Fish larval composition, abundance and seasonality in a southern African estuarine lake

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The ichthyoplankton community of Swartvlei, an estuarine lake on the southern Cape coast, has a low species diversity (< 10 species) owing to the tenuous link with the marine environment and paucity of fishes breeding in South African estuaries. The larval assemblage was dominated by the clupeid *Gilchristella aestuaria*, which was distributed across the entire lake and comprised 78% of the total catch. Mean annual ichthyoplankton abundance was relatively low (38 larvae 100 m^{-3}), possibly as a result of the extremely low phytoplankton productivity and poor zooplankton biomass. Fish larvae and zooplankton peak in abundance between October and March, with very low densities recorded for the remainder of the year. During a 24 h sampling session in February 1988, ichthyoplankton abundance increased significantly ($p < 0,001$) in surface waters after sunset and declined following sunrise.

Die visplanktongemeenskap van Swartvlei, 'n estuariene meer op die suidelike Kaapkus, het 'n lae spesiesverskeidenheid (< 10 spesies) omdat die verbinding met die see skraal en onderbroke is, en ook omdat daar min visspesies is wat in Suid Afrikaanse riviermondinge teel. *Gilchristella aestuaria*-larwes, wat oor die hele meer versprei was, het 78% van die larwegemeenskap behels. Die gemiddelde jaarlikse hoeelheid visplankton is laag (38 larwes 100 m^{-3}), heelwaarskynlik as gevolg van die baie lae fitoplankton-opbrengs en lae soöplankton-biomassa. Vislarwes en soöplankton toon die hoogste konsentrasies tussen Oktober en Maart, maar is skaars gedurende die res van die jaar. Gedurende 'n 24 h-versamelingsperiode in Februarie 1988 het die digtheid van vislarwes betekenisvol vermeerder ($p < 0,001$) in oppervlak-water na sonsondergang en afgeneem na sonsopkoms.

Research on southern African estuarine fish populations has concentrated on the juvenile and adult life stages (e.g. Wallace & van der Elst 1975; Blaber 1977; Whitfield 1980; Marais 1983; Beckley 1984). An understanding of the early life histories of estuarine associated fishes is, however, important if the utilization of estuaries as nursery areas by the juveniles of these species is to be placed in context. The following project, which forms part of a wider ichthyoplankton research programme by the author, was initiated to provide information on estuarine fish larval ecology; a topic which has been neglected in South Africa (Melville-Smith & Baird 1980) and elsewhere (Jenkins 1986).

Plankton studies in southern African estuaries have been restricted largely to the invertebrate component (e.g. Grindley & Wooldridge 1974; Wooldridge 1976, 1977; Coetzee 1981, 1985), despite the possible impact of ichthyoplankton predators on zooplankton. In a review of estuarine plankton research (Grindley 1981), only passing reference is made to the fish larval study conducted by Melville-Smith & Baird (1980) in the Swartkops estuary. These authors were the first to open the ichthyoplankton 'black box' with their investigation of the fish larval community in a tidal South African estuary, and the following paper represents the first equivalent study in a southern African coastal lake.

Study area

Swartvlei (Figure 1) is an estuarine coastal lake situated on the southern Cape coast (34°S / 22°46'E) and linked to the sea by a 7,2 km winding channel (Swartvlei estuary). The estuary mouth is normally closed during winter and open in summer, with major water level fluctuations in the lake being governed primarily by mouth phase and river inflow (Whitfield, Allanson & Heinecken 1983). River waters, which flow mainly over Table Mountain sandstone, are low in dissolved solids and stained with humates (Robarts & Allanson 1977). The mean annual rainfall in the catchment is between 900 and 1000 mm (Adamson 1975) with no identifiable wet and dry seasons.

