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Abundance of larval and 0+ juvenile marine fishes in the lower reaches of three southern African estuaries with differing freshwater inputs

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ABSTRACT: Although numerous studies have been conducted on the biology and ecology of larval and juvenile marine fishes in estuaries, information on the factors influencing abundance, which in turn reflects the magnitude of immigration into these systems, is generally lacking. In an effort to provide some insight into the possible role of freshwater discharge on the abundance of marine larval and juvenile fishes, 3 permanently open eastern Cape Province estuaries with similar tidal prisms and mouth dimensions, but differing riverine inputs and turbidity characteristics, were selected as study sites. The Great Fish system can be characterized as a turbid estuary (>50 NTU) with a moderate axial salinity gradient (>20 g kg^{-1}), the Sundays as a semi-turbid estuary (>10 NTU) with a strong axial salinity gradient (>30 g kg^{-1}), and the Kariega as a relatively clear estuary (<10 NTU) with a weak axial salinity gradient (<10 g kg^{-1}). Although the number of marine fish taxa entering the 3 estuaries was similar (18 to 20 species), littoral densities of larvae and 0+ juveniles in the lower reaches of the Great Fish (280 ind. 100 m^{-2}) and Sundays (290 ind. 100 m^{-2}) estuaries were significantly ($p < 0.01$) greater than those in the Kariega system (50 ind. 100 m^{-2}). Ichthyoplankton densities in the lower reaches of the 3 estuaries were highest in the Great Fish estuary (13 ind. 100 m^{-3}), followed by the Sundays Estuary (7 ind. 100 m^{-3}) and Kariega Estuary (4 ind. 100 m^{-3}). Regression analyses indicated that several factors were associated with the abundance of the early life stages at the ichthyonekton study sites, the most important of which were estuarine axial salinity gradient, water temperature and axial turbidity gradient. The possible significance of these and other associated variables in influencing migration processes into eastern Cape estuaries is discussed.

KEY WORDS: Estuary · Salinity gradient · Ichthyoplankton · Ichthyonekton · South Africa

INTRODUCTION

Each year millions of larval and juvenile marine fishes enter southern African estuaries, which are then utilised as sheltered, food-rich nursery areas (Wallace 1975, Wallace & van der Elst 1975, Blaber 1985). Although the actual transport of the early life stages into estuaries may be by active swimming against ebb tidal currents or passive drift with the flood tide (Beckley 1985, Whitfield 1989a, Harrison & Cooper 1991), factors influencing the immigration of marine fishes into southern African estuaries are unknown.

South Africa is a semi-arid country (average precipitation = 497 mm yr^{-1}) and increased freshwater abstraction by growing human populations will result in less river water reaching estuaries. More than 50% of river runoff in southern Africa is already captured and stored in impoundments, with only about 8% of mean annual runoff reaching the sea (Department of Water Affairs 1986). This disturbance of the natural freshwater supply to estuaries could have major negative consequences for the biota in these environments, and there is therefore an urgent need to investigate the possible consequences of freshwater deprivation on estuarine ecosystems (Whitfield & Bruton 1989).

Previous work in southern African estuarine systems (e.g. Cyrus & Blaber 1987a, b, c, Marais 1988) indicated that salinity and turbidity were important factors influencing the distribution and abundance of marine migrant species in estuaries on the subcontinent. Based on results from the above studies, it can be postulated that larval and juvenile fish abundance, and hence immigration into estuaries, should be linked to salinity and turbidity characteristics of these systems which are in turn related to the magnitude of riverine inputs. In an effort to provide some insight into the possible role of freshwater and its associated organic/inorganic components on juvenile fish abundance, 3 permanently open eastern Cape Province estuaries with differing freshwater inputs and turbidity characteristics were selected as study sites. A primary aim of the research was to document and compare variability in larval and juvenile fish species composition and abundance in the lower reaches of the Sundays, Kariega and Great Fish estuaries, and to relate this variability to important environmental factors such as salinity, turbidity and temperature.

