The effects of a single freshwater release into the Kromme Estuary. 4: Larval fish response

NA Strydom* and AK Whitfield
JLB Smith Institute of Ichthyology, Private Bag 1015, Grahamstown 6140, South Africa

Abstract

In total 17 families comprising more than 29 species of larval teleost fishes were recorded in the Kromme Estuary during the study period. Dominant species included *Atherina breviceps, Caffrogobius gilchristi, Diplodus sargus capensis, Gilchristella aestuaria, Glossogobius callidus, Rhabdosargus holubi* and *Rhabdosargus globiceps.* The larval fish catch in the estuary indicated a marine dominance with a relatively high species diversity. The introduction of a regulated freshwater pulse of 2×10^6 m^3 into the estuary from the Mpofu Dam was monitored. Pre- and post-release collections of fish larvae were made on a weekly basis for a two-month period between October and December 1998. The regulated freshwater release into the estuary resulted in no significant changes to the fish family composition, species diversity or estuarine association of the larval fish assemblage. No significant increase in total larval fish abundance or recruitment response by estuarine-dependent species was recorded. A limited breeding response by estuarine-resident fish species such as *Caffrogobius gilchristi, Gilchristella aestuaria* and *Glossogobius callidus* was documented. The increases in larval abundance of estuarine-resident species were mainly attributed to spawning events in the Geelhoutboom Tributary. This tributary received freshwater inflow from rainfall, which coincided with the dam release. It appears that the tributary serves to supplement the Kromme Estuary ichthyoplankton with large numbers of larvae belonging to estuarine-resident species. Physical conditions in the estuary returned to marine dominance within two weeks of the freshwater release. It is concluded that the riverine pulse and salinity gradient induced by the release of freshwater was too short-lived and too weak to result in a cueing effect on larval fish in the marine environment. A larger amount of freshwater would be required to produce a positive response by the larvae of estuarine-associated marine species.

Introduction

It has been well documented both in the northern and southern hemispheres that estuaries are important nursery areas for the juveniles of many species of estuarine and marine fish (Day et al., 1981; Dando, 1984; Wallace et al., 1984). This is the direct result of these species being represented in estuaries predominantly by juveniles. Although some species of fish do enter estuarine nursery areas as juveniles, others enter as larvae (Beckley, 1985; Whitfield, 1989; Gaughan et al., 1990; Strydom, 1998). It therefore seems probable that the nursery function of estuaries begins not only at the juvenile phase in the development of estuarine-dependent marine fish but starts at the postflexion larval stage in the development of some of these species. This postflexion larval stage may be very short in duration until the larva transforms into a juvenile fish but during this time the postflexion larva is already making use of the estuary as a nursery area.

The postflexion larvae (older larvae) of estuarine-dependent marine fish recruit into food-rich, sheltered estuarine nurseries from marine breeding grounds. The recruitment of postflexion marine larval fish into estuarine nurseries is also accompanied by the recruitment of postflexion larvae of certain estuarine resident species whose preflexion larvae undergo an obligatory marine phase (Whitfield, 1989). These larvae later return to the estuary as postflexion larvae or early juveniles. Estuaries are also important nursery areas for the larvae of estuarine resident species whose life cycles are completed within the estuarine environment. The larvae of the estuarine round-herring have been recorded utilising optimal tidal stream movement in order to maintain their position within the estuarine nursery environment (Melville-Smith et al., 1981). In assessing the role that estuaries play in the reproductive strategies and early life histories of estuarine-associated species, it becomes imperative to understand the importance of cues in attracting recruitment size larval fish into estuaries. Freshwater input into estuaries has been identified as a probable cue in facilitating recruitment of larval fish into these systems (Boehlert and Mundy, 1988; Whitfield, 1994a).

River flow influences the salinity, turbidity and biochemical properties of estuarine waters. Fish possess a highly developed sense of smell (Stabell, 1992) and estuarine water flowing into the marine environment may serve as a cue in guiding estuarine-dependent larval fish species into these nursery habitats. River flow also brings nutrients and organic material into estuarine systems. Nutrient input, via riverine base flow, has been shown to increase primary and secondary production in estuaries (Hilmer and Bate, 1991; Schlacher and Wooldridge, 1996), thus benefiting estuarine fish stocks. Whitfield (1994a) found a positive correlation between estuarine-dependent larval and juvenile marine fish abundance and river flow into estuaries.

Poor catchment management and freshwater deprivation have had serious impacts on many South African estuaries through their effect on biotic diversity as well as essential ecological processes (Whitfield and Wooldridge, 1994). Reddering (1988) emphasised the fact that reduced river discharge due to excessive freshwater abstraction has a profound effect on the biological behaviour of estuaries. The Kromme Estuary, on the warm temperate coast of South Africa, is a typical example of a freshwater-starved estuary (Jerling and Wooldridge, 1994). Impoundments within the catchment have substantially reduced freshwater inflow into the estuary and, as a result, there is an absence of a typical longitudinal salinity gradient with hypersaline conditions in the upper reaches being regularly recorded (Heymans and Baird, 1995). Almost the entire

* To whom all correspondence should be addressed.
☎(046) 636-1002; fax (046) 622-2403; e-mail: aopem@mweb.co.za
Received 3 November 1999; accepted in revised form 10 May 2000.