Swartvlei is normally a meromictic lake (Allanson & Howard-Williams 1984) with water below 7 m being anaerobic for much of the year. Surface salinities vary between 1 and 20‰ whereas bottom salinities range between 12 and 20‰ (Whitfield 1986). The lake is 8,8 km^2 in area with a mean depth ($\bar{z}$) of 5,5 m and a

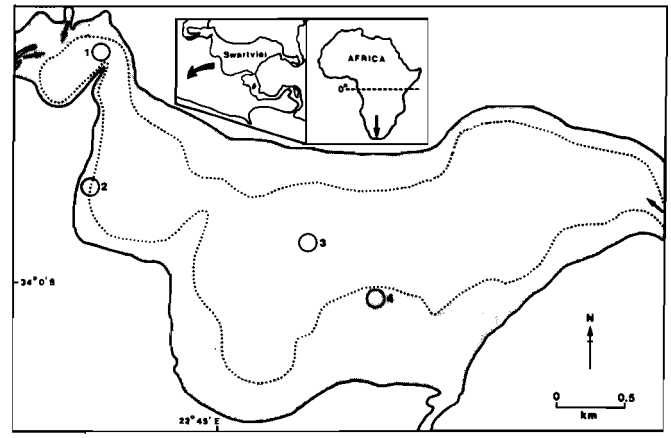

Figure 1 Swartvlei showing sampling Stations 1–4. The littoral shelf area has been shaded and arrows indicate river entrances into the lake.