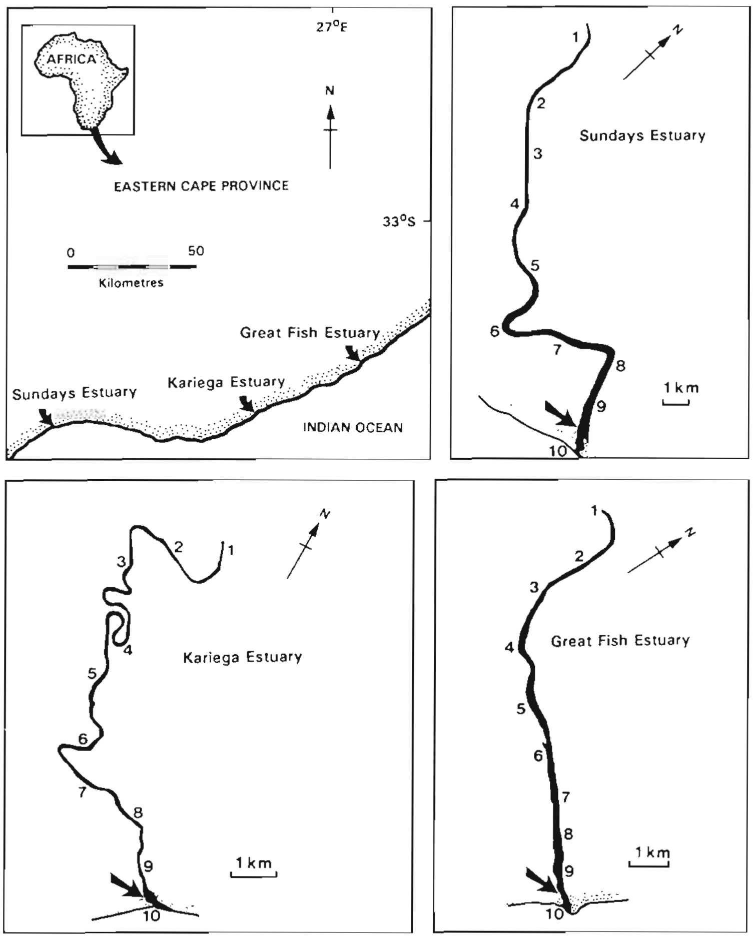

Fig. 1. The Great Fish, Kariega and Sundays estuaries on the eastern Cape Province coast of South Africa. The locations of physical/chemical sampling sites are indicated by numbers and the regions where ichthyoplankton and ichthyonekton samples were collected are indicated by arrows

STUDY AREAS

The Great Fish, Sundays and Kariega estuaries (Fig. 1) are 3 small bar-built coastal plain estuaries situated on the southeast coast of southern Africa. In terms of a classification system developed by Whitfield (1992) they would be characterized as permanently open estuaries on the subcontinent. However, it should be emphasized that the Kariega Estuary often has an absence of '... a measurable variation of salinity due to the mixture of sea water with fresh water derived from land drainage' (Day 1980), which necessitated that the estuaries in this study be defined as those water bodies between the head (ebb and flow) and mouth of each system. The key characteristics of each estuary are summarized in Tables 1 & 2.

MATERIALS AND METHODS

Field sampling. Quarterly sampling (March, June, September, December) of the larval and juvenile marine fishes in the lower reaches of the Great Fish, Kariega and Sundays estuaries was conducted during 1989 and 1990. The estuaries were sampled on consecutive days (seine netting) and nights (plankton netting) in order to minimise tidal cycle differences between the estuaries. Two types of sampling gear were used.

(1) A 75 cm diameter WP2 plankton net (500 µm aperture mesh) fitted with a calibrated digital flowmeter was used to sample ichthyoplankton in the channel surface waters (lower reaches) of each estuary (Fig. 1). Ten samples were collected from each system, commencing approximately 30 min after dark and timed to coincide with the high tide wherever possible. The net was attached to a boom fitted on the bow of a flat-bottomed boat equipped with a 35 hp outboard engine. The net was towed alongside the boat for 2 to 3 min at a speed of ca 1 to 2 knots and sampled the upper 75 cm of the water column. After each tow, flowmeter readings were recorded and the sample immediately preserved in 5 % buffered formalin. The volume of water filtered by the plankton net ranged between 30 and 90 m^3 per sample. Fish captured in the above net were designated as ichthyoplankton.

(2) A 5 × 1 m seine net (500 µm aperture mesh) was used to sample the shal-

Table 1. Key characteristics of the Great Fish, Kariega and Sundays estuaries using information from this study, the Department of Water Affairs & Forestry, Reddering & Esterhuysen (1982), Allanson & Read (1987), Gaillard & Huizinga (1988), Hilmer & Bate (1990) and MacKay & Schumann (1990)

Characteristic	Great Fish Estuary	Kariega Estuary	Sundays Estuary
Length	12 km	18 km	21 km
Main channel width	30–100 m	40–90 m	50–100 m
Main channel depth	0.5–3.5 m	1.0–4.0 m	1.0–4.0 m
Spring tidal range (lower reaches)	1.0–1.5 m	1.0–1.5 m	1.2–1.5 m
Spring tidal prism	1.6×10^6 m^3	1.9×10^6m^3	2.2×10^6 m^3
Mean annual river discharge	224×10^6 m^3	5×10^6 m^3	13×10^6 m^3
Mean monthly river discharge 1989/1990	52.7×10^6 m^3 (SE = 27.4)	0.5×10^6 m^3 (SE = 0.4)	Data not available
Flushing time	1 d	45 d	1–4 d
Salinity stratification	Strongly developed	Weakly developed	Moderately developed
Submerged aquatic macrophytes	Absent	Extensive	Present
Phytoplankton status (Chlorophyll *a*)	Mesotrophic/eutrophic (< 25 µg l^{-1})	Oligotrophic (< 1 µg l^{-1})	Eutrophic (< 110 µg l^{-1})

low littoral waters (i.e. < 1 m depth) of each estuary. All sampling was conducted during the day at or near low tide and consisted of a series of 10 seine hauls on the southwestern bank of each estuary, just inside the mouth (Fig. 1). All sampling sites had a relatively firm sand substratum with an absence of any submerged aquatic macrophytes or filamentous algae. The distance of each seine haul was measured and converted to an area based on the width of net as it was pulled through the water. Captured fish were immediately preserved in 5% buffered formalin for laboratory analysis. Fish sampled with the seine net were designated as ichthyonekton.