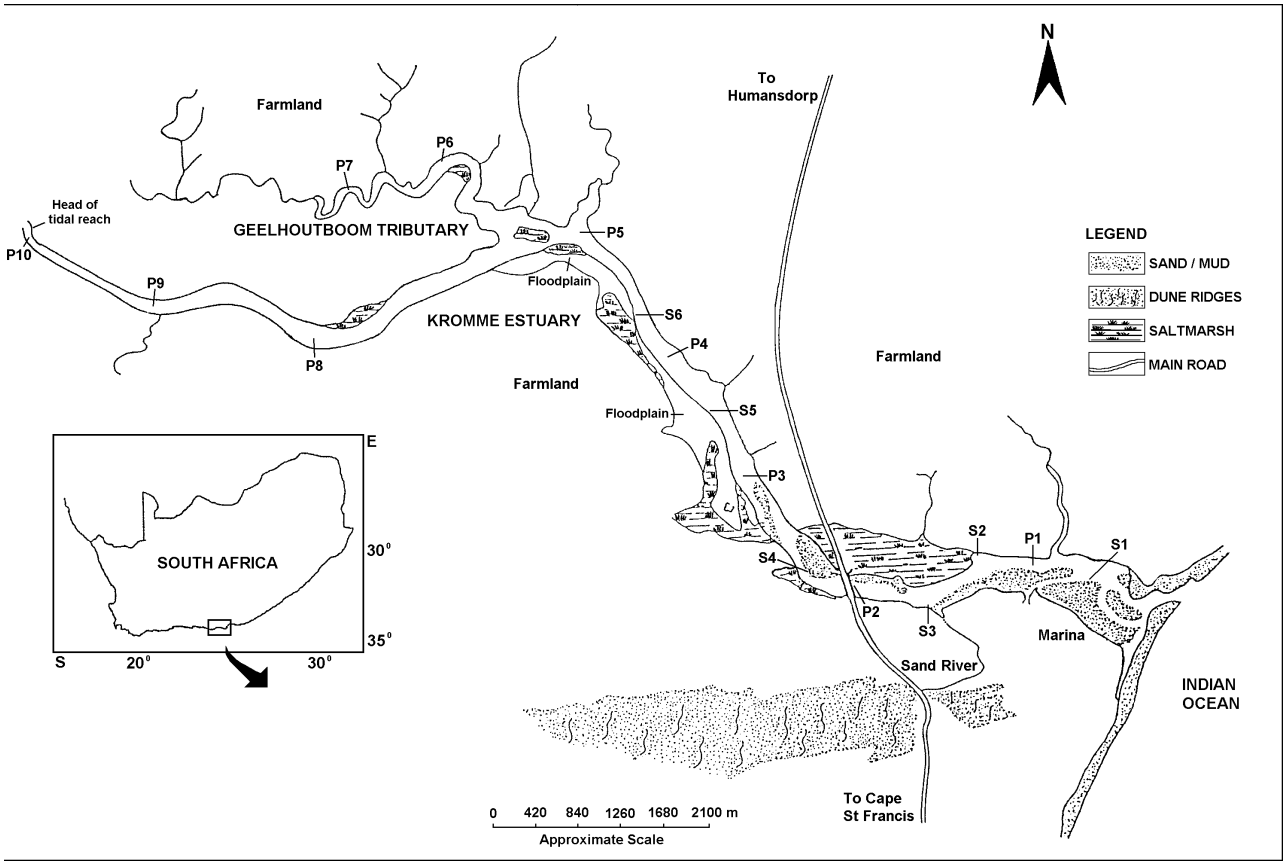

Figure 1
The Kromme Estuary and Geelhoutboom Tributary showing the location of sampling sites

runoff from the Kromme River drainage area is retained in dams. The impoundment of freshwater to meet ever-increasing human demands, together with low rainfall, has starved the Kromme Estuary of an adequate riverine supply. Whitfield and Bruton (1989) emphasised that dams or reservoirs result in the downstream flow becoming largely dependent on the operating criteria of the reservoirs. When the Mpofu Dam was built in 1982, a monthly water release programme was initiated to supply the Kromme Estuary with enough freshwater to control the development of hypersaline conditions. This programme failed due to unauthorised extraction of this supply by farmers upstream of the estuary. A decision was then taken by the research group to test a single-pulse freshwater release from the Mpofu Dam into the estuary and to monitor the effects on the estuarine fauna and flora.

The present study incorporated a monitoring programme aimed at the larval fish community of the Kromme Estuary before and after a regulated single-pulse release of 2 x 10^6 m^3 of freshwater from the Mpofu Dam situated 4 km upstream of the estuary head. The study aimed to obtain pre- and post-release information pertaining to the species composition, diversity, estuarine association and abundance of larval fish in the estuary. The intention was to gain information on the effect of a single 2 x 10^6 m^3 pulse of freshwater into the estuary. Special attention was given to assessing whether this amount of water provided a cueing effect on recruitable estuarine-dependent larval fish. In addition, an assessment was made whether the release was sufficient to alter a marine-dominated system into a more typically estuarine system in terms of species composition, diversity, estuarine association and abundance of the larval fish community.

Study site

The Kromme Estuary

The warm temperate Kromme Estuary (Fig. 1) opens into St Francis Bay on the south-east coast of South Africa. The estuary is one of the largest in the area being 13.7 km long with an average width of approximately 80 m and an approximate surface area of 3 km^2. Extensive sand banks occur in the lower 3 km, resulting in water depths of < 2 m at spring low tide. Upstream, water depth averages 3 to 4 m increasing to 7 m in places (Jerling and Wooldridge, 1994).

The Kromme River rises in the Tsitsikamma Mountains and is approximately 95 km long. The catchment area covers 936 km^2 and the virgin mean annual runoff is approximately 105.5 x 10^6 m^3 (Reddering and Esterhuizen, 1983). Two dams have been built in the catchment. These are the Churchill Dam (completed 1943) and the Mpofu Dam (completed 1982). Both dams provide water to the Port Elizabeth metropolitan area and their combined catchment area represents about 90% of the total catchment area of the Kromme system (Baird and Pereyra-Lago, 1992). The Churchill Dam has a capacity of 33.3 x 10^6 m^3 and is 36 km above the tidal reach of the estuary. The Mpofu Dam has a capacity of 100 x 10^6 m^3 and is situated only 4 km above the tidal reach. If the capacities of the two dams (133.3 x 10^6 m^3) are compared with the mean annual runoff of the Kromme (105.5 x 10^6 m^3) it is apparent that, on average, very little river discharge reaches the estuary (Adams and Talbot, 1992). This is compounded by the low mean annual rainfall, that is between 700 mm to 1 200 mm (Bickerton and Pierce, 1988). During dry periods, river flow below the larger dam

ceases altogether and the longitudinal salinity gradient within the estuary is often reversed (Jerling and Wooldridge, 1994).

Sampling sites

Larval fish sampling localities are shown in Fig. 1. Plankton sampling sites (P1 - P10) span the whole length of the estuary and the first 2 km of the Geelhoutboom Tributary. Beach-seine netting sites (S1 - S6) were concentrated in littoral waters in the lower reaches of the estuary to monitor any recruitment response.

Materials and methods

Biological sampling frequency

Larval fish samples were collected during eight sessions at weekly intervals between October and December 1998. Pre-release sample collection dates occurred on 25/10, 1/11, 8/11 and 15/11. In graphical representations, these dates are numbered B1, B2, B3 and B4 respectively (B = before). Post-release sample collection dates occurred on 22/11, 29/11, 6/12 and 13/12. In graphical representations, these dates are numbered A1, A2, A3 and A4 respectively (A = after). Samples were collected by means of a modified beach-seine net during daylight hours along the margins of the estuary (littoral waters) and boat-based mid-channel plankton netting at night. Sampling was standardised by conducting collections on neap tides in order to minimise the effects of moonlight and the cumulative effect of spring high tidal water volume on larval densities. These adjustments in sampling strategy are based on findings by Strydom (1998).

Biological sampling procedures

Mid-channel plankton netting was conducted at 10 sites throughout the estuary (sites P1 to P10, Fig. 1), using two slightly modified WP2 plankton nets (570 mm mouth diameter and 0.2 mm mesh aperture size) fitted with Kahlsico 005 WA 130 flowmeters. Nets were simultaneously lowered from two short booms (1.5 m length) fixed on either side of the bow of a 4.5 m twin-hull boat. A graduated pole was used to keep one of the nets just above the bottom during sampling where depth permitted bottom sample collection, otherwise two subsurface samples were collected. On all occasions two samples were collected per site. Towing speed ranged between 1 to 2 knots and each tow lasted for 3 min.

Littoral water sampling was conducted at six sites in the lower and middle reaches (Sites S1 to S6 in Fig. 1) of the estuary by means of a 1.5 m deep x 4.5 m long modified beach-seine net with a mesh aperture size of 0.5 mm. This net was specifically designed for catching larval fish and consisted of a small beach seine-net fitted with a central tapering cone (similar to a WP2 plankton net with mouth diameter of 0.6 m) that ended in a tie. The cone resulted in the concentration of larvae at the tapered end and allowed easy removal of the transparent larvae. Any larvae adhering to the sides of the beach-seine net or the cone were also easily washed down into the tapered end for removal. Each bank site was divided into four 25 m stretches and sampled by pulling the net across these distances parallel to the estuary bank. In total, 100 m comprising four replicates was sampled at each marginal water site.