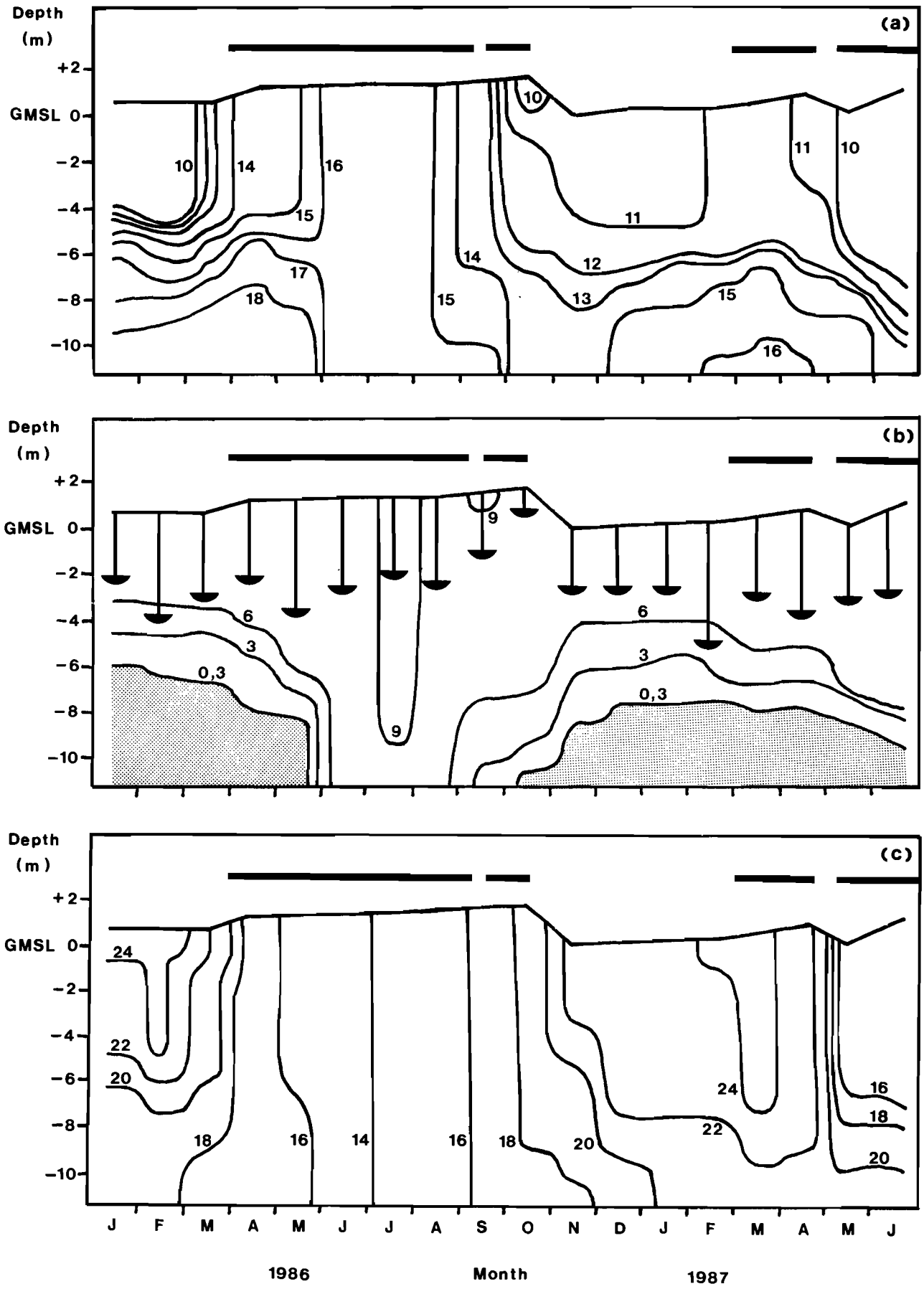

Figure 2 Depth/time distribution of (a) salinity (‰), (b) dissolved oxygen (mg l^{-1}) and (c) water temperature (°C) at Station 3. All depths are related to geodetic mean sea level (GMSL) and the closed estuary mouth phase is indicated by a horizontal bar. Secchi disc values are depicted below the water surface in (b) and the anaerobic monimolimnion is shaded.

maximum depth of 16,7 m (Howard-Williams & Allanson 1981). A gently sloping wide shelf occurs out to a depth of approximately 2 m, beyond which the lake floor drops steeply to a fairly flat bottom at 11 m. A detailed bathymetric map of Swartvlei was published in Allanson & Howard-Williams (1984). The shelf, which is usually covered with the macrophyte *Potamogeton pectinatus* and charophytes, occupies an area of 3,8 km^2.

Materials and methods

Surface plankton samples were collected monthly between February 1986 and June 1987 at four stations (Figure 1). Collections were made with a 75 cm diameter WP2 plankton net (500 μm St Martin's nylon mesh) fitted with a previously calibrated Kahlsico digital flow meter (No. 005WB138). The net was attached to a boom on the bow of a 4-m boat such that samples were collected from undisturbed waters approximately 0,5 m from the side. The net was towed for 3 min in a circular to oval trajectory at approximately 1,5 m s^{-1}. Netting commenced approximately half an hour after dark and replicate samples were collected at each station. Plankton was preserved at the sampling site with buffered formaldehyde to give a total formalin concentration of approximately 5%.

In the laboratory, fish larvae were separated from the rest of the plankton using a stereo-microscope. All larvae were then identified, measured (standard length) to the nearest 0,1 mm using an ocular micrometer and their numbers expressed per 100 m^3 of water sampled.

At each station the surface salinity and temperature were recorded immediately before a plankton tow. In addition, a diurnal (10h00–12h00) hydrographic profile of the lake was conducted monthly at Station 3 using a YSI 51A dissolved oxygen/temperature meter, AO Instruments refractometer (salinity), Beckman Expandomatic SS2 meter (pH) and 140 mm Secchi disc (water transparency).

A 24-h station was conducted in February 1988, during which time surface plankton samples were collected at 2-h intervals from Stations 1–3 using the 75 cm diameter (500 μm mesh) WP2 plankton net. Samples were preserved at the site of collection with buffered formaldehyde and returned to the laboratory for analysis. Hydrographic profiles, as described above, were conducted at midday (12h00–13h00) and midnight (24h00–01h00) at each station.

In this study the word larva designates that stage in the life history from hatching to attainment of complete fin ray counts and beginning of squamation, at which stage the fish becomes a juvenile (Kendall, Ahlstrom & Moser 1984). The transitional stage between larva and juvenile is called the metamorphic larva (Melville-Smith 1978) and examples from Swartvlei are shown in Figure 3.

