The influence of a marina canal system on the ecology of the Kromme estuary, St Francis Bay

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The influence of the marina canals on the lower reaches and mouth area of the Kromme estuary was investigated. Surveys were conducted during 1978 and 1979 in the marina system as well as in the main estuary in the vicinity of the marina. Analyses and comparisons of the biotic communities in the marina and in the main estuary showed a very similar composition, but differences in density were observed for several of the species. The plankton and nekton samples in the estuary and in the marina showed the same seasonal trends in abundance. The abiotic characteristics of the marina canals were also investigated and special attention was given to water circulation in the system during a tidal cycle. These observations showed that water circulation throughout the entire system was good, indicating efficient flushing and tidal turnover. Temperature, salinity and dissolved O_2 values indicated well-mixed and saturated waters. It is concluded that the marina has, in effect, increased the habitat area for plankton, benthic macro-invertebrate fauna and fish and that it does not have an adverse effect on the ecology of the Kromme estuary.

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'n Ondersoek om die invloed van marina-kanale op die mond en aangrensende gebiede van die Krommegetyrivier is gedoen. Opnames is gemaak gedurende 1978 en 1979 in die marinasisteem sowel as in die getyrivier in die omgewing van die marina. Analises van en vergelykings tussen die biotiese gemeenskappe in die marina en getyrivier dui op soortgelyke gemeenskappe, maar verskille in digtheid van verskeie spesies is waargeneem. Plankton- en nekton-monsters in die marina en getyrivier toon dieselfde seisoenstendense in talrykheid. Die abiotiese eienskappe van die marina is ook ondersoek en spesiale aandag is gegee aan watersirkulasie in die marinasisteem gedurende 'n gety siklus. Hierdie waarnemings het gedui op doeltreffende watersirkulasie deur die hele sisteem. Temperatuur, soutgehalte en opgeloste O_2-waardes toon goed gemengde en suurstof-versadigde waters aan. Die gevolgtrekking is gemaak dat die marina in werklikheid die habitatarea vir plankton, bentiese makro-invertebraatfauna en vis vergroot het en dat dit geen nadelige gevolge op die ekologie van die Krommegetyrivier het nie.

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There is considerable demand in South Africa for the utilization of estuaries for activities such as outdoor recreation, recreational fishing, waste disposal and the ever-increasing development of residential waterfront real estate. Developments of this kind are often associated with the excavation of canals to increase waterfront housing areas and to provide boat-berthing facilities. Numerous such developments are found along the coasts of the United States of America (Crompton, Beardsley & Ditton 1976). Only two marinas have to date been developed in estuaries in South Africa, namely the 'Marine Glades' on the Kromme estuary in the Eastern Cape and the Marina da Gama near Muizenberg on the Cape Peninsula. The development in the latter has been limited to the enlargement of Sandvlei and the construction of residential waterways which started in 1970. An ecological impact study was conducted by Begg (1976).

Estuaries are considered as suitable areas for marina developments in that they are normally well protected from effects of severe wave action while still providing a direct link to the sea. Saltmarshes in the lower reaches of estuaries particularly offer, according to Nicol (1976) suitable, well-protected sites. However, inevitable differences of opinion have evolved between the interests of developers and ecologists, and increased environmental awareness in recent years has focused much attention on these conflicts.

The reason for these conflicts is readily apparent. Estuaries provide food and sanctuary for all, or part, of the life-history stages of a large number of invertebrates, fish and birds. In addition, saltmarshes are highly productive areas (Teal 1962, Pierce 1979, Baird & Winter 1979) producing large quantities of food materials, which may be utilized in other parts of the estuarine system. Greater emphasis is at present placed upon ecological considerations, and in the U.S.A. developments of new coastal harbours and marinas have been curtailed in certain states but '. . . it was felt by the U.S. Army Corps of Engineers that much of this opposition was not based upon real regard for ecological considerations, but based upon the self-interest of individuals operating under the cloak of ecology' (Meyer 1972).

Many studies have been conducted overseas on the effects of marina development on the environment (Odum 1970, Barada & Partington 1972, Meyer 1972, Trent, Pullen & Moore 1972, Lindall & Trent 1975, Power 1975, Crompton *et al.* 1976), but only a few papers on this subject have been published in South Africa (Anon 1973, Begg 1976, Heydenrych 1976, Nicol 1976, Baird 1979). Begg (1978) recently produced a resource inventory of the estuaries of Natal, an invaluable work for future development and conservation of Natal estuaries, while Olson (1977) has devised a priority ranking system for estuarine management.

It has been shown (Lindall & Trent 1975) that regardless of their location in estuaries, marina canals may seriously degrade coastal resources. Poor excavation practices and inadequate provisions for good water circulation often cause damage to the environment. As a result canal construction may lead to destruction of wetlands and/or saltmarsh vegetation, undesirable changes in water quality and sediment type and changes in the composition and densities of faunal communities.

The objectives of this study were first, to investigate the influence of the Marina Glades development on the Kromme river estuary, with special reference to the faunal communities and secondly to establish the possible reasons for the ecological state in which the marina and immediate estuarine environment exist at present.

Brief history and description of the marina

The Kromme River estuary opens in St Francis Bay, approximately 55 km to the west of Port Elizabeth (Fig. 1). This estuary is one of the few relatively unspoilt estuaries in the Eastern Cape. There is no industrial development along its banks and effluent disposal in the estuarine waters is minimal. A number of holiday houses are situated along the estuary while a marina has been developed near the mouth. A road bridge has recently been built across the river, approximately 3 km from the sea, bisecting the saltmarshes, while a large reservoir dam, the Elandsjacht dam, is being planned higher up in the catchment area to augment the freshwater supply to Port Elizabeth.

The marina is situated on the west bank of the estuary (Fig. 1) and consists of a network of canals with waterfront housing development (Fig. 2). Mooring facilities are available for about 8 – 10 yachts in the New Yacht Basin (Fig. 2) which also has a launching ramp for smaller craft. The canals are navigable by small boats and yachts up to 17 m and boats of about 20 metric tons have access to the sea via the permanently open river mouth. At present there are about 12 km of canals with a mean width of approximately 25 m, while the lagoon (Fig. 2) has a width of approximately 60 m. Excavations commenced in 1959. Dredging operations are virtually continuous to keep the canals at the desired depths. The dredge pumps approximately 200 t of sand per hour.

The provision of waterfront housing was the prime objective of this development. Waterfront developments created by excavating canals in the estuarine zone can be categorized as bayfill, inland and intertidal (Lindall & Trent 1975). In this case an inland development was created by excavating areas above the high-water tide mark and connecting the resulting canals to the main estuary.

A number of houses have been built along the marina canals since 1959 and the latest municipal evaluation of the Marina Glades township is about R10 million.