Physio-chemical recordings

Pre- and post-release vertical temperature (°C) and salinity ($^0/_{00}$) profiles were obtained at each site using a Valeport CTD instrument. Recordings were made at intervals of 0.5 m between the surface and bottom of the water column. Water transparency measurements were also taken at all sites using a Secchi disc. All Secchi disc depth recordings were converted into an extinction coefficient (*k*) using methods described by Dawes (1981) where $k = 1.7 / D$ (secchi depth in cm).

Biological sample treatment

In total 160 plankton samples and 192 seine-netted samples were collected during the study period. Samples were preserved on site with 5% formaldehyde in seawater. Whole samples were processed in the laboratory and all larval fish removed. Larval fish were identified to the lowest possible taxon according to Russell (1976), Brownell (1979), Leis and Rennis (1983), Leis and Trnski (1989); Melville-Smith (1978), Moser et al. (1984); Olivar and Fortuño (1991) and Smith and Heemstra (1995).

All terminology pertaining to larval fish follows that of Kendall et al. (1984). The term "larva" is used to designate all stages in the early life history from hatching to the attainment of a full fin ray complement, squamation and the subsequent loss of all larval characteristics, at which stage the "larva" becomes a "juvenile". The term "larva" is further divided into yolk-sac, preflexion, flexion and postflexion larval stages. The yolk-sac stage refers to hatched larvae still in possession of yolk-sac reserves. This stage is terminated by the complete absorption of the yolk. The flexion stage is characterised by rapid fin ray development, change in body shape, change in locomotive ability and feeding techniques. All specimens older than the postflexion stage where classified as juvenile. At this stage the fish resembles the adult form and these individuals were excluded from the analyses in the present study.

Larval density calculations and expressions

Plankton catches were expressed as numbers of larvae/100 m^3 of water filtered by the nets. Larval fish density (numbers of larvae/ 100 m^3) was calculated using a simple formula based on a predetermined calibration value for each flow meter used: Total number of fish larvae/100 m^3 = [total number of larvae caught per haul/ (revolutions on flow meter / predetermined calibration value in m^3)] x 100. Modified beach-seine net catches were expressed as catch per unit effort (CPUE) in terms of numbers. One unit of effort refers to a single seine pulled parallel to the estuary bank over a distance of 25 m in littoral waters.

Statistical analyses

The following diversity indices were calculated using PRIMER software.

1. Margalef's species richness index: $D = (s - 1) / \ln N$
2. Pielou's eveness index: $J' = H'$ (observed) / H' (max)
3. Shannon-Wiener diversity index: $H' = -\Sigma_i P_i (\ln P_i)$

Diversity indices were defined and interpreted with the aid of information provided by Magurran (1988). Other descriptive and inferential statistical information was generated using QuatroPro for Windows. All statistical tests were parametric.

Results

Environmental variables

Physio-chemical recordings were taken throughout the sampling period. Pre- and post-release salinity, temperature and water transparency recordings for the Kromme Estuary and Geelhoutboom

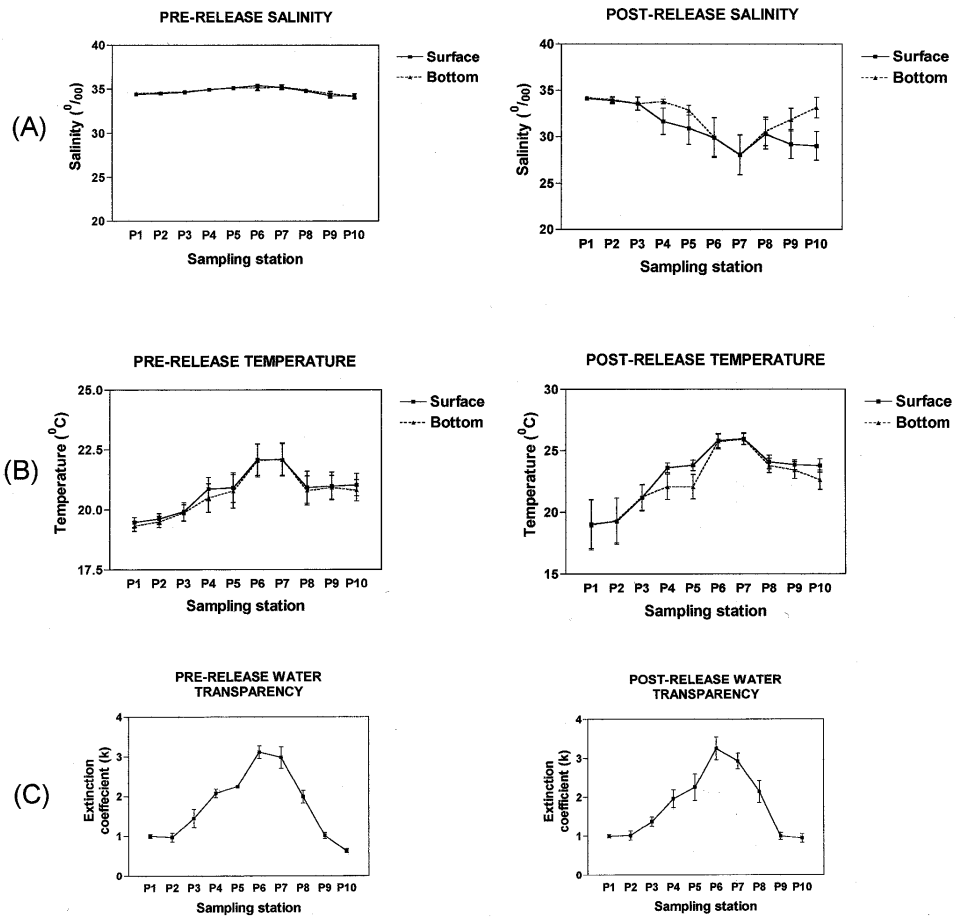

Figure 2

Pre- and post-release variations in mean (SE) salinity (A), temperature (B) and turbidity (C) in the Kromme Estuary (October to December 1998)

Tributary (Sites P6 and P7) are shown in Fig. 2. Only surface and bottom values are shown for the salinity and temperature recordings.

Salinity (Fig. 2A) in the water column was well mixed with surface and bottom values ranging between 33 and 35‰ prior to the freshwater release. Post-release salinities (Fig. 2A) ranged from 28 to 35‰ in the surface waters and 30 to 34‰ in the bottom waters. The freshwater input into the Geelhoutboom Tributary as a result of local rainfall is clearly visible in the post-release averages for Sites P6 and P7. The tributary salinity averaged 35 ‰ before the release and ranged from 27 to 30‰ after the release. The tributary sites no longer served as a separate control for the freshwater release into the Kromme Estuary and were therefore included in all analyses and considered an integral part of the Kromme system.

Pre-release temperature regimes (Fig. 2B) showed no stratification in the water column, which was evident from the lack of variation between surface and bottom water temperatures. Pre-release water temperatures ranged from 19 to 21°C. Post-release water temperatures also showed little variation between surface and bottom waters with temperatures ranging from 19 to 24°C. The lower reaches of the estuary exhibited a marine temperature influence and were generally cooler than the middle and upper reaches which were typical of summer temperatures (20 to 24°C). Evidence of an upwelling event in the marine inshore region was present on the third post-release sampling session. Temperatures in the lower reaches of the estuary dropped to 13°C whereas in the middle and upper reaches the range was 23 to 26°C. Upwelling events serve to introduce nutrient-rich water into the marine inshore environment and this water is then flushed into the estuary through tidal action. The Geelhoutboom Tributary waters (Sites P6 and P7) appeared warmer than the main estuary and this is attributed to the shallow, narrow nature of the tributary.

