERS:						
Mollusca:						
Haminoea alfredensis	0.11 (Z)	1979/80				
Assimenia ovata (=bifasciata)	0.400	1989	7.711	[1988]		
Assimenia globulus					0.010	1992

	Kromme		Swartkops		Sundays	
Species	Productivity	Year	Productivity	Year	Productivity	Year
Polychaeta:						
Marphysa sanguinea	0.21 (Z)	1979/80				
SUSPENSION FEEDERS:						
Crustacea:						
Upogebia africana	7.56 (Z)	1979/80	88.7	1975/76	7.630	[1988]
	24.28	1979/80	18.680	[1988]	18.94	1992
	7.250	[1988]			21.80	1994
	23.8 (M)	1989				
	5.557	[1995]				
Mollusca:						
Arcuatula (=Lamya) capensis	3.04 (Z)	1979/80				
	99.835	[1995]				
Donax serra					0.142	1992
					0.015	1994
Donax sordidus					0.040	1992
Dosinia hepatica	0.46 (Z)	1979/80	0.3	1975/76		
	0.36	1979/80	0.198	[1988]		
	0.396	[1988]				
	0.767	[1995]				
Eumarcia paupercula	0.02 (Z)	1979/80				
	0.33	1979/80				
Loripes clausus	5.235	1978				
	3.93 (Z)	1979/80				
	1.46	1979/80				
	6.158	[1995]				
Macoma litoralis	12.71	1979/80	0.205	1975/76	0.620	1992
	1.21	1979/80	0.029	[1988]		
	7.533	[1988]				
	8.167	[1995]				
Macoma ordinaria	0.540	1978				
Solen capensis	35.448	1978	2.100	1975/76	0.58	1992
	3.55 (Z)	1979/80			33.50	1994
	3.09	1979/80				
	2.612	[1995]				
Solen cylindraceus	1.26 (Z)	1979/80	1.700	1975/76		
	0.84	1979/80				
Solen spp.	1.781	[1988]	1.187	[1988]	0.596	[1988]
Polychaeta:						
Desdemona ornata					19.000	1994
FEEDING TYPE NOT IDENTIFIED:						
Ceratonereis erythraensis	0.21 (Z)	1979/80				
	0.55	1979/80				
Ceratonereis keiskama					18.850	1994
Paralocydonia sp.					0.320	1994

	Kromme		Swartkops		Sundays	
Species	Productivity	Year	Productivity	Year	Productivity	Year
Polychaeta, unident.	0.6097 35.885	1978 [1995]			0.050	1994
Ochaetostoma capensis	0.30 (Z)	1979/80	1.742	1975/76		
Oligochaeta, unident.					16.130	1994
ICHTHYOPLANKTON	$mg\cdot m^{-2}\cdot d^{-1}$		$mg\cdot m^{-2}\cdot d^{-1}$		$mg\cdot m^{-2}\cdot d^{-1}$	
	0.004 0.001	1978 1994/95	0.002	1976-78	0.001	1986/87
ICHTHYONEKTON - SMALLER COMPONENT	$mg\cdot m^{-2}\cdot d^{-1}$		$mg\cdot m^{-2}\cdot d^{-1}$		$mg\cdot m^{-2}\cdot d^{-1}$	
ZOOPLANKTIVORES:						
Ambassis gymnocephalus			0.02 0.07	1977-79 1987-89	3.18 0.29	1980/81 1987-89
Atherina breviceps	771.23 14040.29 7212.25 49.78	1981 1987-89 1990 1994/95	2.67 1.08	1977-79 1987-89	0.79 0.51	1980/81 1987-89
Engraulis japonicus	0.130	1987-89				
Etrumeus teres					0.001	1980/81
Gilchristella aestuaria	604.46 2529.84 30.84 842.32	1981 1987-89 1990 1994/95	14.81 22.39	1977-7919 87-89	39.29 28.82	1980/81 1987-89
Hemiramphus far	28.680	1994/95	0.09	1977-79		