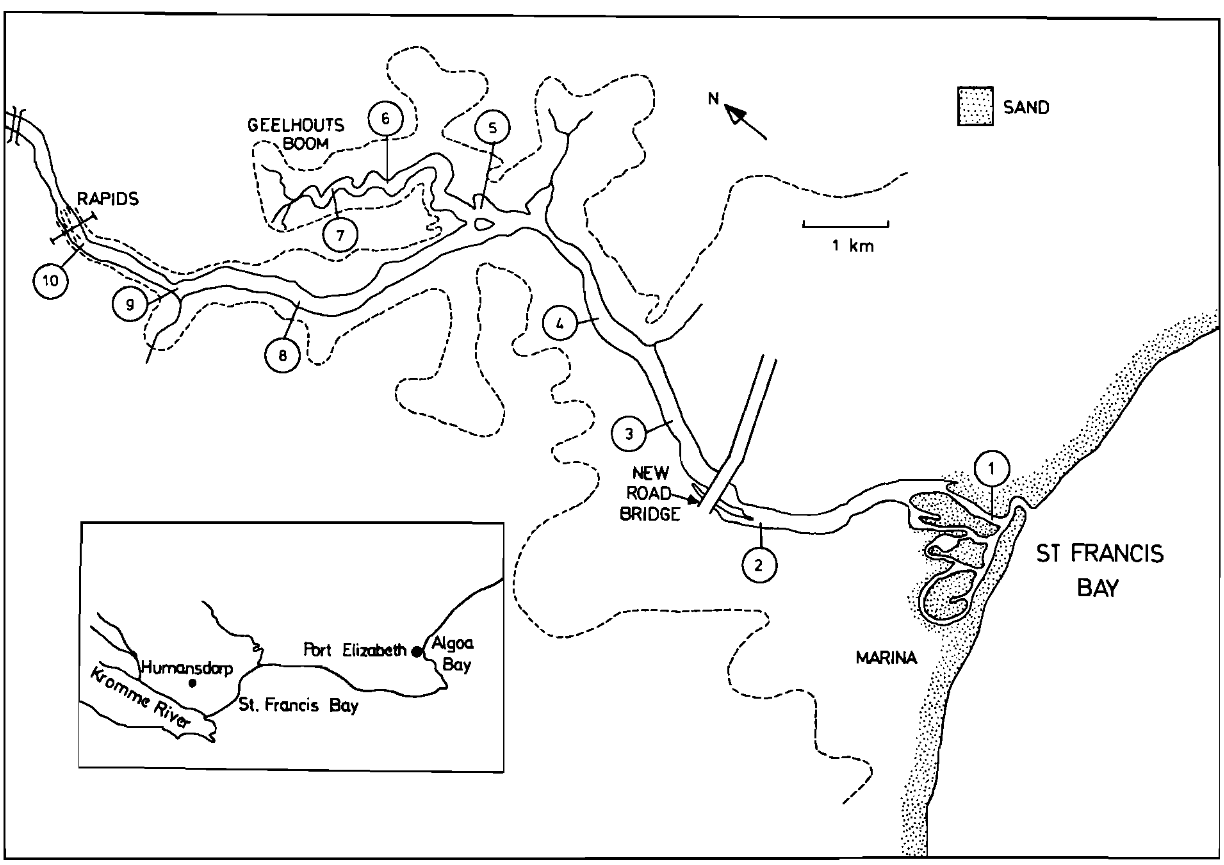

Fig. 1 Map of the Kromme River estuary and marina.

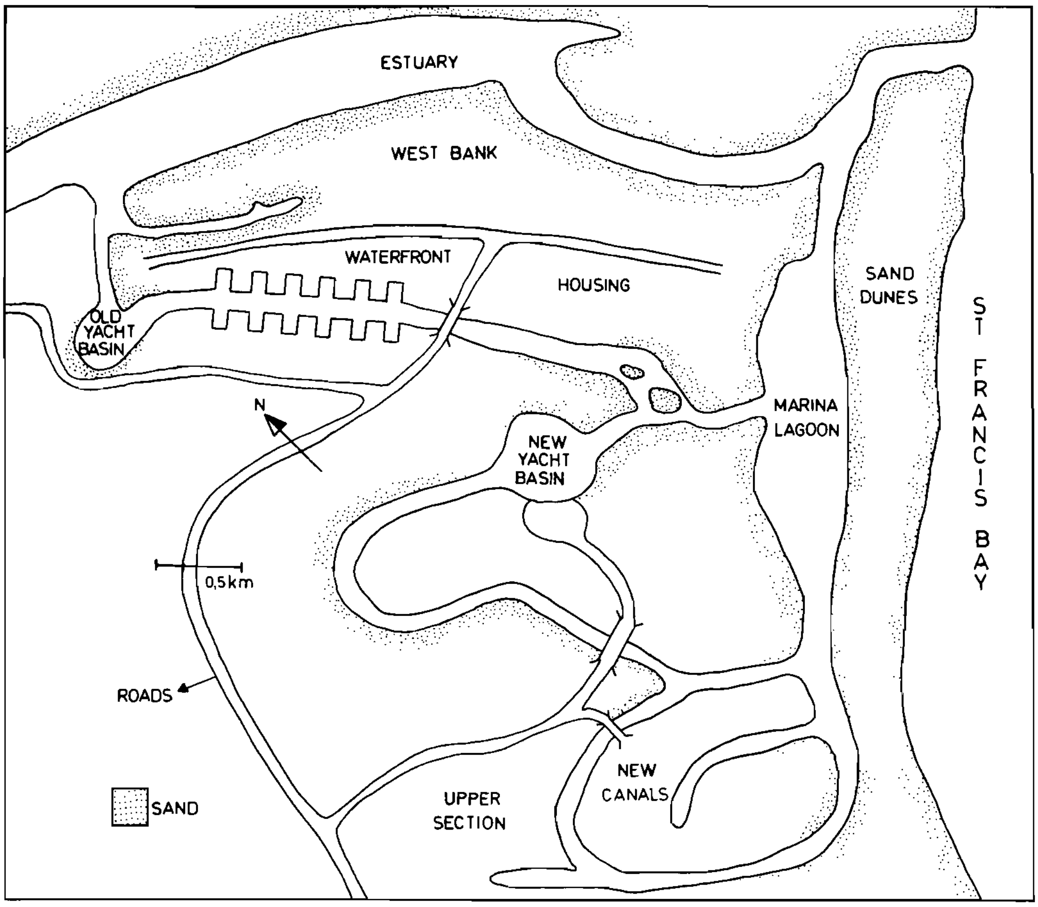

Fig. 2 Detailed map of the marina.

Material and Methods

Two detailed surveys of the marina canal system and the mouth region of the main estuary were conducted during June (26th – 30th) and November (26th – 30th) 1978. In addition, a survey of the whole estuary was conducted during January 1978 and another less intensive one of the lower reaches, mouth and canals during January 1979.

Temperature, salinity and dissolved oxygen measurements of surface and bottom waters taken at four stations (5, 19, 24 and 27, Fig. 3) during June and at three stations (13, 15 and 17, Fig. 3) during November. Surface and bottom current velocities were measured with a Savonious type rotor at Stations 5, 19, 24 and 27 in the canals. All measurements were taken at spring high tides.

During November 1978 drogue studies were conducted at three stations (8, 23 and 30, Fig. 3). A drogue consisted of a brightly coloured float attached to a rope of about 50 cm at the end of which were two rectangular (30 × 15 cm) marine ply boards, bisecting each other at right angles. A weight was also attached to the end of the rope. Drogues were released synchronously every 30 minutes at each station over a full spring tidal cycle. The time was measured in seconds for a drogue to travel the distance between two poles, set exactly 20 m apart. The direction of flow at each release was also noted. At Station 8, the canal widens into a wide lagoon approximately 60 m from bank to bank. Here the drogue was released at three positions; near each bank and in the middle of the stream. In addition to drogue measurements at the three fixed stations, drogues were also released at random positions in the canals during the course of this particular study. This was done in order to determine the current direction during a tidal cycle in the entire system. Tidal height fluctuations were also measured at Stations 8, 23 and 30 on a graduated wooden pole.

The following biotic communities were sampled during June and November 1978: zooplankton, ichthyoplankton, meiofauna, intertidal macrofauna and nekton.

Zooplankton and ichthyoplankton were sampled by means of two nets, each fitted with a Kahlsico 005WA 130 flow meter, at 10 stations in the estuary (Fig. 1) and at two stations (20 and 26, Fig. 3) in the canals. The nets were operated from 1,5-m booms fixed on either side of the bow of a 4,5-m ski-boat and towed for three minutes at the surface. The samples were fixed in a 5% formaldehyde solution, analysed in the laboratory to species level and expressed in numbers per m^3 of water. One net had a mouth diameter of 40 cm and a mesh aperture of 124 μm and was used to sample smaller plankters such as copepods and fish eggs. Larger organisms, such as mysids and fish larvae, were captured with a larger net of 57-cm mouth diameter and a mesh size of 190 μm.