Pre- and post-release water transparency variations are shown in Fig. 2C. Transparency is presented in terms of an extinction coefficient (*k*). Decreased water clarity is represented by an increase in extinction coefficient. The freshwater release did result in minor changes to the transparency of estuarine waters. The pre-release extinction coefficient (*k*) ranged from 0.5 to 3.2 and the post-release *k* was marginally higher at 1 to 3.3.

Fish composition

In total, 17 families of teleost fish were recorded in the estuary and tributary. These families comprised 23 identified species and at least six species identified to family level. These taxa were represented by 16 109 specimens of which 6 329 individuals were collected by plankton nets and 9 780 individuals by seine net. The family Atherinidae, represented by a single species (*Atherina breviceps*), was numerically dominant and comprised 43% of the total number of fish larvae caught. Other dominant families included the Gobiidae (26%) represented by four species, the Sparidae (11%) represented by four species and the Clupeidae (11%) represented by two species. All other families comprised less than 10 % of the total fish caught. A summary of available species information for the entire study period is shown in Table 1.

Figure 3 shows the pre- and post-release family composition of larval fish at all sampling sites using all gear types during the study period. Only dominant families are represented with the Atherinidae ranked first during the pre-release period and the Gobiidae during the post-release period.

Species diversity

Diversity indices were calculated over the entire study period incorporating all species caught and total numbers caught per species (Table 2). The family Mugilidae was treated as a separate species for the purposes of this analysis. Margalef's species richness was represented by a value of 2.99. A relatively high species diversity (H' = 1.96) reflects the occurrence of marine species in the catch. However, the Pielou eveness value (J' = 0.58) indicated that numerical distribution amongst species was confined to a few dominant taxa and other species made a small or insignificant numerical contribution.

TABLE 1

FAMILY AND SPECIES REPRESENTATIONS; PRE-RELEASE, POST-RELEASE AND TOTAL CATCH; DEVELOPMENTAL STAGE AND ESTUARINE ASSOCIATION CATEGORY AFTER WHITFIELD (1994b) AND HARRIS AND CYRUS (1996). [KEY: PRE-RELEASE AND POST-RELEASE CATCH COLUMNS: (X;Y) = (NUMBER CAUGHT BY PLANKTON NET (X); NUMBER CAUGHT BY SEINE NET (Y); YS = YOLK-SAC, PR = PREFLEXION, FL = FLEXION, PO = POSTFLEXION, JU = JUVENILE, IA = ESTUARINE RESIDENTS, IB = ESTUARINE AND MARINE RESIDENTS, IIA = MARINE SPECIES DEPENDENT ON ESTUARIES, IIB = MARINE SPECIES MAINLY IN ESTUARIES BUT ALSO AT SEA, IIC = MARINE SPECIES IN ESTUARIES BUT MORE ABUNDANT AT SEA, III = SHORE- AND REEF-ASSOCIATED MARINE SPECIES, V = CATADROMOUS SPECIES)]

Family	Species	Pre-release catch	Post-release catch	Total catch	Developmental stage	Estuarine association category
Atherinidae	*Atherina breviceps*	4 729 (16;4 713)	2 224 (23;2 201)	6 953	Pre, F, Po	Ib
Blenniidae	*Omobranchus woodi*	64 (64;0)	246 (246;0)	310.00	Pre, F, Po	Ia
	Parablennius pilicornis	0 (0;0)	1 (0;1)	1.00	Po	III
	Blenniid 1	13 (13;0)	0 (0;0)	13.00	Pre	III?
	Blenniid 2	0 (0;0)	3 (3;0)	3.00	Pre	III?
Clinidae	Clinid 1	1 (0;1)	0 (0;0)	1.00	Po	Ib?
Clupeidae	*Etrumeus teres*	22(11;11)	8 (8;0)	30.00	Pre, F, Po	III
	Gilchristella aestuaria	434 (433;1)	1 345 (1 337;8)	1 779	Ys, Pre, Po	Ia
Cynoglossidae	*Cynoglossus capensis*	0 (0;0)	1 (0;1)	1.00	Pre, F, Po	III?
Elopidae	*Elops machnata*	7 (1;6)	0 (0;0)	7.00	Po	IIa
Engraulidae	*Engraulis japonicus*	4 (1;3)	2 (0;2)	6.00	Po	III
	Stolephorus holodon	1 (0;1)	10 (10;0)	11.00	Po	IIc
Gobiidae	*Caffrogobius gilchristi*	22 (21;1)	1 830 (1 830;0)	1 852	Ys, Pre, F, Po	Ib
	Glossogobius callidus	816 (816;0)	932 (932;0)	1 748	Po	Ib
	Psammogobius knysnaensis	178 (150;28)	254 (65;189)	432.00	Ys, Pre, F, Po	Ia?
	Gobiid 1	141 (97;44)	105 (99;6)	246.00	Pre, Po	I?
Gobiesocidae	Gobisocid 1	4 (4;0)	5 (5;0)	9.00	Pre	III?
	Gobisocid 2	1 (0;1)	0 (0;0)	1.00	Pre	III?
Haemulidae	*Pomadasys olivaceum*	21 (0;21)	0 (0;0)	21.00	Po	III
Monodactylidae	*Monodactylus falciformis*	9 (4;5)	2 (1;1)	11.00	Pre, Po	IIa
Mugilidae		191 (4;187)	314 (5;309)	505.00	Po	IIa,b,c,V?
Sciaenidae	*Argyrosomus japonicus*	1 (0;1)	3 (1;2)	4.00	Pre	IIb
Sparidae	*Diplodus sargus capensis*	285 (4;281)	56 (3;53)	341.00	Po	IIc
	Rhabdosargus globiceps	416 (2;414)	108 (1;107)	524.00	Po	IIc
	Rhabdosargus holubi	814 (46;768)	74 (9;65)	888.00	Po	IIa
	Spondyliosoma emarginatum	1 (0;1)	11 (0;11)	12.00	Po	III
Soleidae	*Heteromycteris capensis*	43 (1;42)	265 (2;263)	308.00	Pr,e Po	IIb
	Solea bleekeri	5 (2;3)	5 (1;4)	10.00	Po	IIb
Syngnathidae	*Syngnathus acus*	12 (12;0)	3 (2;1)	15.00	Po	Ib
Tetraodontidae	*Arothron immaculatus*	40 (19;21)	27 (25;2)	67.00	Pre, F, Po	IIIa

Diversity indices were also calculated for the pre- and post-release larval fish community (Table 2). Diversity indices for pre- and post-release catches were compared using a two-sample t-test. Analyses treated beach-seine net and plankton catches separately and combined. No significant difference ($P > 0.05$) in pre- and post-release species diversity (D, H', J') was recorded.

TABLE 2

DIVERSITY INDICES FOR THE LARVAL FISH ASSEMBLAGE IN THE KROMME ESTUARY

	Total number of species	Total number of individuals	Margalef's species richness (d)	Shannon-Wiener diversity (H')	Pielou's eveness (J')
Total	30	16 109	2.99	1.96	0.58
Pre-release	27	8275	2.88	1.62	0.49
Post-release	25	7834	2.68	1.98	0.62

Estuarine association

In total, 29 larval fish species were identified and categorised according to their association with the estuary. A full description of these categories can be found in Whitfield (1994b) and Harris and Cyrus (1996). The representative number of taxa per estuarine association category is shown in Fig. 4 and the estuarine association category for individual species is shown in Table 1.