Table 2. Descriptive statistics (mean ± SE and range) for selected physical/chemical variables from the Great Fish, Kariega and Sundays estuaries during 1989 and 1990

Variables	Great Fish	Kariega	Sundays
Temp. (°C)	17.4 ± 0.4 11–25	19.1 ± 0.4 11–25	18.4 ± 0.4 12–24
Salinity (g kg^{-1})	10.6 ± 1.3 0–35	33.2 ± 1.0 1–42	17.1 ± 1.3 0–35
Turbidity (NTU)	65.2 ± 5.8 3–190	6.9 ± 0.7 2–35	10.7 ± 0.6 2–32
Axial salinity gradient (g kg^{-1})	26.3 ± 3.8 5–35	9.9 ± 3.9 0–34	32.0 ± 1.32 3–35
Axial turbidity gradient (NTU)	109.0 ± 17.3 39–170	6.5 ± 3.6 0–30	6.0 ± 1.4 0–13

Water temperatures were determined *in situ* at the time of sampling using a calibrated electronic thermometer, but salinity and turbidity samples were collected in glass containers for subsequent laboratory analysis. Since all fish were collected in the upper 1 m of the water column, all physical/chemical measurements during ichthyoplankton and ichthyonekton sampling were recorded at 0.5 m below the water surface. In addition, a series of 10 stations (Fig. 1) were used to characterize the physical environment along the length of each estuary on each sampling occasion. Once again each system was sampled at a similar phase (high water) of the tidal cycle to ensure comparability of the data.

Laboratory analysis. All water analyses were conducted within 12 h of returning from the field. Salinity was measured using a temperature-compensated optical salinometer and turbidities with a calibrated turbidimeter. Water samples were vigorously shaken to ensure resuspension of particulates prior to decanting the water for turbidity analyses.

Ichthyoplankton and ichthyonekton samples were sorted following the procedure described by Richards & Berry (1973). All fish were identified to the lowest possible taxon using references given in Harrison & Whitfield (1990). Each fish was measured to the nearest 0.1 mm body length (BL), which represents notochord length in preflexion larvae and standard length in postflexion larvae/juveniles.

Data analysis. The mean, standard error and range of physical/chemical variables recorded at each of

10 stations in each estuary were calculated. The axial salinity and turbidity gradients, which represent differences between values recorded at Stn 1 (head) and Stn 10 (mouth) for each estuary, were also analyzed. Temperature, salinity and turbidity information (using pooled data from all sampling periods) from corresponding stations in each of the 3 estuaries were subjected to a 1-way ANOVA. Differences between corresponding sampling stations in each of the estuaries were analysed using a Scheffé multiple range test (Zar 1984).

Densities of ichthyoplankton were standardised to represent the mean number per 100 m^3 of water filtered, whereas ichthyonekton densities were based on the mean number of fish per 100 m^2 of littoral zone sampled. A large proportion of the ichthyoplankton, particularly larval and postlarval Mugilidae, could not be identified to species. For this reason, most statistical comparisons of ichthyoplankton data between the estuaries were conducted at the family level, whereas most of the ichthyonekton could be identified to species.

Multiple linear and stepwise-regressions were used to ascertain whether the environmental variables at the site of capture (salinity, temperature, turbidity) or axial salinity and turbidity gradients within the estuary show any statistical relationship with fish densities. The significance of the linear regressions was tested using analysis of variance. Since fish densities were generally skewed, they were log-transformed [$\ln(x+1)$] so that their distribution approached normality. This was confirmed using the Shapiro & Wilk (1965) test for normality. Conclusions drawn from the results of the ANOVAs concentrated on those cases where significance levels were < 0.01.

Species similarities (by season) between ichthyonekton catches in each estuary were analyzed using the Morisita-Horn index (C_λ) on log-transformed [$\ln(x+1)$] catch composition data. Details on both the Morisita-Horn formula and its behaviour can be obtained from Wolda (1981).

RESULTS

Physical/chemical parameters

No significant differences (ANOVA) in water temperature were found between equivalent stations in the 3 estuaries, with all systems falling within the range 11 to 25 °C (Table 2) There were, however, highly significant differences ($p < 0.001$) between mean salinities and turbidities recorded at equivalent stations in the 3 estuaries. Using a Scheffé multiple range test it was possible to identify where these differences occurred. The Great Fish and Kariega estuaries were significantly different ($p < 0.01$) in terms of both salinity and turbidity (Table 3). Although the Great Fish Estuary also differed significantly ($p < 0.01$) from the Sundays Estuary in terms of turbidity, salinities were similar at equivalent stations in the 2 systems (Table 3). The Kariega and Sundays estuaries had similar turbidities but significantly different salinities and axial salinity gradients (Tables 2 & 3). The mean axial turbidity gradient was considerably higher in the Great Fish Estuary (mean = 109 NTU) compared to the Kariega and Sundays systems (means = 6 to 7 NTU). Using information from Table 2, together with the classification system of Cyrus (1988), the Great Fish system may be characterized as a turbid estuary (>50 NTU) with a moderate axial salinity gradient (>20 g kg^{-1}), the Sundays as a semi-turbid estuary (>10 NTU) with a strong axial salinity gradient (>30 g kg^{-1}), and the Kariega as a relatively clear estuary (<10 NTU) with a weak axial salinity gradient (<10 g kg^{-1}).