Meiofauna was sampled at Stations 1, 3, 4, 6, 9, 11, 21 and 28 (Fig. 3). The method used is described by Dye (1978a) and extraction was done by means of an Oosternbrink flotation extractor. Meiofauna was sampled to a depth of 20 cm with a corer of 10 cm^2 surface area. Animal density was thus expressed in numbers per 200 cm^3. The different taxa were separated and counted. No attempt was made to estimate the density at different

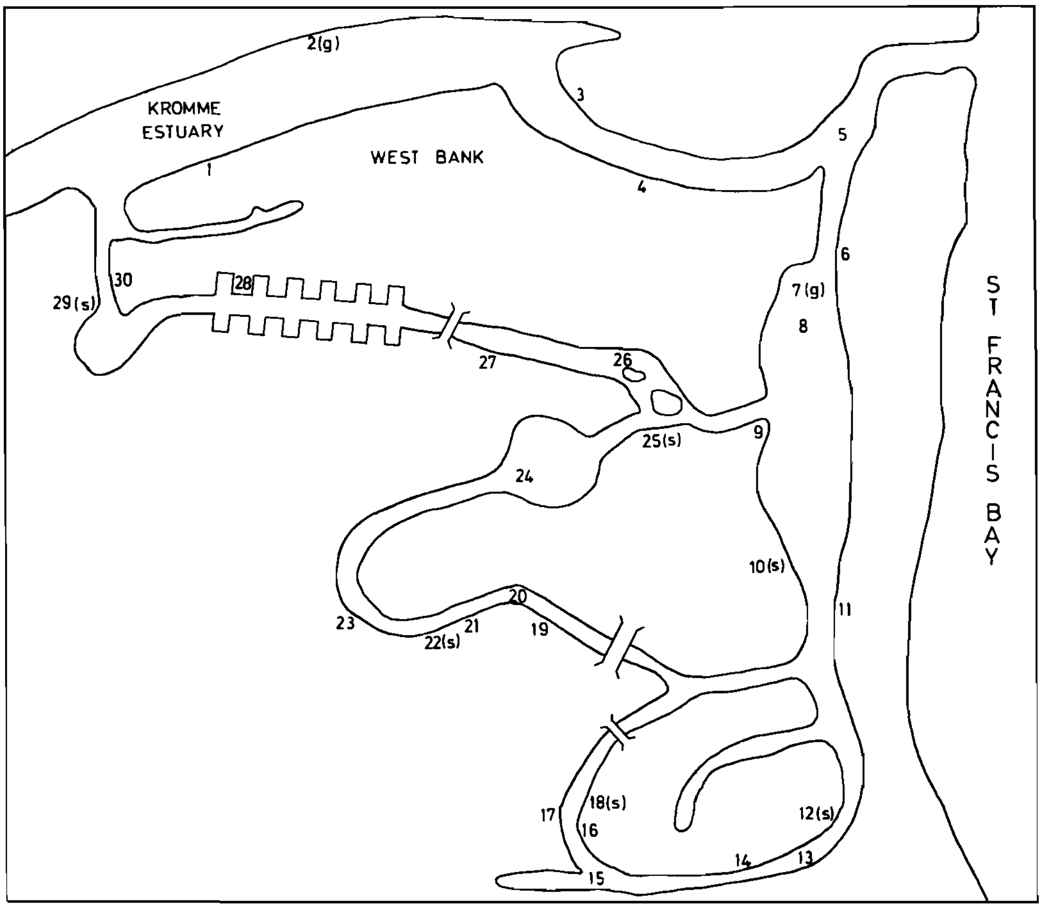

Fig. 3 Map of marina and lower reaches and mouth of estuary showing positions of stations (Stations 5, 8, 13, 15, 17, 19, 23, 24, 27 and 30; hydrographic stations: Stations 1, 3, 4, 6, 9, 11, 14, 16, 21 and 28; macro- and meiofauna stations: Stations 2(g), (Fg), 10(s), 12(s), 18(s), 22(s), 25(s) and 29(s); fish sampling stations: Stations 20 and 26; plankton stations.

depth zones within the 20-cm core. The vertical distribution of meiofauna in similar sandy substrates in the Swartkops estuary has been investigated by Dye (1978b).

Intertidal macrobenthic organisms were sampled at Stations 1, 3, 4, 6, 9, 11, 14, 16, 21 and 28 (Fig. 3) during June and November. Macrofauna was obtained by digging 4 × 0,25-m^2 quadrates at each station to a depth of approximately 50 cm; two between LWST and the mid-tide level and two between MTL and HWST. The content of each quadrate was washed through a 4-mm mesh aperture sieve. Each sample was analysed for species, numbers, size composition and biomass. The data of the four quadrates at each station were then pooled to give the standing crop, species composition, and population structure of the different species at each station.

In addition, further samples were taken at each station of the most abundant species in the sandbanks of the main estuary and in the marina to obtain large numbers for representative size-frequency distributions. The sand prawn *Callianassa kraussi*, and the bloodworm, *Arenicola loveni*, were sampled by means of a baitpump and the pencil bait, *Solen capensis*, with thin wire spears. Counts were also made at Stations 1, 3, 4, 6, 9, 11, 21 and 28 of *Callianassa, Arenicola* and *Solen* burrows along a 20 × 0,25-m transect, parallel to the waterline at mid-tide level. These counts were pooled with the numbers obtained from the 0,25-m^2 quadrates in the calculation of the density distribution of these species.

Fish were sampled by gill-netting (Stations 2(g) and 7(g)) and by seine-netting (Stations 10(s), 12(s), 18(s), 25(s) and 29(s), Fig. 3) during June and November 1978. The catches were analysed for species, numbers, mass and size. Seine-netting was also attempted in the mouth area of the main estuary, but many fish escaped due to the uneven bottom and strong currents. The resultant sample was considered non-representative and the results from the canal catches were therefore compared with seine-net catches from the mouth region of the Swartkops estuary also made during June and November.

Note was also taken of other species present in the marina, but which could not be sampled quantitatively.

Results

Abiotic characters

Temperature, salinity and dissolved oxygen

Temperature, salinity and dissolved O_2 results are presented in Table 1. During November 1978 only surface temperature and salinity were measured at approximately the same position. Summer temperatures were approximately 5 °C to 7 °C higher, but salinities and dissolved O_2 values were in the same order as winter samples.

The results show that the temperature, salinity and dissolved O_2 values measured at the surface and near the bottom in the marina do not differ markedly from those in the main estuary (Station 5). Furthermore, there appears to be no vertical stratification of these parameters in the canal system. It was concluded that the water column was well mixed and oxygen-saturated.

Table 1 Temperature, salinity and dissolved O_2 in the marina canals (Stations 13, 15, 17, 19, 24 and 27) and in the Kromme estuary (Station 5), June and November 1978. (For station positions, see Fig. 3)

Station	Depth (m) at HWST	Canal width (m)	Temperature (°C)	Salinity (°/oo)	Diss. O_2 (mgl^{-1})
5	3,2	42	0 m:17,1 (J)	36,0	7,20
			2,5 m:16,4 (J)	36,0	6,15
			0 m:20,8 (N)	34,4	7,20
13	1,0	10	0 m:20,0 (N)	34,0	7,10
			0,95 m:19,0 (N)	34,0	7,18
15	0,9	4	0 m:20,5 (N)	34,3	7,20
			0,8 m:19,6 (N)	34,0	7,05
17	1,8	5	1,5 m:19,5 (N)	34,0	7,10
19	1,2	10	0 m:15,10(J)	33,5	7,20
			1,1 m:14,90(J)	33,5	6,90
24	2,3	30	0 m:15,2 (J)	34,0	7,13
			2,2 m:15,2 (J)	34,0	6,75
			0 m:20,0 (N)	34,5	7,15
27	2,8	11	0 m:15,7 (J)	34,0	7,15
			2,8 m:15,7 (J)	34,0	7,15

Hydrographic features of the canal system

Current measurements at Stations 5, 19, 24 and 27 (Fig. 3) showed strong flow at the surface and near the bottom (Table 2) and in the same direction at all depths at a particular state of the tide. The direction of flow on the incoming tide, however, was opposite to the flow during an outgoing tide (Figs. 4 and 5). Surface measurements registered slightly higher current velocities than those close to the bottom (Table 2). At Station 24 (Fig. 3) variable and low current flow was recorded during both incoming and outgoing tides. The New Yacht Basin is comparatively large and deep so that low measurements can be expected there.

From the drogue studies conducted at Stations 8, 23 and 30, directions and velocities could also be determined during flood and ebb tides, and these results are presented in Table 2. In these calculations the measurements taken at the turn of the tide were not included, when current flow was minimal.