Individual species of the family Mugilidae were not identified but probably included *Mugil cephalus* (IIa), *Liza dumerilii* (IIb), *Liza richardsonii* (IIc) and *Myxus capensis* (V). Categories IIa (marine species dependent on estuaries), IIb (marine species mainly in estuaries but also at sea), IIc (marine species in estuaries but more abundant at sea) and V (catadromous species) each include one of the four likely species representative of the family Mugilidae. Therefore, a species presence for the family Mugilidae was assigned to each of these categories to cater for the joint classification

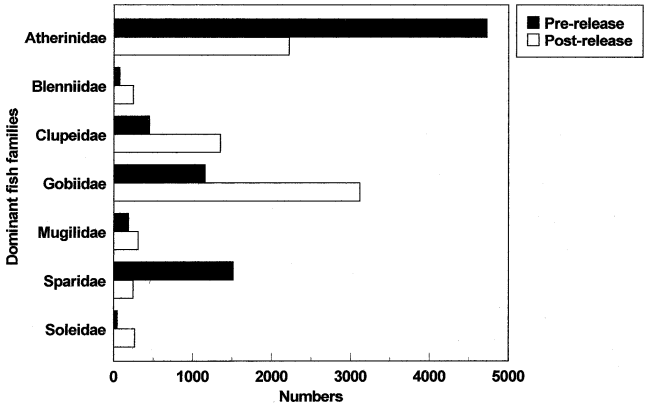

Figure 3
Pre- and post-release family composition of larval fish (plankton and seine net catches combined) in the Kromme Estuary

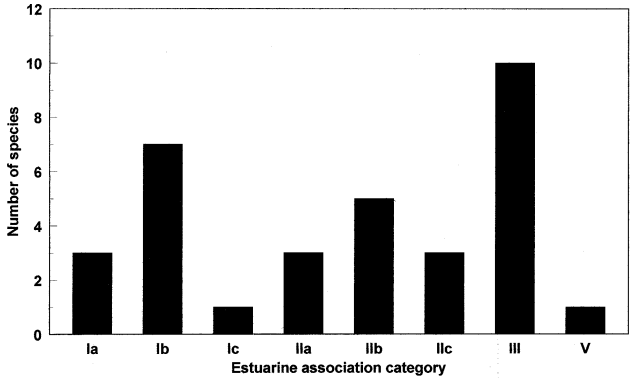

Figure 4
Estuarine association categories for larval fish recorded in the Kromme Estuary (October to December 1998)

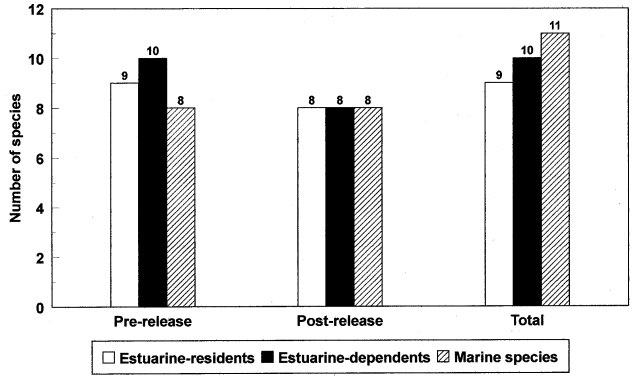

Figure 5
Comparison of broad estuarine association categories for larval fish species recorded in the Kromme Estuary

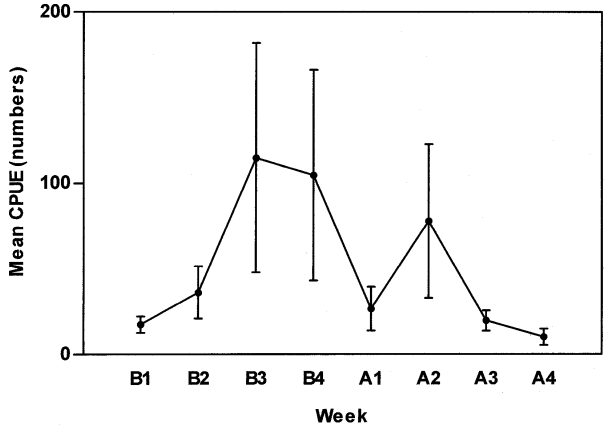

Figure 6
Pre- and post-release mean (SE) CPUE for fish larvae caught by modified beach-seine net at weekly intervals for the Kromme Estuary (B = pre-release; A = post-release)

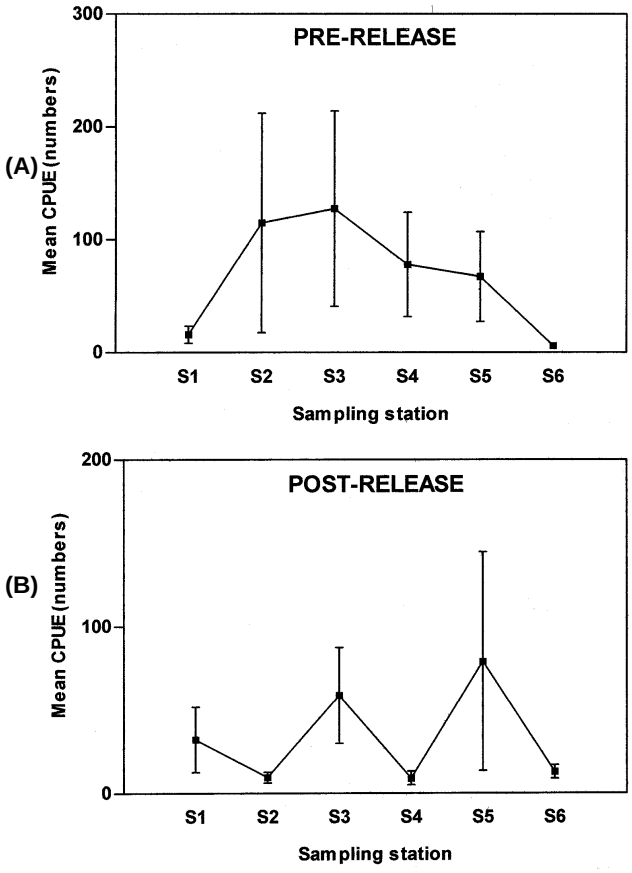

Figure 7
Pre- and post-release mean (SE) CPUE for fish larvae caught by modified beach-seine net at the various sampling stations in the Kromme Estuary

of the mugilids.

The dominant estuarine association category shown in Fig. 4 is marine species (IIIa) with no dependence on the estuarine environment. These species comprised 34% of the total number of species caught in the estuary with all other estuarine association categories having smaller contributions. Estuarine resident species (complete their life-cycle in estuaries) comprised 9% while estuarine resident species that also spawn in the marine environment comprised 18% of the species catch. Marine species that are very dependent on estuaries comprised 9% of the catch while marine species mainly found in estuaries but also found in the marine environment comprised 18%. Marine species mainly found in the marine environment but which do have an estuarine occurrence, comprised 9% while catadromous species comprised < 3% of the total catch. Freshwater species of Category IV (Whitfield, 1994b) were not recorded in the Kromme Estuary.