Hyporamphus capensis	0.440	1987-89	0.09 1.88	1977-79 1987-89	0.002 1.52	1980/81 1987-89
Sardinella gibbosa					0.001	1980/81
Stolephorus commersonni			2.02	1977-79		
Stolephorus holodon					0.004	1980/81
PISCIVORES:						
Argyrosomus hololepidotus	0.030	1994/95	0.300	1977-79	0.79 0.19	1980/81 1987-89
Caranx sexfasciatus			< 0.001	1987-89	0.01 0.01	1980/81 1987-89
Caranx spp.			0.010	1977-79		
Elops machnata			0.250	1977-79	0.060	1980/81
Fistularia petimba			< 0.001 0.01	1977-7919 1987-89		
Lichia amia	0.002 0.70 0.31	1981 1987-89 1990	0.120	1977-79	0.03 0.11	1980/81 1987-89
Pomatomus saltatrix	0.150	1990	0.06 0.003	1977-79 1987-89	0.020	1987-89
Scomberomorus commerson			< 0.001	1977-79		

	Kromme		Swartkops		Sundays	
Species	Productivity	Year	Productivity	Year	Productivity	Year
BENTHIC FEEDERS:						
Acanthopagrus berda			0.070	1977-79	0.44 0.12	1980/81 1987-89
Amblyrhyncotes honckenii	0.420	1987-89	0.05 0.002	1977-79 1987-89	0.010	1980/81
Arothron hispidus			0.020	1977-79		
Caffrogobius multifasciatus	3.39 0.70	1981 1987-89	0.010	1987-89	0.09 0.01	1980/81 1987-89
Caffrogobius nudiceps	0.210	1987-89	0.050	1987-89		
Chirodactylus brachydactylus	< 0.001	1987-89	< 0.001	1987-89	< 0.001	1987-89
Chrysoblephus laticeps			< 0.001	1977-79		
Clinidae	0.200	1994/95				
Clinus superciliosus	0.42 0.28	1981 1987-89				
Cyprinus carpio						1980/81
Diplodus cervinus hottentotus	0.01 0.81 0.51 0.004	1981 1987-89 1990 1994/95	< 0.001	1977-79		
Diplodus sargus capensis	0.15 0.50 0.04	1981 1987-89 1994/95	0.66 0.42	1977-7919 87-89	0.03 0.35 0.03	1980/81 1989/90 1987-89
Galeichthys feliceps	0.04 0.06	1981 1994/95	2.490	1977-79	1.280	1980/81
Glossogobius giurus	6.630	1981			0.010	1980/81
Gobiidae	5.11 2.85	1990 1994/95	0.030	1977-79		
Heteromycteris capensis	0.09 0.006	1981 1987-89	0.010	1987-89	0.15 0.001	1980/81 1989/90
Hippichthys spicifer	< 0.001	1987-89			< 0.001	1987-89
Lacornia fornasini			< 0.001	1987-89		
Lagocephalus scleratus					0.010	1980/81
Lithognathus lithognathus	0.0002 3.16 2.57 2.22	1981 1987-89 1990 1994/95	0.390	1977-79	2.45 0.16 0.20	1980/81 1989/90 1987-89
Lithognathus mormyrus	0.220	1987-89	0.06 0.44	1977-7919 87-89	< 0.001 0.01	1980/81 1987-89
Monodactylus falciformis	0.13 0.26	1981 1994/95	< 0.001	1977-79	9.74 0.22	1980/81 1987-89
Myliobatus aquila	0.470	1994/95	0.020	1977-79	0.030	1980/81
Oligolepsis keiensis					< 0.001	1980/81
Omobranchus woodi					< 0.001	1980/81
Oreochromis mossambicus					0.020	1980/81
Paramonacanthus cingalensis			< 0.001	1977-79		