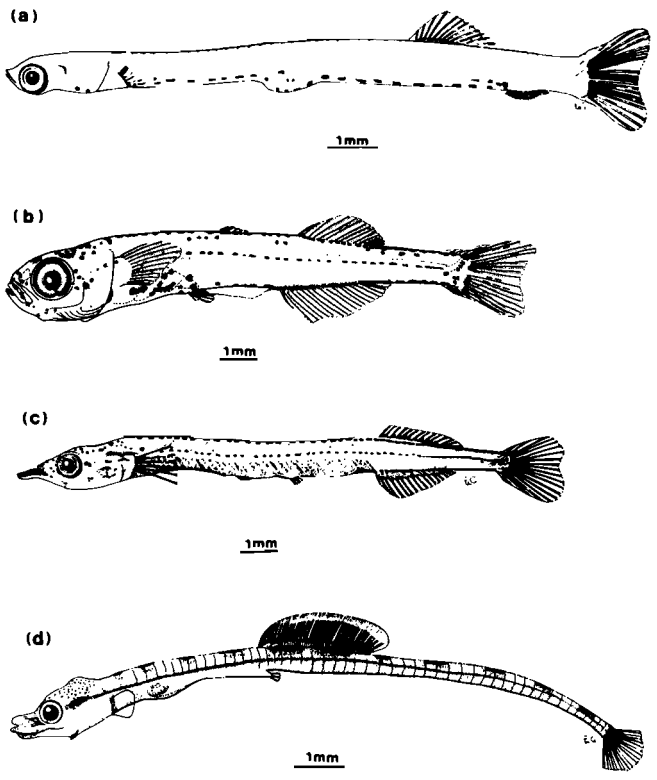

Figure 3 Metamorphic larvae of (a) *Gilchristella aestuaria,* (b) *Atherina breviceps,* (c) *Hyporhamphus capensis* and (d) *Syngnathus acus* from Swartvlei.

Results

Environment

The approximate water depths at each station (Figure 1) during the open mouth phase were as follows: Station 1 (3–5 m), Station 2 (1–4 m), Station 3 (11–12 m) and Station 4 (1–3 m). Water level changes during this study together with periods when the estuary mouth was closed are shown in Figure 2.

Surface salinities during the study period ranged from 10–16‰ and temperatures from 13,5–27,0°C. However, surface salinities and temperatures during each sample run from the four stations did not differ by more than 1‰ or 1°C respectively. Detailed salinity, temperature and oxygen profiles at Station 3 are shown in Figure 2. These profiles are probably representative of the entire lake basin owing to the planar nature of various Swartvlei physico-chemical parameters (Allanson & Howard-Williams 1984). Meromictic conditions prevailed during the major open phases, resulting from the inflow of higher salinity water from the estuary. Details of this process are given in Allanson & Howard-Williams (1984). Vertical salinity stratification was reduced during the closed phase (April–September 1986) and by June 1986 the halocline and anaerobic conditions at the bottom of the lake had disappeared (Figure 2a & b). The monimolimnion was re-established at the end of 1986 and these conditions persisted until March 1987, at which stage the anaerobic layer was in the process of being eroded by wind driven water currents. A strong smell of H_2S was evident in all water samples collected from the monimolimnion. Water temperatures at Station 3 (Figure 2c) ranged between 13,5–25,0°C and 13,5–20,5°C for surface and bottom waters respectively. pH values recorded over 18 months ranged between 7,5–8,1 for surface waters and 7,1–7,7 for the bottom. Secchi

disc readings at Station 3 ranged from 90 cm (14/10/86), following the penetration of turbid floodwaters into the lake, to 530 cm (17/2/87) just prior to estuary mouth closure (Figure 2b).

Ichthyoplankton

The species composition and comparative abundance of larval fishes at each station is presented in Table 1. Species diversity at all four stations was low with a total representation of < 10 species. *Gilchristella aestuaria* comprised 78,5% of the total catch, followed by *Atherina breviceps* 7,5%, *Psammogobius knysnaensis* 5,1%, *Omobranchus woodi* 3,8% and *Syngnathus acus* 3,5%. Mean densities ranged from 22–47 larvae per 100 m^3 and were highest at Station 1 and lowest at Station 2.