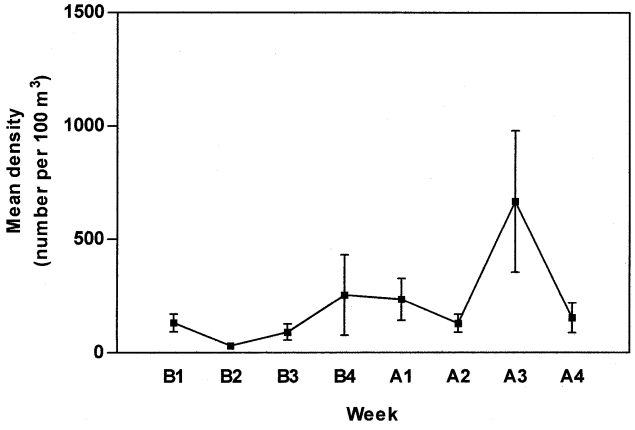

Figure 8
Pre- and post-release mean (SE) weekly density of fish larvae caught by plankton nets in the Kromme Estuary

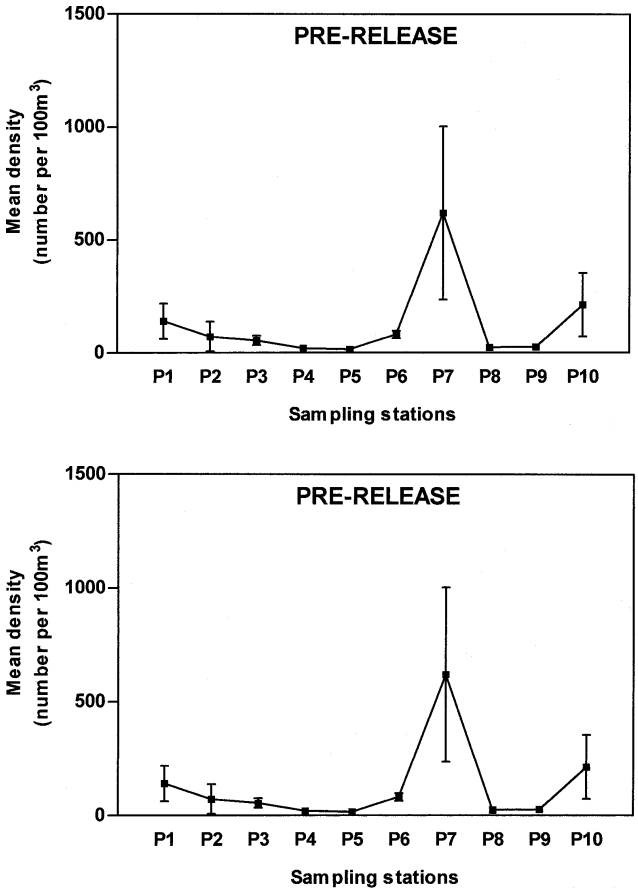

Figure 9
Pre- and post-release mean (SE) density of fish larvae caught by plankton nets at the various sampling stations in the Kromme Estuary

Pre- and post-release catches of fish larvae were separately placed into estuarine association categories and compared. For the purposes of this analysis, species were broadly categorised into estuarine-resident species (larvae belonging to fish which breed in estuaries), estuarine-dependent species (larvae belonging to fish spawning in the marine environment but dependent on estuaries during their early life-history stages) and marine species (larvae belonging to marine fish that have no dependence on estuaries as nursery areas). These pre- and post-release results are shown in Fig. 5. No major changes in the estuarine association of the larval fish community are evident in the data after the release of freshwater into the estuary.

Larval fish abundance

The number of larvae caught by modified beach-seine nets were statistically analysed using a two-sample t-test for differences in mean CPUE of larval fish caught before and after the freshwater release. There was no difference ($P > 0.05$) in mean weekly CPUE of larval fish before and after the release. Mean CPUE was also analysed on the basis of the site in the estuary. There was no difference ($P > 0.05$) between the numbers of larval fish caught before and after the release. Mean CPUE of larval fishes in terms of sampling week and site for the study period are shown in Figs. 6 and 7 respectively.

Plankton catches were analysed, using a two-sample t-test, for variations in density (number / 100 m^3) of larval fish caught before and after the artificial freshwater release. Analyses incorporated all sites in the Kromme Estuary. No difference ($P > 0.05$) in mean weekly density of larval fish before and after the release was recorded (Fig. 8). Mean larval fish density was also analysed on the basis of estuary site, before and after the release. Inter-site differences were recorded ($P < 0.05$) between the density of larval fish caught before and after the release. When sites P6 and P7 (situated in the Geelhoutboom Tributary) were removed from the analysis, inter-site results showed no significant differences ($P > 0.05$) between the pre- and post-release periods. The mean weekly larval fish density is shown in Fig. 8. Mean pre- and post-release site density of larval fishes is shown in Fig. 9.

The Geelhoutboom Tributary as a source of larvae of estuarine-resident species

The inclusion of the Geelhoutboom Tributary sites shows a distinct difference in pre- and post- release densities of larval fish (see above). The tributary was included in the sampling programme to serve as a control for comparison with the main estuary. During the week of the release, local rainfall resulted in the tributary also receiving a pulse of freshwater. The freshwater input into the tributary served to initiate a breeding response by certain estuarine-resident fish species and as a result, the Geelhoutboom Tributary acted as a major source of yolk-sac and preflexion larvae during post-release observations in the estuary. Figure 10 shows a comparison of larval densities of estuarine-resident species in the Kromme Estuary and the Geelhoutboom Tributary.

Figure 11 shows a more detailed account of the estuarine-resident species and the relative contributions of larval fish made by the Kromme Estuary (eight sites) and the Geelhoutboom Tributary (two sites). Larvae of the river goby *Glossogobius callidus* appeared to be mainly supplied by the Geelhoutboom Tributary, since numbers in the Kromme Estuary were extremely low, possibly due to the estuary having lost its link with the river. The larvae of other estuarine-resident species also occurred in large numbers in the Geelhoutboom Tributary.

Discussion

The present study provided an ideal opportunity to gain more insight into the freshwater requirements of Southern African estuaries. This project may be considered pioneering work with respect

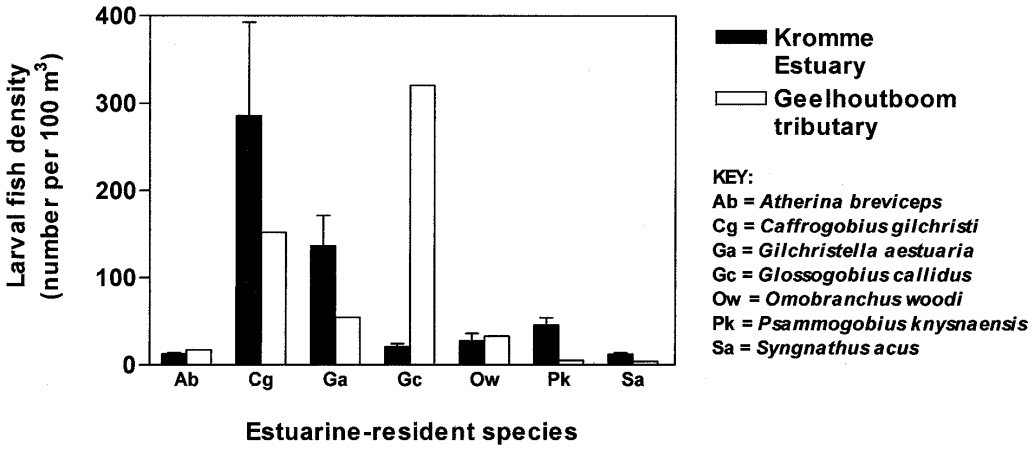

Figure 10
Mean larval fish densities (SE) of estuarine-resident species captured by plankton nets in the Kromme Estuary and Geelhoutboom Tributary during the study period