Table 2 Mean velocity (cm s^{-1}) during flood and ebb tides in the main estuary (Station 5) and marina canals (Stations 19, 24 and 27). (Savonious rotor measurements at Stations 5, 19, 24 and 27; drogue studies at Stations 8, 23 and 30)

Station	Mean current velocity (cm s^{-1}) flood tide	Mean current velocity (cm s^{-1}) ebb tide	Tidal range (cm)
5	35 (0 m)	32 (0 m)	–
	32 (3,0 m)	30 (3,0 m)	
19	Variable flow at surface and bottom	33 (0 m)	–
24	Surface and bottom currents speed variable at both ebb and flood tides.		
27	33 (0 m)	46 (0 m)	–
	31 (2,8 m)	38 (2,8 m)	
8	15	14	80
23	11	10	66
30	34	36	60

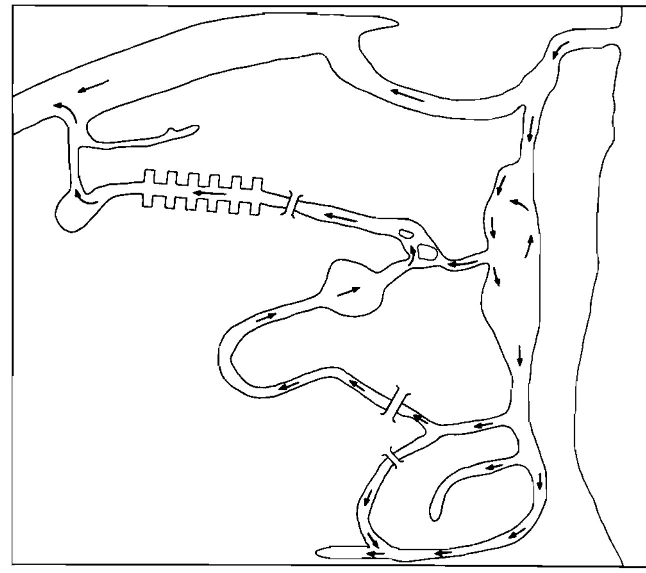

Fig. 4 Current flow pattern during incoming tide.

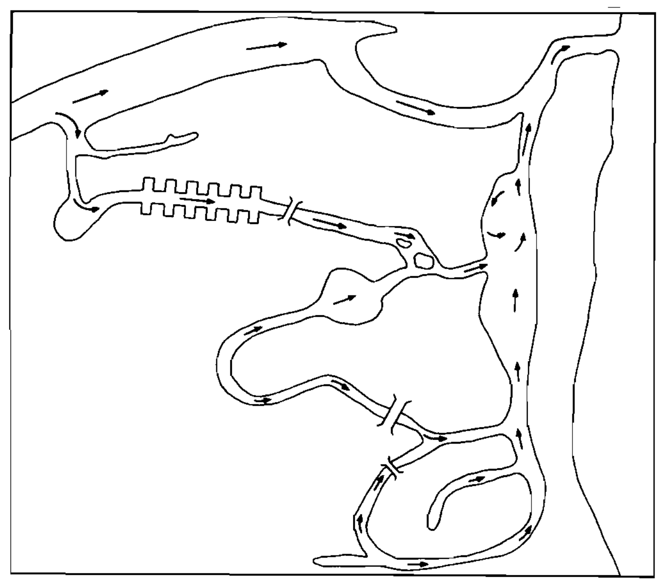

Fig. 5 Current flow pattern during outgoing tide.

Current velocities measured by the Savonius rotor and by drogues indicate speeds up to 46 cm s^{-1} at the surface and 38 cm s^{-1} at the bottom. Lower velocities were recorded at Stations 8 and 23. Station 8 was situated in the lagoon, where eddies develop during ebb and flood tides (Figs. 4 and 5). Current flow at Station 23 was also low (10 – 11 cm s^{-1}, Table 2) which can be expected in that part of the system. Extremely weak current flow was observed in the upper section of the marina (Stations 13, 15 and 17, Fig. 3). In this section the currents were sluggish during both tides and this is the only section of the marina at present where danger exists of decreased water quality due to inadequate flushing.

Substrate of the canal system

The substrate composition of the mouth region of the estuary is mainly alluvial sand. In the marina, inter- and subtidally, the substrate consists mainly of medium-sized sand grains with very little silt. The results of substrate analyses from various positions in the lower sections in the marina (Stations 6, 9, 27 and 29, Fig. 3) and from the west bank of the main estuary (Stations 3 and 4) are shown in Table 3. The intertidal, burrowing faunal communities found in the canal system are typical of those usually associated with a sandy substrate.

Certain sections of the canals have been reinforced with rocks and stones, and silt and clay have accumulated amongst the supporting rocks. This in effect, has created a different environment for macrobenthos than in the rest of the marina. A short mudbank also exists at Station 16 (Fig. 3) where a mudprawn population has established itself.

Table 3 Substrate analysis of main estuary (Stations 3 and 4) and of marina canals (Stations 6, 9, 27 and 29). The median particle diameter (md Q), the skewness (Sk Q) and the quartile deviation (Qd Q) are expressed in Phi units (data from T. Hecht)

	Main estuary (Stations 3 & 4)	Marina canals (Stations 6, 9, 27 & 29)
Md Q	1,31	1,28
Sk Q	−0,02	−0,03
Qd Q	0,37	0,40
% Subsieves	0,83	0,79

Although no subtidal sediment samples were taken, the spoil from dredging operations consists mainly of sand except in the region between Stations 24 and 23 which constitute a sand-mud mixture. In this area current flow was low which allowed the settling out of finer particles (Table 2). The presence of subtidal *Ruppia* was noted in these areas.

The banks of the canals in the upper section of the marina consist almost entirely, with the exception of a short sandy area at Station 14 and a muddy stretch at Station 16, of loose stones and a hard shelly mud. The banks are also vertical and are devoid of any burrowing or other benthic macrofauna.

Biotic communities in the marina and in the main estuary

Zooplankton

Species composition and numbers per m^3 at two stations (20 and 26) in the marina and at ten stations in the estuary for June and November 1978 are given in Tables 4 and 5 respectively. In the mouth region of the estuary (Stations 1 and 2, Fig. 1) and at Station 26 (Fig. 3) species associated with marine waters are recorded. These species, including *Corycaeus* spp., *Euterpina acutifrons, Microsetella norvegica, Paracalanus crassirostris, Pseudodiaptomus nudus* and *Sagitta* spp., enter the estuary on the flood tide, moving out again on the ebb.

At Station 20 in the upper areas of the canal system typical estuarine zooplankton species were recorded and include *Pseudiaptomus hessei, Acartia longipatella, Tortanus capensis* and the mysid *Mesopodopsis slabberi.* The mysid *Rhopalophthalamus terranatalis* was present in the estuary, but was absent in these particular canal samples. *Mesopodopsis slabberi* and *Gastrosaccus brevifissura* were less abundant in the canals compared to the estuary and those in the canals were predominantly juvenile forms, with no adult females with developing eggs or young in their brood pouches. Spatial and temporal succesion of *Acartia longipatella* and *A. natalensis*, already described from the Swartkops and Sundays estuaries (Wooldridge & Melville-Smith 1979), is also evident in the Kromme estuary. Mid-summer samples from January 1978 indicated high numbers of *A. natalensis* particularly at Station 10 in the Kromme tributary (22 000 m^{-3}) and in the Geelhoutsboom tributary at Station 7 (41 000 m^{-3}) (See Fig. 1).

The zooplankton in the marina canals between Stations 8 and 30, where current velocities were relatively high, may be considered to be typical of the mouth region of the estuary. In those regions where currents were weak (between Stations 19 and 24) in the upper areas of the marina, a typical estuarine zooplankton fauna is present.

Ichthyoplankton

Analysis of the samples revealed the presence of 12 fish families and 14 species in the entire estuary which could be identified down to genus and/or species level. In this paper only the larvae of the canals and of the lower reaches and mouth area of the estuary are discussed. A full account of the ichthyoplankton of the estuary is published elsewhere (Melville-Smith 1981).

The species composition of the larval community in the marina was similar to that of the estuary (lower reaches and mouth). Table 6 shows the species recorded as well as the number per m^3.