Variation in larval densities at each of the stations is shown in Figure 4 and indicates that peaks in abundance, although all occurring during summer, were not coincident. The monthly contribution of *G. aestuaria* to the total ichthyoplankton community is shown in Figure 5. With the exceptions of March 1986, August 1986 and January 1987, the monthly abundance of *G. aestuaria* was greater than all other species combined. Fish larvae of all the species sampled reached peak abundance during the summer (October–March) with lowest densities recorded during winter (April–September).

The percentage length composition of the six most abundant taxa from the lake is shown in Figure 6a, with size classes < 8 mm predominating. Only *S. acus*, which broods the larvae in a special pouch on the trunk of the

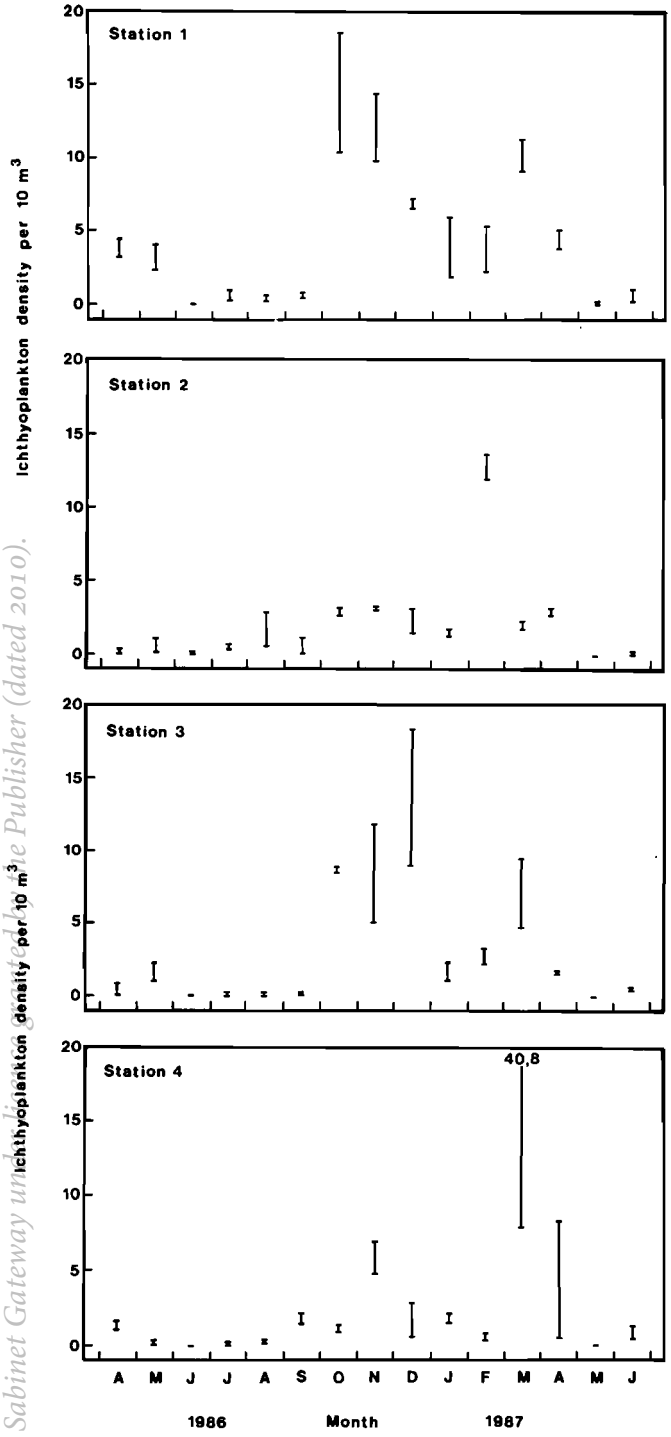

Figure 4 Range in abundance (number 10 m^{-3}) of fish larvae at Stations 1–4 for the period April 1986–June 1987.