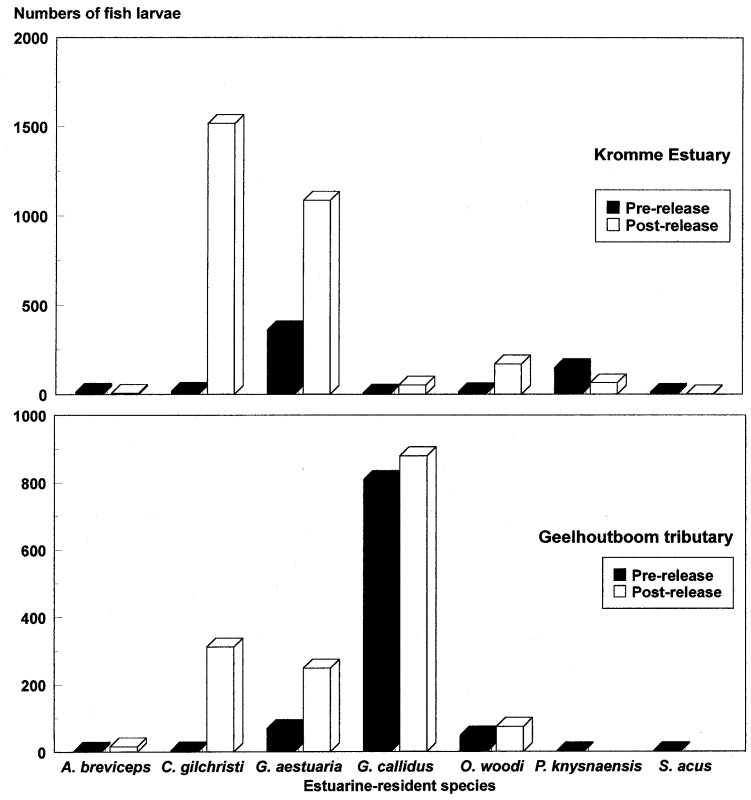

Figure 11
The pre- and post-release occurrence of larvae of estuarine-resident species caught by plankton nets at eight sites in the Kromme Estuary and at two sites in the Geelhoutboom Tributary

to freshwater releases as a management option for regulated rivers and their associated estuaries. Dams, built to serve metropolitan areas and freshwater abstraction for agricultural purposes, have resulted in freshwater deprivation in the Kromme Estuary and have altered the biological characteristics of the estuary. This is particularly evident in the frequent absence of a typical salinity gradient and the resultant dominance of marine fish species in this system.

The 2 x 10^6 m^3 freshwater release from the Mpofu Dam into the Kromme Estuary resulted in minor changes to the salinity regime of the estuary. The most notable effects were observed in the surface waters of the estuary with extensive mixing of the freshwater pulse and the existing estuarine waters being limited to the upper 2 m of the water column. Typical estuarine salinity conditions (i.e. the presence of a salinity gradient) were short-lived, with marine-dominated conditions being restored within two weeks of the freshwater release. Even when present, the longitudinal salinity gradient was too weak to facilitate adequate recruitment of estuarine-associated fish species. Whitfield (1994a) has shown that a longitudinal salinity difference of at least 19‰ is required before an efficient cueing process can be established for immigrating postflexion fishes.

The dominance of marine species in the Kromme Estuary is particularly evident in the changes that the larval assemblage has undergone since the first survey of larval fish in the estuary by Melville-Smith (1981), prior to the building of the Mpofu Dam. Melville-Smith (1981) used the same plankton sampling sites in the main estuary and Geelhoutboom Tributary as those used in the present study. The catch included 12 identified species, one unidentified species and two taxa identified to family level. Exclusively marine species comprised 14% (2 species) of the catch composition. In the present study, exclusively marine species comprised 25% (6 species) of the species captured in plankton trawls. Beach-seine net catches in this study included 8 marine species that comprise 32% of the catch. Species diversity in the Kromme Estuary is also considerably higher (H' = 1.96) than the species diversity observed in the nearby Gamtoos Estuary (H' = 1.09) by Strydom (1998). In both studies, diversity indices are provided for mid-channel and littoral water sampling. The higher species diversity in the Kromme Estuary is a result of the increased number of marine fish species.

Comparisons of the pre- and post-release larval fish assemblages in the main estuary and Geelhoutboom Tributary showed that the release had no major effects on the fish family composition, species diversity or estuarine association of larval fish. Pre- and post-release abundance of larval fish were also compared. Beach-seine net catches revealed no significant changes in abundance of larval fish thus indicating that no recruitment by estuarine-dependent marine species occurred. Plankton catches showed that the Geelhoutboom Tributary, that also received a pulse of freshwater as a result of local rainfall during the main release period, serves as an important source of larvae of estuarine resident fish species. These larvae are then distributed into the main estuary channel through tidal action. The Geelhoutboom Tributary is therefore

serving as an alternative breeding environment for these fish species, thus partially compensating for the loss of estuarine habitat in the marine-dominated main estuary. Increases in numbers of yolk-sac and preflexion larvae in post-release plankton catches also showed a small breeding response by estuarine resident fish in the main estuary. Evidence from this study suggests that estuarine resident species are sensitive to riverine flow, which signals increased nutrient input and therefore increased estuarine primary production, and respond by spawning soon after the event.

Despite the breeding response being stimulated by the input of freshwater into the estuary, some resident fish species produce larvae that have an obligatory marine phase in their development. The larvae of estuarine gobiids (e.g. *Caffrogobius gilchristi*) have a marine phase in their development (Whitfield, 1989). Larvae are flushed into the marine environment as preflexion larvae and undergo flexion in the sea, after which they recruit back into nearby estuaries as postflexion larvae. The success of this recruitment probably depends on the cueing effect of estuarine waters. The Kromme Estuary may therefore lose many of these larvae as a result of the marine dominance within the system and the lack of this probable cueing effect. It is also possible that larvae produced in the Kromme Estuary may recruit into neighbouring estuaries with stronger riverine inputs, e.g. the Gamtoos Estuary.

Freshwater-starved systems, like the Kromme Estuary, that are tidally linked to an adjoining tributary that does receive freshwater, should not be considered as separate entities. Tidal action renders these two parts of the system inseparable in terms of the supply of larvae of estuarine resident fish and management of the system should take this into account.

In conclusion, the changes to the salinity gradient in the Kromme Estuary, induced by the 2×10^6 m^3 freshwater release were short-lived and weak, both horizontally throughout the estuary and vertically within the water column. As a result, the anticipated responses by larval fish to the release did not occur but valuable information was gained in the process. The existing freshwater allocation to the estuary is inadequate and a considerably larger volume of water is required to produce a positive recruitment response by the larvae of estuarine-dependent marine fish species.

Acknowledgements

The Department of Water Affairs and Forestry is sincerely thanked for providing financial assistance for this project. Ms Ané Oosthuizen and Mr Brian Colloty are thanked for valued field assistance. We are grateful to the Department of Zoology, University of Port Elizabeth, for the use of their vehicle and boat.