Of the 14 species recorded in the Kromme estuary, 13 were found in the lower reaches and mouth area while 11 species were sampled in the marina canals. *Hemiramphus* spp. was recorded in the upper reaches only, while two species, *Etrumeus teres* (Sciaenidae) and *Argyrosomus hololepidotus* (Sciaenidae) occurred in the main estuary (lower reaches and mouth) but not in the marina.

Table 6 shows that the species diversity and numbers were lower during winter than in summer. The same trend is clear in both the estuary and the canals. Fish larval density is higher in the main estuary for winter and summer when compared to that of the canal system.

No noticeable difference was found in the composition of fish larvae from the two stations (20 and 26) sampled in the marina canals.

Meiofauna

The density and percentage contribution of the major meiofauna taxa are given in Table 7. Nematodes dominate the meiofuana at all stations (1, 3, 4, 6, 9, 11, 21 and 28, (Fig. 3) and account for 87,9% of the total number. Mystacocarids accounted for 3,6%, harpacticoid copepods 2,9% and the remainder of the meiofauna ('others' in Table 7) 5,6% of the community at all stations.

An analysis of variance was performed on (a) the counts of Nematoda and (b) all the taxa combined using a repeated measures model with one factor (area, with main estuary and marina canals as its two levels) fully crossed with tidal zone sampled (low tide, LWST, and mid-tide, MT, being its two levels) and where the different stations are nested within area but fully crossed with tidal zone (Winer 1971). The analysis of variance

Table 4 Zooplankton species composition and numbers m^{-3} at two stations in the marina canals (20 and 26) and at ten stations in the Kromme river estuary, June 1978. Position of sampling localities given in Fig. 1

Region:	Marina canals		Mouth – bridge		Cottages – Island			Geelhout tributary		Kromme tributary		
Stations:	26	20	1	2	3	4	5	6	7	8	9	10
Annelida												
Polychaete larvae	0	0	92	0	0	0	0	0	0	0	0	0
Crustacea												
Copepoda												
Acartia longipatella	0	46	0	115	0	1 385	591	4 182	1 611	7 945	1 478	2 484
Acartia natalensis	0	0	0	0	0	40	0	84	0	0	0	0
Copepod spp.	280	709	878	316	191	316	169	0	134	251	565	444
Corycaeus sp.	23	0	0	0	0	0	0	0	0	0	0	0
Euterpina acutifrons	29	0	46	29	0	0	0	0	0	0	0	0
Microsetella norvegica	0	0	46	0	0	0	0	0	0	0	0	0
Nauplii larvae	257	435	324	1 378	414	10 483	4 222	16 222	1 611	10 036	2 956	5 500
Oithona spp.	654	320	1 017	0	0	0	0	0	0	0	0	0
Oncaea spp.	0	0	92	0	0	0	0	0	0	0	0	0
Paracalanus crassirostris	46	0	46	0	0	0	0	0	0	0	0	0
Pseudodiaptomus hessei	0	206	0	29	2 832	2 010	2 940	16 226	7 720	7 026	2 086	3 459
Pseudodiaptomus nudus	46	0	46	0	0	0	0	0	0	0	0	0
Tortanus capensis	0	0	0	0	0	0	0	0	0	167	0	0
Mysidacea												
Gastrosaccus brevifissura												
Adult males & non-brooding females	0	0	0	0	0	1	0	0	0	0	0	0
Brooding females	0	0	0	0	0	0	1	0	0	0	0	0
Immature & juveniles	2	1	3	7	1	23	26	0	0	0	1	1
Total *G. brevifissura*	2	1	3	7	1	24	27	0	0	0	1	1
Mesopodopsis slabberi												
Adult males & non-brooding females	0	2	0	0	9	6	22	16	60	0	0	0
Brooding females	0	0	0	0	0	2	1	0	0	0	0	0
Immature & juveniles	<1	1	2	2	15	24	51	199	243	25	34	25
Total *M. slabberi*	<1	3	2	2	24	32	74	215	303	25	34	25
Rhopalophthalamus terranatalis	0	0	0	0	0	0	1	8	7	0	1	0
Cumacea												
Iphinoe truncata	0	0	0	2	0	0	0	0	0	2	0	0
Brachyura												
Megalopa larvae	1	0	0	2	4	0	0	0	0	0	0	0
Zoea larvae	0	0	1	2	0	0	0	4	0	0	0	0
Chaetognatha												
Sagitta spp.	0	0	46	0	0	0	0	0	0	0	0	0

shows no significant difference between the average number of Nematoda and the number of all taxa combined found in the main estuary and in the marina canals (P>0,25).

In the Kromme estuary and the canals high numbers occurred at the mid-tide level at most stations for all taxa (Table 7). The meiofauna community is most probably limited by desiccation at high water and by scouring at low tide (Dye *pers. comm.*).

The mean standing crop (all stations) is 530,4 individuals per 200 cm^3 which is slightly lower than the value of 648,2 for meiofauna in similar sandy substrates in the Swartkops estuary (Dye & Furstenberg 1978).

There appears to be more meiofauna in the Kromme estuary than in the marina canals and Swartkops estuary; the mean standing crops being 710,5; 447,4 and 648,2 individuals per 200 cm^3 respectively.

Table 5 Zooplankton species composition and numbers m^{-3} at two stations in the marina canals (20 and 26) and at ten stations in the Kromme river estuary, November 1978. Position of sampling localities given in Fig. 1. (N.s. indicates no 40 cm net sample)

Region:	Marina canals		Mouth – Bridge		Cottages – Island			Geelhout tributary		Kromme tributary		
Stations:	26	20	1	2	3	4	5	6	7	8	9	10
Crustacea												
Copepoda												
Acartia longipatella	0	9 810	0	5 768	10 749	14 780	4 812	12 260	4 585	N.s.	2 085	687
Acartia natalensis	0	0	0	0	0	0	0	0	2 487	N.s.	0	253
Copepod spp.	217	0	0	0	0	0	0	0	0	N.s.	0	0
Nauplii larvae	0	15 695	0	8 497	8 567	10 461	2 761	10 194	8 549	N.s.	1 203	1 310
Oithona spp.	867	0	0	0	0	0	0	0	0	N.s.	0	0
Pseudodiaptomus hessei	162	8 407	0	1 302	18 979	20 731	22 244	9 644	19 584	N.s.	8 101	5 349
Pseudodiaptomus nudus	162	0	0	0	0	0	0	0	0	N.s.	0	0
Tortanus capensis	0	12	0	0	0	0	0	0	0	N.s.	0	0
Mysidacea												
Gastrosaccus brevifissura												
Adult males & non-brooding females	0	0	6	32	0	0	0	13	0	0	0	0
Brooding females	0	0	2	4	0	0	0	0	0	0	4	0
Immature & juveniles	3	0	22	648	40	0	7	26	0	7	15	3
Total *G. brevifissura*	3	0	30	684	40	0	7	39	0	7	19	3
Mesopodopsis slabberi												
Adult males & non-brooding females	0	14	0	0	53	43	29	26	48	36	18	0
Brooding females	0	0	0	0	18	50	80	13	11	14	7	0
Immature & juveniles	21	162	0	0	477	92	374	957	179	645	261	0
Total *M. slabberi*	21	176	0	0	548	185	483	996	238	695	286	0
Rhopalophthalamus terranatalis	0	0	0	0	18	26	7	102	77	21	47	5
Cumacea												
Iphinae truncata	24	0	29	0	0	0	0	0	0	0	0	0
Amphipoda												
Melita zeylanica	0	0	0	0	0	0	0	0	0	7	0	0
Brachyura												
Megalopa larvae	0	0	15	14	0	0	0	0	0	64	0	0
Zoea larvae	161	0	10	114	0	40	0	0	0	423	241	181
Chaetognatha												
Sagitta spp.	5	0	0	0	0	0	0	0	0	0	0	0

In this study the vertical distribution of meiofauna has not been investigated. Dye (1978b), however, reported in some detail on this aspect of meiofaunal ecology in the Swartkops estuary. According to Dye the proportion of meiofauna appears to increase with depth down to about 20 cm. There does not seem to be one singular stimulus affecting this vertical distribution but rather a combination of O_2, desiccation and grain size. The activity of other burrowing animals, eg. *Callianassa kraussi*, may also affect the distribution (Dye 1978b). The vertical distribution of meiofauna in the Kromme system is most probably influenced by similar environmental factors and similar trends in depth distribution can be expected.