Fish composition and similarities

Analyses were performed on marine migrant species of fish, i.e. those taxa that spawn at sea, enter estuaries mainly as juveniles, and usually return to sea prior to sexual maturity (Whitfield 1990). A total of 16 686 juvenile marine fishes, comprising 21 species, were cap-

Table 3. Differences (Scheffé multiple range test) between selected physical/chemical variables recorded at 10 stations in each estuary. ns: not significant; $^*p < 0.05$; $^{**}p < 0.01$

Variable	Stn	Great Fish vs Kariega	Great Fish vs Sundays	Kariega vs Sundays
Salinity	1	**	ns	**
	2	**	ns	**
	3	**	ns	**
	4	**	ns	**
	5	**	ns	**
	6	**	ns	**
	7	**	ns	*
	8	**	ns	ns
	9	**	**	ns
	10	*	*	ns
Turbidity	1	**	**	ns
	2	**	**	ns
	3	**	**	ns
	4	**	**	ns
	5	**	**	ns
	6	**	**	ns
	7	**	**	ns
	8	**	**	ns
	9	**	**	ns
	10	*	*	ns

Table 4. Numbers, densities (ind. 100 m^{-2}) and ranking of ichthyonekton taxa in the lower reaches of the Great Fish, Kariega and Sundays estuaries. Species comprising less than 5 individuals and recorded in only 1 estuary are excluded from this analysis

Family / Species	Great Fish Estuary n	Density	Rank	Kariega Estuary n	Density	Rank	Sundays Estuary n	Density	Rank
Carangidae									
Lichia amia	5	0.18	12	–	–	–	–	–	–
Elopidae									
Elops machnata	2	0.07	13	1	0.03	12	–	–	–
Haemulidae									
Pomadasys olivaceum	–	–	–	1	0.03	12	17	0.68	12
Mugilidae									
Crenimugil crenilabis	–	–	–	–	–	–	139	5.56	8
Liza dumerilii	2747	97.89	1	2	0.06	10	2783	111.41	1
Liza richardsonii	2021	72.02	3	388	12.23	2	598	23.94	4
Liza tricuspidens	2	0.07	13	11	0.35	7	23	0.92	10
Mugil cephalus	178	6.34	4	7	0.22	8	189	7.57	6
Myxus capensis	66	2.35	6	–	–	–	–	–	–
Valamugil buchanani	34	1.21	9	2	0.06	10	5	0.20	15
Unidentified [a]	2506	89.31	2	511	16.11	1	2035	81.46	2
Soleidae									
Heteromycteris capensis	15	0.53	10	25	0.79	6	25	1.00	9
Solea bleekeri	–	–	–	1	0.03	12	1	0.04	16
Sparidae									
Diplodus sargus capensis	2	0.07	13	149	4.70	4	942	37.71	3
Lithognathus lithognathus	63	2.25	7	5	0.16	9	17	0.68	12
Rhabdosargus globiceps	47	1.67	8	1	0.03	12	292	11.69	5
Rhabdosargus holubi	156	5.56	5	372	11.73	3	154	6.16	7
Sarpa salpa	–	–	–	–	–	–	8	0.32	14
Teraponidae									
Terapon jarbua	7	0.25	11	105	3.31	5	20	0.80	11
Total	7851	279.77	–	1581	49.84	–	7248	290.14	–

[a] Unidentified Mugilidae < 20 mm body length which could not be identified to the species level

tured with the ichthyonekton seine net. The catch composition of 18 of these species is given in Table 4. Additional species included single specimens of *Gerres acinaces* and *Mondactylus falciformis* from the Sundays Estuary, and 4 specimens of *Liza macrolepis* from the Great Fish Estuary. All 3 eastern Cape estuaries were dominated by juveniles of the families Mugilidae and Sparidae, which together comprised 99, 91 and 99% of the catch in the Great Fish, Kariega and Sundays estuaries respectively (Table 4). Fish densities were highest in the Sundays (290 ind. 100 m^{-2}) and Great Fish (280 ind. 100 m^{-2}) estuaries and relatively low in the Kariega Estuary (50 ind. 100 m^{-2}). There were no significant differences (Scheffé multiple range test) between fish densities in the Sundays and Great Fish estuaries but there were significant differences ($p < 0.01$) between fish densities in the Kariega estuary and the other 2 systems.

Ichthyoplankton families captured in the WP2 plankton net are shown in Table 5. As was the case with the seine net samples, the families Mugilidae and Sparidae dominated the ichthyoplankton assemblage, comprising 88, 93 and 79% of the catches in the Great Fish, Kariega and Sundays estuaries respectively. However, the contributions by the 2 families in each system differed considerably, with mugilids dominating the Great Fish Estuary catches, the sparids predominating in the Kariega system, and both families well represented in the Sundays Estuary (Table 5). Highest fish densities were recorded in the Great Fish Estuary (13 ind. 100 m^{-3}), followed by the Sundays (7 ind. 100 m^{-3}) and Kariega (4 ind. 100 m^{-3}) estuaries. The Scheffé multiple range test revealed that fish densities in the Great Fish Estuary were significantly higher than those recorded in the Kariega ($p < 0.01$) and Sundays ($p < 0.05$) estuaries.