Pavoclinus pavo	< 0.001	1987-89				
Platycephalus indicus			0.16 0.19	1977-79 1987-89	0.01 0.09	1980/81 1987-89

	Kromme		Swartkops		Sundays	
Species	Productivity	Year	Productivity	Year	Productivity	Year
Pomadasys commersonni	0.10	1981	2.29	1977-79	7.55	1980/81
	0.02	1994/95	0.21	1987-89	1.80	1987-89
Pomadasys olivaceum	0.35	1981	0.07	1977-79	0.01	1980/81
	0.07	1987-89	0.22	1987-89	0.01	1989/90
					0.08	1987-89
Psammogobius knysnaensis	0.77	1981	0.460	1987-89	0.11	1980/81
	0.17	1987-89			0.21	1987-89
Rhabdosargus globiceps	1.430	1990			0.03	1980/81
					1.22	1989/90
Rhabdosargus holubi	5.40	1981	4.15	1977-7919	6.65	1980/81
	16.78	1987-89	2.71	87-89	0.64	1989/9019
	19.37	1990			3.74	87-89
	30.75	1994/95				
Rhabdosargus sarba			< 0.001	1977-79		
Sarpa salpa	2.17	1987-89	< 0.001	1977-79	< 0.001	1980/81
	0.39	1990			0.01	1989/90
Scomberoides sp.			< 0.001	1977-79		
Solea bleekeri	0.190	1981	0.010	1987-89	0.13	1980/81
					0.0003	1989/9019
					0.04	87-89
Soleidae sp.	0.37	1990	0.030	1977-79		
	0.45	1994/95				
Spondyliosoma emarginatum	< 0.001	1981			0.030	1980/81
Syngnathidae	0.070	1990				
Syngnathus acus	0.10	1981	< 0.001	1977-7919	0.010	1980/81
	0.02	1987-89	0.02	87-89		
	0.03	1994/95				
Terapon jarbua			< 0.001	1977-79	< 0.001	1980/81
					0.01	1989/90
Torpedo fuscomaculata					0.010	1980/81
Torpedo nobiliana			0.040	1987-89		
Torpedo sinuspersici			0.320	1987-89		
MUGILIDAE:						
Liza dumerilii	12.13	1981	14.01	1977-7919	4.08	1980/81
	16.05	1987-89	26.28	87-89	7.57	1989/90
	7.36	1990			8.93	1987-89
	5.76	1994/95				
Liza richardsonii	8.50	1981	4	1977-7919	1.67	1980/81
	18.02	1987-89	4.16	87-89	2.21	1989/90
	3.53	1990			0.62	1987-89
	7.99	1994/95				
Liza tricuspidens	0.13	1981	0.32	1977-7919	1.44	1980/81
	0.06	1987-89	1.07	87-89	0.48	1989/90
	0.36	1990			0.15	1987-89
Mugil cephalus	0.42	1981	0.18	1977-7919	17.29	1980/81
	4.27	1990	0.02	87-89	0.64	1989/90
					0.14	1987-89
Myxus capensis	0.010	1981	0.030	1977-79	0.07	1980/81
					0.003	1987-89
Valamugil buchanani					0.87	1980/81
					0.12	1989/90

	Kromme		Swartkops		Sundays	
Species	Productivity	Year	Productivity	Year	Productivity	Year
Valamugil cunnesius					0.010	1980/81
Mugilidae sp.	0.19 4.61	1987-89 1994/95	0.550	1987-89	0.44 0.67	1989/90 1987-89
Crenimugil crenilabis					1.530	1989/90
Ichthyonekton - Larger component	mg·m⁻²·d⁻¹		mg·m⁻²·d⁻¹		mg·m⁻²·d⁻¹	
Zooplanktivores:						
Thryssa vitirostris					< 0.001	1976-79
Piscivores:						
Argyrosomus hololepidotus	0.08 0.09 0.138	1977-80 1990 1994/95	0.03 0.018	1975-79 1992/93	0.22 0.413	1976-79 1992/93