Intertidal macrofauna

Since the substrate of the mouth area in the main estuary and in the marina is mainly sand, results of the analysis of the samples from the two areas show that the communities are, in general, of a very similar composition (Table 8). A total of 16 species have been recorded in intertidal zones of the two areas. Three species, *Glycera tridactyla, Tellina gilchristi* and *Macoma ordinaria* were found only in the main estuary whilst *Natica tecta* and *Thaumastoplax spiralis* were sampled only in the marina.

In both areas, bait organisms such as the sandprawn, *Callianassa kraussi*, the pencil bait, *Solen capensis* and the bloodworm, *Arenicola loveni*, predominated in terms of numbers and biomass. However, the density of these organisms, particularly *C. kraussi* and *A. loveni*, differed significantly in the two areas.

Sandprawn densities were much lower in the estuary (Table 8). Numbers per m^2 varied in the estuary between 4,4 (June 1978) and 6,5 (November 1978) and in the canals between 16,9 (June) and 15,7 (November). The

Table 6 Larval fish species abundance in the Kromme estuary (lower reaches and mouth only) and in the marina canals for June and November 1978

	Main estuary (No. m $^{-3}$)		Canal system (No. m $^{-3}$)	
Family and Species	June	November	June	November
Clupeidae				
Gilchristella aestuarius	0,33	1,48	0	0,10
Gobiidae (unidentified spp.)	0,05	1,04	0	0,05
Psammogobius knysnaensis	0	0,59	0	0,12
Engraulidae				
Stolephorus commersonni	0	0,02	0	0,02
Etrumeus teres	0	0,03	0	0
Soleidae				
Heteromycteris capensis	0	0,06	0	0,02
Monodactylidae				
Monodactylus falciformis	0,03	0,07	0,03	0,07
Sparidae				
Rhabdosargus spp.	0	0,03	0,03	0,03
Sciaenidae				
Argyrosomus hololepidotus	0	0,04	0	0
Atherinidae				
Hepsetia breviceps	0	0,06	0	0,02
Blenniidae				
Ombranchus woodi	0	0,07	0,07	0,17
Tetradontidae	0	0,01	0	0,02
Unidentified spp.	0	0,04	0	0,04
Total larvae m $^{-3}$ water	0,41	3,63	0,13	0,66

biomass (g dry mass m $^{-2}$) was 0,92 (June) and 4,99 (November) in the main estuary and 12,66 (June) and 15,76 (November) in the canals. These results clearly show the higher standing crops of *C. kraussi* in the marina. There also appears to be a difference in the population structure of this species in the two areas. Fig. 6c illustrates that the sandprawns in the marina are bigger (population mean 10,4-mm carapace length) than those in the main estuary ($\bar{x}$ = 7,0-mm carapace length). Sandprawns are popular bait organisms and therefore heavily exploited, more so on the sandbanks of the main estuary than in the marina. Larger individuals are preferred, which would account for their absence in the samples, or the growth of the population could have become stunted due to bait exploitation.

The bloodworm, *A. loveni*, showed a similar pattern in density distribution. Bloodworms were present in higher numbers, particularly during summer in the marina (5 m $^{-2}$) than in the main estuary (3 m $^{-2}$) (Table 8). Displacement volume measurements of bloodworms from both areas (Fig. 6b(i) and 6b(ii)) showed more of the smaller bloodworms in the marina during November 1978. In January 1979 an additional bloodworm survey was conducted to investigate the influence of bait-digging on this population. Densities were found to be much lower (< 1m $^{-2}$) during January but of significance was the drastic change in population structure. Fig. 6b(iii) clearly shows the absence of larger animals and the population at that time consisted almost entirely of small individuals, which can most likely be related to heavy bait exploitation during the holiday season. The detrimental effect of

Table 7 Composition of meiofauna communities in main estuary (Stations 1, 3 and 4) and marina (Stations 6, 9, 11, 21 and 28) (numbers 200 m $^{-3}$). 'Others' include Gastotricha, Oligochaeta, Polychaeta and Platyhelminthes

		Taxon				
Station, tide level and mean		Nematoda	Harpacticoida	Mystacocarida	'Others'	All taxa
St. 1	LWST	607	9	13	19	
	MT	609	2	2	31	
St. 3	LWST	981	7	16	7	
	MT	1 204	15	59	209	
St. 4	LWST	107	5	3	9	
	MT	301	15	16	17	
mean		634,8	8,8	18,2	48,7	710
percent		89,4	1,2	2,6	6,8	100,0
St. 6	LWST	603	11	14	12	
	MT	673	49	55	54	
	HWST	206	2	5	9	
St. 9	LWST	196	5	45	9	
	MT	462	42	35	35	
	HWST	331	9	6	5	
St. 11	LWST	343	10	8	8	
	MT	336	45	38	28	
	HWST	191	18	14	78	
St. 21	LWST	278	2	6	26	
	MT	314	16	17	1	
St. 28	LWST	787	0	1	10	
	MT	331	9	6	5	
mean		388,5	18,2	19,2	21,5	447,4
percent		86,8	14,1	4,3	4,8	100,0

this practice on the bloodworm population is clearly illustrated by these figures. The population structure of bloodworm in the marina did not change from that of November, where bait exploitation is less intensive.

Solen capensis occurred in both areas and although there was a decrease in numbers from June to November, they were present in nearly equal quantities in the estuary and in the marina (Table 8). Biomass values were 25,91 and 30,83 g dry mass m $^{-2}$ during winter in the estuary and marina respectively while in summer biomass values were much lower namely 7,82 and 11,29 dry mass m $^{-2}$ respectively. A reduction in the standing crops of 70% and 63% was calculated for the estuary and marina respectively. This species is also used as bait but not as frequently as bloodworm and sandprawn. The reasons for the seasonal decrease in abundance is not clear.

In addition to the sand communities, a few species which inhabit a muddy substrate have been sampled in the vicinity of Stations 28 and 16 where mud deposition has taken place. Random sampling for the mudprawn, *Upogebia africana*, and the crab, *Sesarma catenata*, was carried out at Station 28 by Hecht (*pers comm.*). The densities of these two species varied between 24 and 36 m $^{-2}$ respectively. The densities are much lower than in the mudbanks of the main estuary, 119 and 92 m $^{-2}$ for the two species respectively. High densities of *U. africana* were recorded at Station 16 in the upper section of the

Table 8 Density distribution (number m^{-2}) of macrobenthos in the main estuary (Stations 1, 3 and 4) and marina canals (Stations 6, 9, 11, 21 and 28), with standard mean error given in parentheses

	June 1978				November 1978			
Species	Main estuary		Marina		Main estuary		Marina	
Annelida, Polychaeta								
Glycera tridactyla	2	–	0	–	3,5	–	0	–
Arenicola loveni	2,7	(0,53)	3,0	(0,23)	2,9	(1,35)	5,1	(2,9)
Unidentified polychaetes	4	–	4	–	9	–	4	–
Crustacea, Decapoda								
Anomura								
Diogenes brevirostris	30	–	32	–	10	–	4	–
Callianassa kraussi	4,4	(1,46)	16,9	(2,17)	6,5	(0,52)	15,7	(2,91)
Upogebia africana	0	–	24	–	0	–	36	–
Brachyura								
Thaumastoplax spiralis	0	–	0	–	0	–	4	–
Sesarma catenata	0	–	0	–	10	–	15	–
Nemertea								
Polybrachiorhynchus dayi	0	–	0	–	4	–	2,5	–
Mollusca, Pelycopoda								
Solen capensis	11,0	(1,12)	13,5	(1,8)	5,0	(0,71)	5,1	(1,13)
Dosinia hepatica	0	–	8	–	0	–	0	–
Loripes clausus	0	–	4	–	24	–	0	–
Tellina gilchristi	10	–	0	–	0	–	0	–
Psammotellina capensis	0	–	0	–	4,5	–	2	–
Macoma ordinaria	6	–	0	–	0	–	0	–

marina. Here the mudbank is about 20 m long with a relatively narrow intertidal area but a mean of 374 m^{-2} mudprawns has been obtained. The population consists, however, mainly of smaller animals (< 12,0-mm carapace length) and showed a unimodal size distribution whereas the population in the main estuary has a large proportion of animals > 12,0-mm carapace length.