Altogether 20, 19 and 18 species of marine fishes were recorded in the Sundays, Great Fish and Kariega estuaries respectively. The Morisita-Horn index analysis suggests that the Great Fish and Sundays estuaries' ichthyonektonic communities were more similar to one another ($C_\lambda = 0.87$) than were those of the Great Fish

Table 5. Numbers, densities (ind. 100 m^{-3}) and ranking of ichthyoplankton families in the lower reaches of the Great Fish, Kariega and Sundays estuaries

Family	Great Fish Estuary			Kariega Estuary			Sundays Estuary		
	n	Density	Rank	n	Density	Rank	n	Density	Rank
Ambassidae	3	0.07	4	–	–	–	–	–	–
Elopidae	3	0.07	4	2	0.05	5	–	–	–
Haemulidae	49	1.18	2	–	–	–	3	0.08	6
Monodactylidae	–	–	–	1	0.02	7	–	–	–
Mugilidae	419	10.11	1	16	0.39	2	104	2.60	2
Pomatomidae	–	–	–	4	0.10	3	1	0.03	7
Sciaenidae	3	0.07	4	1	0.02	6	5	0.13	5
Soleidae	3	0.07	4	4	0.10	3	34	0.85	3
Sparidae	39	0.94	3	147	3.58	1	113	2.83	1
Teraponidae	1	0.02	8	–	–	–	13	0.33	4
Total	520	12.53		175	4.26		273	6.85	

and Kariega (C_λ = 0.75) estuaries or Sundays and Kariega (C_λ = 0.82) estuaries. A seasonal analysis (Fig. 2) shows that it was only during December that the Great Fish and Sundays estuaries were not the most similar in terms of comparative fish communities. This was because relatively low numbers of Mugilidae and large numbers of *Diplodus sargus* and *Rhabdosargus globiceps* were captured in the Sundays but not in the Great Fish Estuary during this month.

Length frequency and regression analyses

Length-frequency analyses of the 3 principal mullet species from the ichthyonekton catches in the Great Fish and Sundays estuaries are shown in Fig. 3, and that of *Rhabdosargus holubi* in Fig. 4. Although *R. holubi* < 10 mm BL could be positively identified, mugilids < 15 mm BL were seldom identified to species and are therefore excluded from the above analysis. On a comparative basis, the Great Fish Estuary always had a higher proportion of smaller individuals (Figs. 3 & 4), suggesting that either fish enter this estuary at a smaller size, or that mugilids > 20 mm BL and *R. holubi* > 10 mm BL move more rapidly into the middle and upper reaches of the Great Fish system when compared to the Sundays and Kariega estuaries.

Seasonal multiple regression analyses (all 3 estuaries combined) of marine species in the ichthyonekton revealed that estuarine axial salinity gradient, water temperature and axial turbidity gradient were the environmental variables most closely associated with fish abundance (Table 6). Seasonal multiple correlation coefficients were highly significant ($p < 0.001$) and R was greater than 0.65 during March, June, September and December. An analysis of the 5 most abundant species indicated that salinity at the site of capture was the most important variable associated with the abundance of mugilids *Liza richardsonii*, *L. dumerilii* and *Mugil cephalus*, whereas for the sparids *Rhabdosargus holubi* and *Diplodus sargus capensis*, temperature and axial salinity gradient respectively were the most important variables (Table 6). The axial turbidity gradient was the second most important variable for several fish species (e.g. *L. richardsonii*, *M. cephalus* and *R. holubi*), as well as being a prominant component in the seasonal analysis (Table 6).

A scatter diagram of monthly ichthyonekton densities versus estuarine axial salinity gradient is shown in Fig. 5. Although the linear regression correlation coefficient r = 0.39 (df = 22, $p < 0.05$) is a relatively poor fit, it is important to note that no data points were

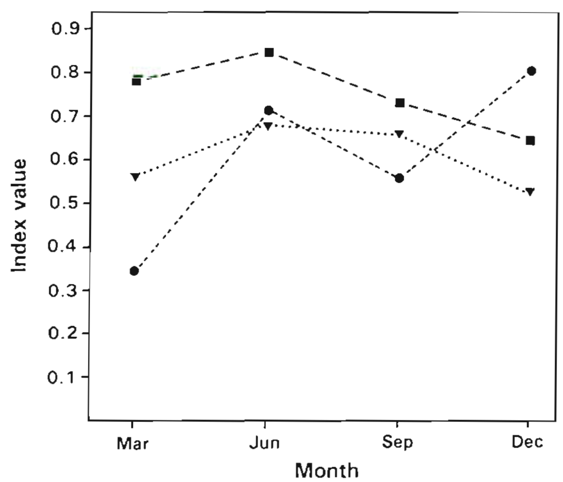

Fig. 2. Ichthyonekton community similarity based on log-transformed species abundance data using the Morisita-Horn index (C_λ). Similarity between (●) the Great Fish and Kariega communities, (▼) the Kariega and Sundays communities, and (■) the Great Fish and Sundays communities