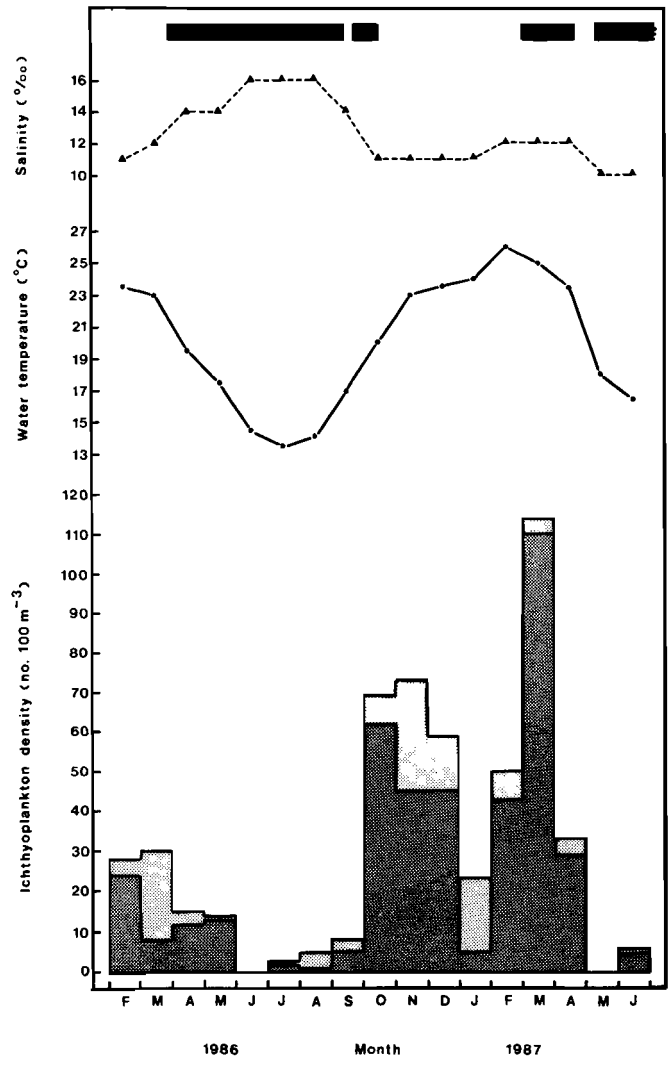

Figure 5 Contribution of *Gilchristella aestuaria* larvae (dark shading) to the total ichthyoplankton catch (light shading) between February 1986 and June 1987. The periods when the estuary mouth were closed (horizontal solid bars), surface salinity and water temperature at the time of sampling are also shown.

Table 1 Mean density (number 100 m^{-3}) and percentage composition of larval fishes at Stations 1–4 (February 1986–June 1987)

	Station 1		Station 2		Station 3		Station 4		Station 1–4	
Larval taxa	No. 100 m^{-3}	%	No. 100 m^{-3}	%	No. 100 m^{-3}	%	No. 100 m^{-3}	%	No. 100 m^{-3}	%
Gilchristella aestuaria	40,1	85,0	13,6	61,3	30,2	95,0	21,1	64,5	26,2	78,5
Atherina breviceps	0,3	0,7	2,7	12,0	0,3	1,0	6,7	20,5	2,5	7,5
Psammogobius knysnaensis	0,7	1,5	3,4	15,1	0,3	1,0	2,4	7,3	1,7	5,1
Omobranchus woodi	4,4	9,4	0,3	1,2	0,3	0,9	0,1	0,3	1,3	3,8
Syngnathus acus	0,8	1,8	1,8	8,3	0,2	0,7	1,8	5,4	1,2	3,5
Hyporhamphus capensis	–	–	0,1	0,2	0,3	1,0	0,7	0,2	0,2	0,7
Caffrogobius spp.	0,2	0,5	–	–	–	–	–	–	0,1	0,2
Gobiidae	0,5	1,0	0,1	0,6	–	–	–	–	0,1	0,4
Unidentified larvae	0,1	0,1	0,3	1,2	0,1	0,4	–	–	0,1	0,3
Total	47,1		22,3		31,7		32,8		33,4	