Diving with the aid of SCUBA in the canals and the main estuary revealed *Callianassa* burrows, approximately 4 m^{-2}. The burrows in the canals showed a very patchy distribution, sometimes as many as 10 m^{-2}.

Nekton

Fish were sampled by means of gill (g) and seine (s) nets at Stations 2(g), 7(g), 10(s), 12(s), 18(s), 22(s), 25(s) and 29(s) (Fig. 3). Results are presented in Tables 9 and 10. With both techniques, the total number of individuals and the total biomass were greater for the catches made in the main estuary. The greater biomass and number of fish in the gill-net catches in the estuary are mainly due to large numbers of barbel, *Tachysurus feliceps*, caught during November.

Seine-net catches, made at six different positions in the canals, were analysed separately and the results have not shown a definable distribution pattern of fish within the marina. Species such as *Liza richardsoni, L. dumerili, Gilchristella aestuarius, Lithognathus lithognathus, Diplodus sargus* and species of Gobiidae and Soleidae were recorded at at least three stations while the other species were sampled at one or two stations. The entire canal system therefore appears to be accessible to estuarine fish.

Table 9 Gill-net fish catch composition and catch per unit effort (number per 15 h gill-net set) in Kromme estuary and marina canals

	Canals		Kromme estuary	
Species	$\overline{\text{no}}$./set	biomass (kg)	$\overline{\text{no}}$./set	biomass (kg)
Acanthopagrus berda (mudbream)	1	0,024	0	–
Argyrosomus hololepidotus (kob)	3	2,868	3	5,877
Lichia amia (leervis)	1	0,506	2	1,127
Lithognathus lithognathus (steenbras)	0	–	1	0,159
Liza richardsoni (mullet)	0	–	3	0,757
Liza tricuspidens (mullet)	2	1,420	1	0,534
Mugil cephalus (mullet)	1	0,031	0	–
Myliobatus aquila (duckbill)	3	3,537	0	–
Pomadasys commersoni (tiger)	2	0,085	0	–
Pomatomus saltatrix (elf)	0	–	1	0,687
Rhabdosargus holubi (stompie)	1	0,168	1	0,063
Tachysurus feliceps (barbel)	1	0,235	22	11,965
Total	15	8,874	34	21,169

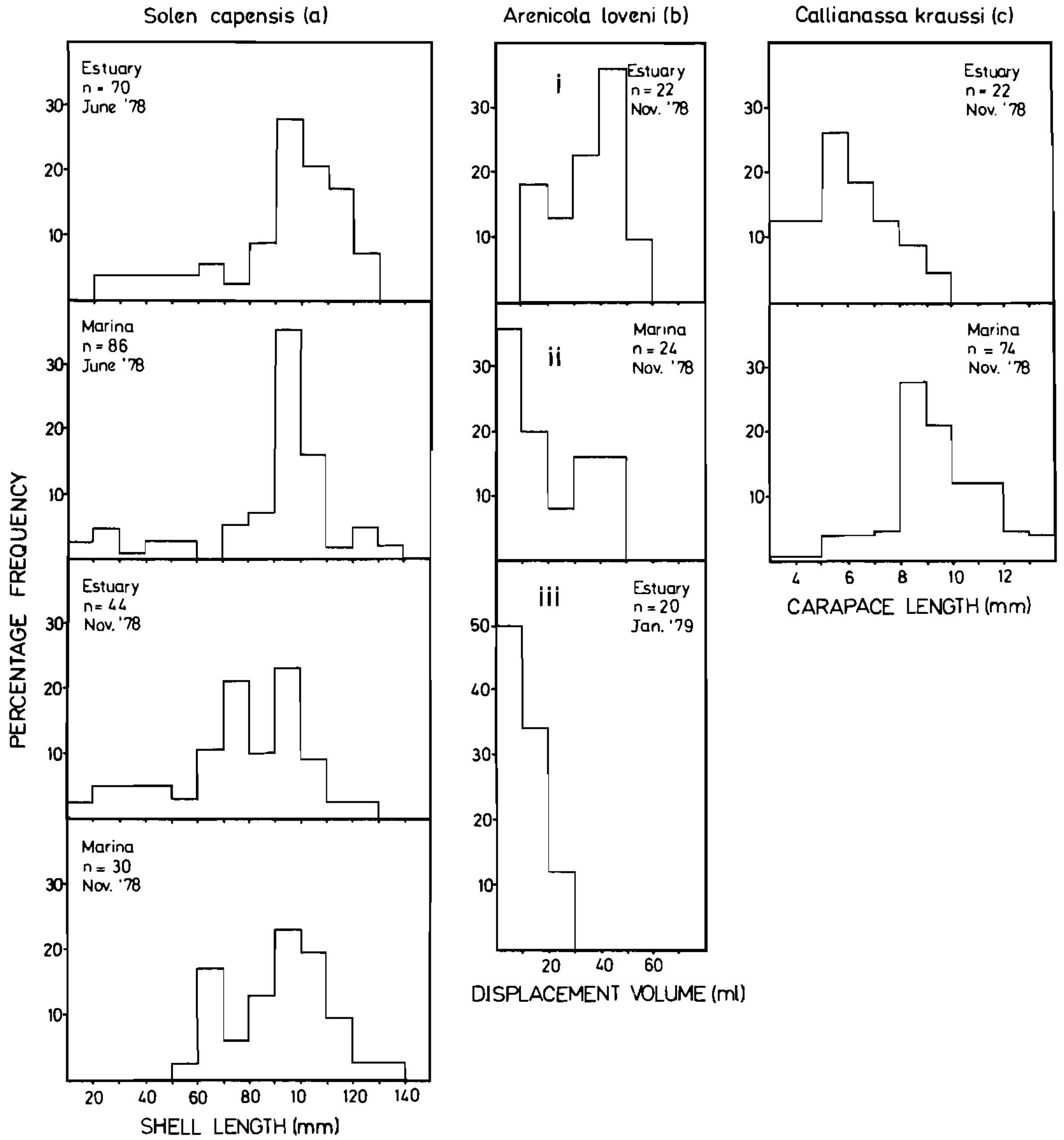

Fig. 6 Population structures of (a) *Solen capensis*, (b) *A. loveni* and (c) *C. kraussi*.

When seine-net catches of the marina are compared to hauls made with the same gear in the mouth region of the Swartkops estuary, the results again show a larger number of individuals and a greater total biomass for estuarine catches (Table 10). The difference is mainly due to the large number of *L. dumerili* and *G. aestuarius* caught in the estuary. The species composition of the two areas, Swartkops estuary and Kromme Marina, is, however, very similar, with the same species occurring in both areas. These results, as well as those from regular gill- and seine-net catches made in the Kromme and Swartkops estuaries (Baird, Marais & Winter 1979, Winter 1980) show that all the species recorded in the canals were sampled at one stage or the other in the estuaries. Size of fish species caught in the estuaries and marina were comparable and fell within the same range.

Additional species

Several species were recorded in the marina, but not quantitatively sampled, in addition to those sampled by conventional methods. Some of these are normally not found in the mouth areas of estuaries. A list of these species is given below and the approximate position where these species were observed is given in brackets and refers to Fig. 2.