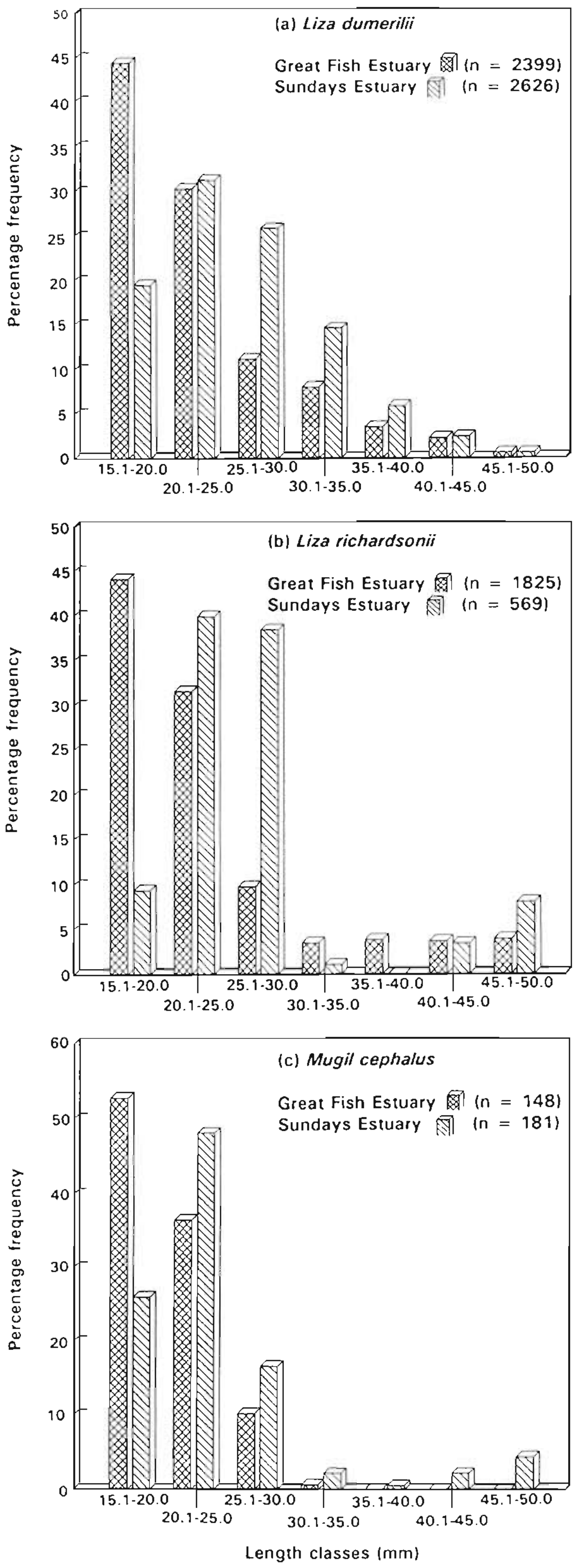

Fig. 3. Length-frequency distribution (15 to 50 mm BL) of juvenile *Liza dumerilii* (a), *L. richardsonii* (b) and *Mugil cephalus* (c) in the lower reaches of the Great Fish and Sundays estuaries

recorded above the dashed diagonal line (Fig. 5). Low ichthyonekton densities (< 150 ind. 100 m^{-2}) were recorded in the lower reaches of estuaries with an axial salinity gradient < 20 g kg^{-1}, whereas high fish densities (> 200 ind. 100 m^{-2}) were only recorded in those systems where the axial salinity gradient was > 20 g kg^{-1} (Fig. 5).

Axial salinity gradient also featured as the single most important environmental variable associated with the abundance of ichthyoplankton in the Kariega (R =

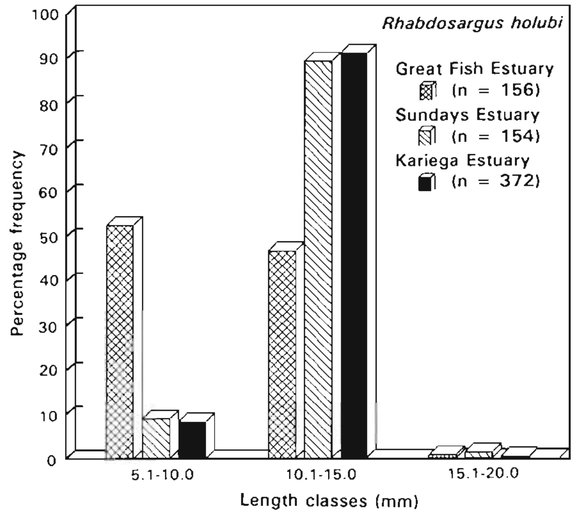

Fig. 4. Length-frequency distribution (5 to 20 mm BL) of juvenile *Rhabdosargus holubi* in the lower reaches of the Great Fish, Sundays and Kariega estuaries