Caranx spp.			< 0.001	1975-79	< 0.001	1976-79
Chanos chanos			0.040	1975-79		
Elops machnata	0.02 0.01 0.096	1977-80 1990 1994/95	0.1 0.134	1975-79 1992/93	0.06 0.326	1976-79 1992/93
Lichia amia	0.27 0.003 0.168	1977-80 1990 1994/95	0.04 0.071	1975-79 1992/93	0.05 0.011	1976-79 1992/93
Megalops cyprinoides					< 0.001	1976-79
Pomatomus saltatrix	0.03 0.0002	1977-80 1994/95	0.01 0.007	1975-79 1992/93	0.010	1976-79
Benthic feeders:						
Acanthopagrus berda	< 0.001	1977-80	< 0.001	1975-79		
Cyprinus carpio					0.010	1976-79
Dasyatus brevicaudatus	0.050	1977-80				
Diplodus cervinus hottentotus					< 0.001	1976-79
Diplodus sargus capensis	0.020	1977-80			< 0.001	1976-79
Galeichthys feliceps	0.19 0.08 0.07	1977-80 1990 1994/95	0.04 0.073	1975-79 1992/93	0.06 0.101	1976-79 1992/93
L. annulatus					< 0.001	1976-79
L. umbratus					< 0.001	1976-79
Lithognathus lithognathus	< 0.001 0.001	1977-80 1994/95	< 0.001	1975-79	< 0.001 0.010	1976-79 1992/93
Monodactylus falciformis	0.05 0.028 0.01	1977-80 1990 1994/95	< 0.001 0.001	1975-79 1992/93	< 0.001 0.003	1976-79 1992/93
Myliobatus aquila	0.05 0.118	1977-80 1994/95	0.01 0.012	1975-79 1992/93	0.010	1976-79
Oreochromis mossambicus					< 0.001	1992/93
Pachymetopon aeneum			< 0.001	1992/93		

	Kromme		Swartkops		Sundays	
Species	Productivity	Year	Productivity	Year	Productivity	Year
Platycephalus indicus			0.01	1975-79	< 0.001	1976-79
			0.007	1992/93	0.010	1992/93
Pomadasys commersonni	0.11	1977-80	0.18	1975-79	0.09	1976-79
	0.084	1990	0.072	1992/93	0.041	1992/93
	0.045	1994/95				
Pomadasys olivaceum	< 0.001	1977-80				
Rhabdosargus holubi	0.01	1977-80	0.01	1975-79	< 0.001	1976-79
	0.013	1990	0.003	1992/93	0.001	1992/93
	0.007	1994/95				
Rhinobatus annulatus	< 0.001	1977-80				
Sarpa salpa	< 0.001	1977-80	< 0.001	1975-79		
	0.003	1994/95				
Torpedo fuscomaculata			< 0.001	1992/93		
Torpedo sinuspersici			< 0.001	1975-79		
MUGILIDAE:						
Liza dumerilii	< 0.001	1977-80	< 0.001	1975-79	< 0.001	1976-79
	0.013	1990	0.004	1992/93	0.005	1992/93
	0.004	1994/95				
Liza richardsonii	0.02	1977-80	0.05	1975-79	0.03	1976-79
	0.026	1990	0.051	1992/93	0.041	1992/93
	0.040	1994/95				
Liza tricuspidens	0.01	1977-80	0.03	1975-79	0.01	1976-79
	0.028	1990	0.019	1992/93	0.109	1992/93
	0.015	1994/95				
Mugil cephalus	0.01	1977-80	0.05	1975-79	0.03	1976-79
	0.106	1990	0.004	1992/93	0.032	1992/93
	0.0001	1994/95				
Myxus capensis					< 0.001	1976-79
Valamugil buchanani	< 0.001	1977-80	< 0.001	1975-79	< 0.001	1976-79
			0.006	1992/93		
Mugilidae spp.	0.040	1977-80				