Table 10 Seine-net fish catch composition in marina canals compared to mouth area of Swartkops estuary

	Canals		Swartkops estuary	
Species	No./haul	Biomass (g)	No./haul	Biomass (g)
Clinidae	1	1,0	5	3,8
Diplodus cervinus (wildeperd)	1	4,5	5	12,3
Diplodus sargus (blacktail)	3	2,2	24	18,2
Gilchristella aestuarius (silverside)	609	444,6	1 762	1 286,3
Gobiidae	4	2,9	6	5,0
Lithognathus lithognathus (steenbras)	6	119,4	4	79,6
Liza dumerili (mullet)	9	814,7	29	2 625,1
Liza richardsoni (mullet)	35	3 168,2	36	3 258,7
Platycephalus indicus	0	–	1	32,0
Pomodasys olivaceum	1	6,0	1	4,3
Pomatomus saltatrix (elf)	2	800	0	–
Rhabdosargus holubi (stompie)	22	576,9	41	1 075,1
Soles	20	14,6	0	–
Total	713	5 955,0	1 914	8 400,4

Balanus elizabethae — acorn barnacle (New Yacht Basin)
Codium spp — green algae (vicinity of Station 21)
Cyclograpsus punctatus — shore crab (vicinity of Station 28)
Hepsetia breviceps — silverside (New Yacht Basin)
Hydatina physis — Gastropoda (New Yacht Basin)
Hymenosoma orbiculare — crown crab (Station 16)
Notarchus (Bursatella) leachi with egg strings — sea slug (near Station 21)
Octopus granulatus — common octopus (New Yacht Basin, Station 28)
Palaemon pacificus — sand shrimp (Station 14, New Yacht Basin)
Parechinus angulosus — sea urchin (New Yacht Basin)
Potamilla reniformis — fan-worm (amongst *Pyura* on pylons in New Yacht Basin)
Pyura stolonifera — red-bait (New Yacht Basin, Station 28)
Ruppia spiralis — spermatophyte (subtidally, in canal between Stations 21 and 24)
Sabellastarte longa — giant fan-worm (New Yacht Basin)
Scylla serrata — Knysna crab (vicinity of Station 28)
Sepia officinalis — cuttle-fish (New Yacht Basin)
Siphonaria oculus — (attached to rocks, Station 14).

Discussion and Conclusions

Analyses of the composition of the biotic communities present in the marina canals have shown that they do not differ in composition from those in the main estuary. It was found that the density and biomass of zooplankton, ichthyoplankton, meiofauna and nekton were slightly higher in the main estuary than in the marina canals. In some cases the differences were not statistically significant and the variations may be due to sampling errors and to patchiness. In both areas numbers and diversity were lower during winter. The distribution of these communities in the marina canals was random. The system therefore provided suitable living conditions for the various species.

The density and size distributions of bait organisms, which also predominated in terms of numbers and biomass, however, do not conform to the general trend observed for the other faunal communities. These species namely *Callianassa kraussi, Arenicola loveni* and *Solen capensis*, occurred in higher densities in the marina than in the main estuary. Differences were also noted in population structure of bloodworm and sandprawns in the two areas. It is most likely that the heavy bait exploitation on the sandbanks of the estuary can be related to these differences between the populations in the two areas. The sandprawn population seems to be particularly affected since it appears to be more valuable to bait diggers than the other two species.

A. loveni population structures during June and November appeared to be very similar. However, the size composition changed dramatically after the holiday season. When sampled in January, the estuarine population consisted almost entirely of smaller individuals whilst the population in the marina maintained its November structure.

These results illustrate the effect of the exploitation of certain species populations. It can lead, as for *C. kraussi*, to stunted growth or, as for *A. loveni*, to a loss of larger individuals. In fact, bloodworm is virtually absent from the sandbanks of the mouth region of the Swartkops estuary; a result of excessive bait-digging. Although not directly related to the aims of this study, these observations clearly show that more attention should be given by the authorities to the question of bait exploitation in estuaries.

The presence of relatively undisturbed adult or breeding populations of bloodworm and sandprawn has a distinct advantage. The marina may serve as an area from where larvae may be recruited to the rest of the main estuary.

In order to maintain the canals at desired depths to allow the passage of yachts and motorboats, continuous dredging takes place. The spoil is deposited, or attempted to be so, on undeveloped housing areas above the high-water mark. This is not always possible, with the result that tons of spoil are deposited on some intertidal areas with an obvious adverse effect on the macrofaunal populations. At the same time subtidal populations are eliminated during dredging operations. Dredging, therefore, appears to have a destabilizing effect on inter- and subtidal benthic populations. A possible solution to this problem is to dispose of the spoil on specific reserved sites.

It can be concluded that the marina canal system is an extension of the main estuary which provides sufficient food, shelter and habitats for a large number of estuarine and marine species. What are the factors and characteristics, then, of the system which allow the marina to maintain itself in such a healthy ecological state?

It has been shown that no thermal or dissolved O_2 stratification is present in the canal system and that surface and bottom current-flow is strong at most places. The water in the canals appears to be well mixed and oxygen saturated. Water circulation during a tidal cycle indicates efficient flushing of the entire system, with the possible exception of the upper section of the marina. Current speeds, however, varied at different positions in the canals. Low and variable current speeds were recorded between the new yacht basin and Station 23, and in the upper section, between Stations 13 and 15. Bottom grabs have shown the accumulation of fine silts and biogenic material which could lead to local eutrophication in these areas. Drogue studies, however, did indicate water movement, albeit slow, in those areas during ebb and flood tides.

Maximum current velocities were measured near Station 27 (Fig. 3) where a narrow road bridge spans the canal which gives access to the residential area on the west bank. The bridge forms a constriction but it is not clear whether it inhibits water-flow in the rest of the system. It does not appear to have an effect during the outgoing tide as most of the water leaves the marina via the access canal closest to the mouth. During the incoming tide it may reduce the efficiency of circulation in the canals above the new yacht basin and Station 11. These comments are, however, purely speculative and need to be verified by a detailed hydrographic study of the estuary and marina. Such studies have recently been conducted in Swartvlei (CSIR 1978) and the Swartkops estuary (Department of Zoology, UPE, unpublished data).

A certain amount of organic material, particularly leaves from overhanging trees, is continually released into the canals. It would appear from this investigation that the largest proportion of this material is exported by means of currents. Furthermore, sewage effluent is not discharged into the marina and in the absence of any agricultural or industrial development, nutrient input is maintained at low levels.

The canals become gradually shallower as one leaves the mouth. Near Station 27 the depth is 2,75 m, at Station 21 1,10 m and at Station 15 less than 1,0 m. It seems to be important therefore that the canal depths should not exceed those of the main estuary to prevent the formation of pockets of stagnant water.

The authors are of the opinion that the good environmental conditions which prevail at present in the marina and which are conducive to estuarine life are mainly due to efficient water circulation by tidal action. The result is that good water-quality standards, especially dissolved O_2, are being maintained and the system provides adequate water exchange with the parent body of water. The presence of two access canals, at Stations 5 and 30 respectively, allow free water circulation with the main estuary and Figs. 4 and 5 clearly show the importance of these two canals to the marina. The lower one (closest to the mouth) is of particular importance since it acts as the major in-and-out-flow canal during flood and ebb tides.

Published biological studies of marina canals in estuaries indicate that species composition, abundance and growth of organisms can be detrimentally affected by reduced water and sediment quality that usually occur in canals with sluggish circulation and a lack of flushing action (Lindell & Trent 1975).

As a direct or indirect result of low dissolved O_2, research workers on the canals in the estuaries of the Gulf of Mexico have reported a reduction in abundance and species composition of benthic organisms in Texas (Barada & Partington 1972, Gilmore & Trent 1974) and Florida (Hall & Lindall 1974). Sykes & Hall (1970) have also shown that molluscs averaged 60,5 m^{-2} in undredged areas but dredged canals contained an average of only 1,1 individuals m^{-2}, while Trent *et al.* (1972) and Lindall, Fable & Collins (1975) have observed a gradual decrease in the numbers of fish and crustaceans in dredged canals.

It is clear from this study that the Marina Glades development in the Kromme estuary is, at present, in a healthy state; that the development has had no discernible adverse effect on estuarine environment and that an additional habitat area has in effect been created for estuarine and marine life. The only undesirable aspects of the marina, in our opinion, are:

(i) the sluggish circulation in the upper section of the marina, where inefficient water exchange leads to low water quality and eventually to stagnant water,
(ii) that dredging operations may create excessively deep basins, which could lead to the formation of stagnant bodies of water, and
(iii) the constrictive effect of the bridge near Station 27 (Fig. 3).

Further excavations of additional canals are also not recommended unless a thorough study can be made of their impact on the existing water-circulation pattern.

It is recommended that the development of marinas in estuaries, similar to the Marina Glades, or in sheltered bays, must allow efficient tidal circulation. At least two access canals should be present.

Successful future marina developments will depend on a healthy blend of architectural, engineering and ecological concepts. The balancing of dredged and reclaimed areas, roads and service lay-outs, size and depth of waterways and the vital aspects of adequate and efficient water circulation and water quality are the main topics that should be investigated and incorporated in the master plan.

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