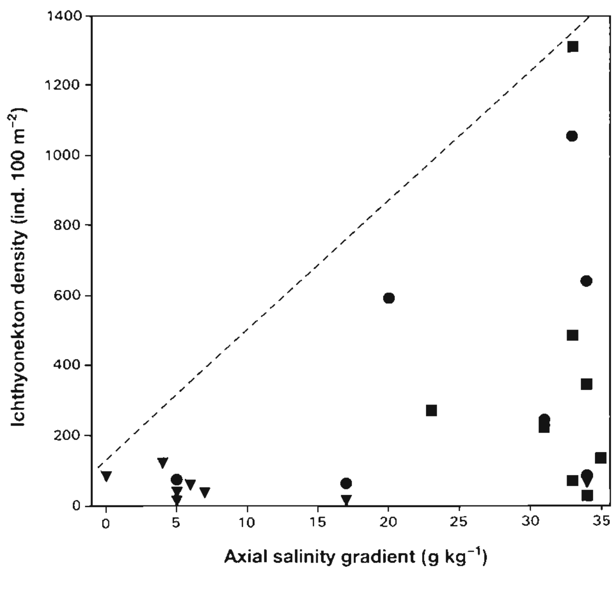

Fig. 5. Graphic representation of ichthyonekton densities versus the axial salinity gradient in each of the 3 eastern Cape Province estuaries (● Great Fish; ▼ Kariega; ■ Sundays)

Table 6. Regressions of ichthyonekton densities (log-transformed data from all three estuaries) versus the environmental variables: sa, salinity; te, temperature; tu, turbidity; sg, axial salinity gradient; tg, axial turbidity gradient. Only the estimated regression coefficients of the 3 most important variables determined by the multiple stepwise regression are shown. Genera: *L.* = *Liza*; *M.* = *Mugil*; *R.* = *Rhabdosargus*; *D.* = *Diplodus*

Component			**All species**		
Month:	March	June	September	December	Annual
Regression	R = 0.85***	R = 0.69***	R = 0.66***	R = 0.67***	R = 0.36***
Variable 1	sg R = 0.60	te R = 0.28	te R = 0.54	te R = 0.55	sg R = 0.33
Variable 1+2	tg R = 0.84	tg R = 0.39	sa R = 0.61	sg R = 0.59	te R = 0.34
Variable 1+2+3	sa R = 0.85	tu R = 0.58	tg R = 0.64	tg R = 0.62	tg R = 0.35
			All months		
Species:	*L. richardsonii*	*L. dumerilii*	*M. cephalus*	*R. holubi*	*D. sargus*
Regression	R = 0.40**	R = 0.43**	R = 0.55	R = 0.33*	R = 0.42*
Variable 1	sa R = 0.24	sa R = 0.29	sa R = 0.41	te R = 0.21	sg R = 0.27
Variable 1+2	tg R = 0.33	te R = 0.34	tg R = 0.48	tg R = 0.31	te R = 0.35
Variable 1+2+3	te R = 0.39	tg R = 0.39	tu R = 0.52	sa R = 0.32	tg R = 0.40

R: Multiple correlation coefficient (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$)

0.39) and Sundays (R = 0.52) estuaries. In the Great Fish Estuary, however, water temperature was the most significant variable (R = 0.68). The multiple correlation coefficient R was 0.74 ($p < 0.001$), 0.66 ($p < 0.001$) and 0.57 ($p < 0.001$) for the Great Fish, Kariega and Sundays estuaries respectively.

DISCUSSION

The physical and biological characteristics of southern African estuaries are highly variable, both on a spatial and temporal scale, but all systems receive a freshwater input which gives rise to an aquatic medium with salinities, turbidities and temperatures very different to that of the adjacent sea (Day 1981a, b). Do any of the above physical/chemical variables influence larval and juvenile marine fish immigration into, and hence subsequent abundance in, estuaries?

Salinity

The ability to adjust to salinity fluctuations is the single most important adaptation required by fishes entering southern African estuaries (Whitfield 1983). Since most fish species in estuaries seldom occur in salinities outside their tolerance range (Whitfield et al. 1981), it can be assumed that they possess some mechanism for the detection of dissolved mineral salt concentrations. Marais (1988), for example, working in eastern Cape Province and Transkei estuaries found a highly significant ($p < 0.001$) negative correlation between gill net catches and increasing salinity, i.e. both numbers and biomass of captured fish were highest in those estuaries with the largest riverine input. The stronger similarity (Morisita-Horn index) between the ichthyonekton of the geographically distant but high/moderate river flow Great Fish and Sundays estuaries, when compared with assemblage similarities to the centrally situated low/absent river flow Kariega Estuary, may be linked to freshwater influences.

Allen & Barker (1990) determined that the larvae of certain marine fish species were significantly more abundant in years when extended periods of low salinity were recorded in the otherwise high salinity North Inlet Estuary, South Carolina, USA. Based on the physical parameters investigated in this study, axial salinity gradient in eastern Cape estuaries appears to be the single most important factor associated with the abundance of larval and juvenile marine fishes. Further evidence to support this view can be derived from Table 4 where ichthyonekton densities in the Great Fish and Sundays estuaries (strong axial salinity gradients) were more than 5 times greater than those recorded in the Kariega system, which had a poorly developed axial salinity gradient (Table 2). Ichthyoplankton densities also appeared to be related to freshwater inputs, with the Great Fish Estuary having the highest and the Kariega Estuary the lowest densities (Table 5). However, it is possible that olfactory cues associated with riverine inputs stimulate immigration of these euryhaline fishes into estuaries and not salinity gradients or reduced salinities per se. Marine environment salinities in the surf zone adjacent to the above estuaries usually exceed 30 g kg^{-1}, even at low tide when estuarine output is maximal (A. K. Whitfield unpubl.). Continental shelf measurements off the large Richards Bay Estuary (28° 49′ S, 32° 05′ E) revealed that a basic salinity of 35.3 g kg^{-1} was usually maintained, except when river flooding occurred and surface salinities then declined to 33.2 g kg^{-1} (Pearce 1978).