References

ADAMS JB and TALBOT MMB (1992) The influence of river impoundment on the estuarine seagrass *Zostera capensis* Setchell. *Bot. Mar.* **35** 69-75.

BAIRD D and PEREYRA-LAGO R (1992) Nutrient status and water quality assessment of the Marina Glades canal system on the ecology of the Kromme Estuary, St. Francis Bay. *Water SA* **18** (1) 21-34.

BECKLEY LE (1985) Tidal exchange of ichthyoplankton in the Swartkops Estuary mouth, South Africa. *S. Afr. J. Zool.* **20** 15-20.

BICKERTON IB and PIERCE SM (1988) Report No. 33: Krom (CMS45), Seekoei (CMS46) and Kabeljous (CMS 47). In: Heydorn AEF and Morant PD (eds) *Estuaries of the Cape. Part. Synopses of Available Information on Individual Systems.* Stellenbosch, *CSIR Research Report*. 432 pp.

BOEHLERT GW and MUNDY BC (1988) Roles of behaviour and physical factors in larval and juvenile fish recruitment to estuarine nursery areas. *Am. Fish. Soc. Sym.* **3** 51-67.

BROWNELL CL (1979) Stages in the early development of 40 marine fish species with pelagic eggs from the Cape of Good Hope. *Ichthyol. Bull. Smith Inst. Ichthyol.* **40** 1-84.

DANDO PR (1984) Reproduction in estuarine fishes. In: *Fish Reproduction: Strategies and Tactics*, GW Potts and RJ Wootton (eds). Academic Press, London. 155-170.

DAWES CJ (1981) *Marine Botany*. John Wiley and Sons, Inc., New York. 306-309.

DAY JH, BLABER SJM and WALLACE JH (1981) Estuarine fishes. In: Day JH (ed.) *Estuarine Ecology with Particular Reference to Southern Africa*. Balkema, Cape Town. 197-222.

GAUGHAN DJ, NEIRA FJ, BECKLEY LE and POTTER, IC (1990) Composition, seasonality and distribution of the ichthyoplankton in the lower Swan Estuary, south-western Australia. *Aust. J. Mar. Freshwater Res.* **41** 529-543.

HARRIS SA and CYRUS DP (1996) Larval and juvenile fishes in the surf zone adjacent to the St Lucia estuary mouth, KwaZulu-Natal, South Africa. *Mar. Freshwater Res.* **47** 465-482.

HEYMANS JJ and BAIRD D (1995) Energy flow in the Kromme estuarine ecosystem, St Francis Bay, South Africa. *Est. Coast. Shelf. Sci.* **41** 39-59.

HILMER T and BATE GC (1991) Vertical migration of a flagellate-dominated bloom in a shallow South African estuary. *Bot. Mar.* **34** 113-121.

JERLING HL and WOOLDRIDGE TH (1994) The mesozooplankton of a freshwater-starved estuary. In: Dyer KR and Orth RJ (eds.) *Changes in Fluxes in Estuaries*. Olsen and Olsen Publishers, Denmark. 301-306.

KENDALL AW, AHLSTROM EH and MOSER HG (1984) Early life history stages of fishes and their characters. In: Moser HG, Richards WJ, Cohen DM, Fahay MP, Kendall AW and Richardson SI (eds.) *Ontogeny and Systematics of Fishes. Spec. Publ. Am. Soc. Ichthyol. Herpetol.* 11-22.

LEIS JM and RENNIS DS (1983) *The Larvae of Indo-Pacific CoralReef Fishes.* Univ. of Hawaii Press, Honolulu. 269 pp.

LEIS JM and TRNSKI T (1989) *The Larvae of Indo-Pacific Shore Fishes.* Univ. of Hawaii Press, Honolulu. 371 pp.

MAGURRAN AE (1988) *Ecological Diversity and its Measurement.* Princeton Univ. Press. New Jersey. 179 pp.

MELVILLE-SMITH R (1978) Aspects of the Ecology of Fish Larvae in the Swartkops Estuary. M.Sc. Thesis, Univ. of Port Elizabeth. 163 pp.

MELVILLE-SMITH R (1981) The ichthyoplankton of the Kromme river estuary. *S. Afr. J. Zool.* **16** (1) 71-72.

MELVILLE-SMITH R, BAIRD D and WOOLDRIDGE T (1981) The utilization of tidal currents by the larvae of estuarine fish. *S. Afr. J. Zool.* **16** (1) 10-13.

MOSER HG, RICHARDS WJ, COHEN DM, FAHAY MP, KENDALL AW and RICHARDSON SL (1984) Ontogeny and systematics of fishes. *Spec. Publ. 1 Am. Soc. Ichthyol. Herpetol.* Gainesville, FL. 760 pp.

OLIVAR MP and FORTUÑO JM (1991) Guide to ichthyoplankton of the south east Atlantic (Buenguela Current Region). *Sci. Mar.* **55** (1) 1-383.

REDDERING JSV (1988) Prediction of the effects of reduced river discharge on the estuaries of the south-eastern Cape Province, South Africa. *S. Afr. J. Sci.* **80** 726-730.

REDDERING JSV and ESTERHUIZEN K (1983) Research on Sedimentation in Estuaries. Sedimentation in the Kromme Estuary. Univ. of Port Elizabeth, Dept. of Geol., ROSIE Report No. 8.

RUSSELL FS (1976) *The Eggs and Planktonic Stages of British Marine Fishes.* Academic Press, London. 524 pp.

SCHLACHER TA and WOOLDRIDGE TH (1996) Ecological responses to reductions in freshwater supply and quality in South Africa's estuaries: Lessons for management and conservation. *J. Coast. Cons.* **2** 115-130.

SMITH M and HEEMSTRA PC (1995) *Smith's Sea Fishes of Southern Africa.* Macmillan, Johannesburg, South Africa. 1047 pp.

STABELL OB (1992) Olfactory control of homing behaviour in salmonids. In: Hara TH (ed.) *Fish Chemoreception.* Chapman & Hall, London.

STRYDOM NA (1998) Fish Larval Dynamics in the Mouth Region of the Gamtoos Estuary. M.Sc. Thesis, Univ. of Port Elizabeth. 104 pp.

WALLACE JH, KOK HM, BECKLEY LE, BENNET BA, BLABBER SJM and WHITFIELD AK (1984) South African estuaries and their importance to fishes. *S. Afr. J. Sci.* **80** 203-207.

WHITFIELD AK (1989) Ichthyoplankton interchange in the mouth region of a southern African estuary. *Mar. Ecol. Prog. Ser.* **54** 25-33.

WHITFIELD AK (1994a) The abundance of larval and 0+ juvenile marine fishes in the lower reaches of three southern African estuaries with differing freshwater inputs. *Mar. Ecol. Prog. Ser.* **105** 257-267.

WHITFIELD AK (1994b) A review of ichthyofaunal biodiversity in southern African estuarine systems. *Ann. Mus. S. Afr. Centr. Zool.* **275** 149-163.

WHITFIELD AK and BRUTON MN (1989) Some biological implications of reduced freshwater inflow into eastern Cape estuaries: A preliminary assessment. *S. Afr. J. Sci.* **85** 691-694.

WHITFIELD AK and WOOLDRIDGE TH (1994) Changes in freshwater supplies to Southern African estuaries: Some theoretical and practical considerations. In: Dyer KR and Orth JR (eds.)*Changes in Fluxes in Estuaries*: *Implications from Science to Management.* Olsen & Olsen, Fredenburg. 41-50.