It is perhaps significant that the smallest juvenile marine immigrants (Figs. 3 & 4) of the 3 study systems were associated with the Great Fish Estuary, which also had the strongest freshwater input. Another possible explanation is that the Great Fish Estuary is situated closer to the spawning grounds of species shown in Figs. 3 & 4 than either the Kariega or Sundays systems. Miskiewicz (1986) concluded that the proximity of fish spawning grounds to the Lake Macquarie estuarine system in New South Wales was the major factor causing the difference in the average length at which larvae of three sparid species entered the estuary.

Temperature

The importance of water temperature in the structuring of estuarine fish communities is well illustrated by the recent study of Peterson & Ross (1991) who found that this physical variable was the best predictor of fish species richness in the Old Fort Bayou Estuary, Mississippi, USA. River discharge, through its effect on estuarine water temperatures can also have a major influence on juvenile fish recruits. Deegan (1990) has shown that the growth and survival of 0+ *Brevoortia patronus* in Fourleague Bay, Louisiana, USA, were negatively influenced by cooler spring temperatures which arose from high river discharge.

In contrast to the large river volumes entering the northern American estuaries described above, permanently open estuaries along the Cape Province coast are usually more strongly influenced by marine water temperatures due to the relatively low freshwater inputs from rivers (Read 1983). The Great Fish Estuary, which receives the highest river inflow in the eastern Cape, has a flushing time of 1 d compared to the Kariega Estuary where the average flushing time is 45 d (Table 1). Thus water temperatures in the Great Fish Estuary are likely to be more strongly influenced by riverine water temperatures than those in the Kariega Estuary, which is a marine dominated system. The lower mean annual temperature in the Great Fish Estuary compared to the Kariega Estuary (Table 1) can be attributed to the cool (11 to 12 °C) riverine water entering the former system during winter. In theory, the higher mean water temperatures in the Kariega Estuary should be more attractive to tropical and subtropical juvenile marine fishes than those in either the Great Fish or Sundays estuaries, but this is not reflected in either the ichthyoplankton or ichthyonekton catch statistics (Tables 4 & 5).

The immigration of juvenile marine fishes into Cape Province estuaries has a strong seasonal component, with most species entering these systems during summer (Whitfield & Kok 1992). The shallowness and presence of intertidal flats within eastern Cape estuaries, together with an absence of upwelling events which are often recorded in the marine nearshore environment (Schumann et al. 1987), results in water temperatures that are generally higher than those in the adjacent sea during summer (Day 1981a). The link between juvenile fish abundance and estuarine water temperature revealed in this study (Table 6) can therefore be partially explained by the seasonality of marine fish immigration into eastern Cape estuaries (Beckley 1984), particularly tropical and subtropical species whose major recruitment period coincides with higher summer water temperatures.

Turbidity

In many southern African estuaries, freshwater inflow is often associated with high sediment loads (Day 1981b, McCormick et al. 1992), which results in these systems having much higher turbidity levels than the adjacent marine environment. Indeed, it has been suggested by Blaber (1981, 1987) that the occurrence of many marine species in subtropical southeast African estuaries may be related more to water turbidity than to any other factors. Evidence to support the importance of turbidity as a major factor influencing both juvenile and adult fishes is derived from the positive correlation between fish abundance and turbidity in 14 estuaries along the south and southeast coasts of South Africa (Marais 1988). Detailed studies on juvenile marine fish in Natal estuaries, using both field records and choice chamber experiments, have demonstrated that turbidity may have profound effects on the distribution of fishes (Cyrus & Blaber 1987a). These estuarine-associated fishes can be divided into categories according to the turbidity preference of individual species (Cyrus & Blaber 1987b), with 16 of the 20 species studied by Cyrus & Blaber (1987c) showing a preference for turbid waters. The above results may partially explain the relatively high densities of both ichthyoplankton and ichthyonekton in the turbid Great Fish Estuary (Tables 4 & 5).

Although Blaber & Blaber (1980) have suggested that turbidity gradients in the marine environment may aid juvenile fishes to locate estuarine nursery areas, the importance of this factor has yet to be quantified. No marked turbidity gradient was present in the marine environment adjacent to the Sundays Estuary, yet recruitment was as successful as that recorded in the Great Fish system (Table 4), suggesting that olfactory cues associated with axial salinity gradients (riverine inputs) may be more important (Stabell 1992). The abundance of larval and juvenile marine fishes in the Kariega Estuary was at a much lower level than in the Sundays or Great Fish systems (Tables 4 & 5), but the fact that immigration of fishes was still recorded (even in the absence of any river flow) suggests that additional cues may be involved in the migration process. The possibility exists that release of pheromones by fish already in the estuary (Olsén 1992) may be detected by conspecifics in the nearshore marine environment, thus stimulating a rheotactic response. Alternatively, ichthyoplankton and ichthyonekton in the adjacent surf zone (Whitfield 1989b) may simply be responding in a rheotactic manner to tidal currents which enter and leave the estuary (Harrison & Cooper 1991) without being stimulated by an odour gradient (Kleerekoper 1967).

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