Table 2 Environmental data recorded at Stations 1–3 during a 24 h sampling period (4/2/88–5/2/88). The time of sampling and depth at each station are also shown

	Station 1 4,1 m		Station 2 2,9 m		Station 3 11,2 m	
	12h25	00h30	12h45	00h50	12h00	00h05
Salinity (‰)						
Surface	12	12	12	12	12	12
Middle	12	12	12	12	12	12
Bottom	12	12	12	12	15	15
Temperature (°C)						
Surface	27,0	27,0	27,0	26,5	26,5	26,5
Middle	26,5	27,0	27,0	26,5	25,5	25,5
Bottom	26,0	26,0	27,0	26,5	24,0	24,0
Oxygen (mg l^{-1})						
Surface	6,4	6,7	6,7	7,3	6,6	7,0
Middle	6,3	6,5	6,7	7,0	6,3	6,0
Bottom	5,8	6,4	6,6	6,9	0,0	0,0
pH						
Surface	8,1	8,1	8,1	8,1	8,1	8,1
Middle	8,1	8,1	8,1	8,1	7,9	7,9
Bottom	8,1	8,1	8,1	8,1	7,2	7,3
Secchi disc (cm)	21	n/d	33	n/d	33	n/d

male, was more abundant in the > 8 mm size class. Release of the larvae by the male pipefish appears to occur at a length > 10 mm SL. A more detailed analysis of *G. aestuaria* length composition at the four sampling stations is shown in Figure 6b. The modal size class at Stations 2 and 4 was 2–4 mm, and at Stations 1 and 3 it was 6–8 mm.

Physico-chemical measurements recorded during the 24-h study indicated that although environmental conditions at the three stations revealed some differences, most parameters showed little or no diel variation (Table 2). Ichthyoplankton composition and densities are given

Table 3 Diel surface ichthyoplankton densities (no. 100 m^{-3}) recorded during a 24 h sampling session (4/2/88–5/2/88)

	Station 1 No. 100 m^{-3}		Station 2 No. 100 m^{-3}		Station 3 No. 100 m^{-3}	
Fish taxa	Day	Night	Day	Night	Day	Night
Gilchristella aestuaria	2,8	117,0	1,8	20,0	0,8	31,1
Atherina breviceps	0,2	0,7	1,3	–	1,2	0,2
Omobranchus woodi	0,2	12,6	0,2	0,4	–	0,6
Psammogobius knysnaensis	0,2	3,1	–	–	0,2	–
Syngnathus acus	–	0,4	–	–	–	–
Hyporhamphus capensis	–	0,2	–	–	0,2	–
Unidentified larvae	0,2	–	0,2	0,4	–	–
Total	3,6	134,0	3,5	20,8	2,4	31,9

in Table 3 and indicate that densities were highest at Station 1 and lowest at Station 2. Surface larval densities increased significantly (Mann-Whitney U test, $p < 0{,}001$) after sunset and declined following sunrise (Figure 7).

Discussion

Swartvlei fish larval diversity was low owing to the tenuous link with the sea and the paucity of species breeding in South African estuaries (Wallace, Kok, Beckley, Bennett, Blaber & Whitfield 1984). The higher diversity (17 species) from the permanently open Swartkops estuary (Melville-Smith & Baird 1980) is to be expected since at least 10 of the species sampled were larvae which had entered the estuary from the adjacent marine environment. The most abundant species at Swartvlei were also common in the Swartkops and Kromme estuaries. For example, *G. aestuaria* comprised 78% of the total catch at Swartvlei, 54% in the Kromme (Melville-Smith 1981) and 31% in the Swartkops system. In terms of numbers, *G. aestuaria* and the family Gobiidae accounted for 97% of all larvae sampled in the Kromme estuary (Melville-Smith 1981), 91% in the

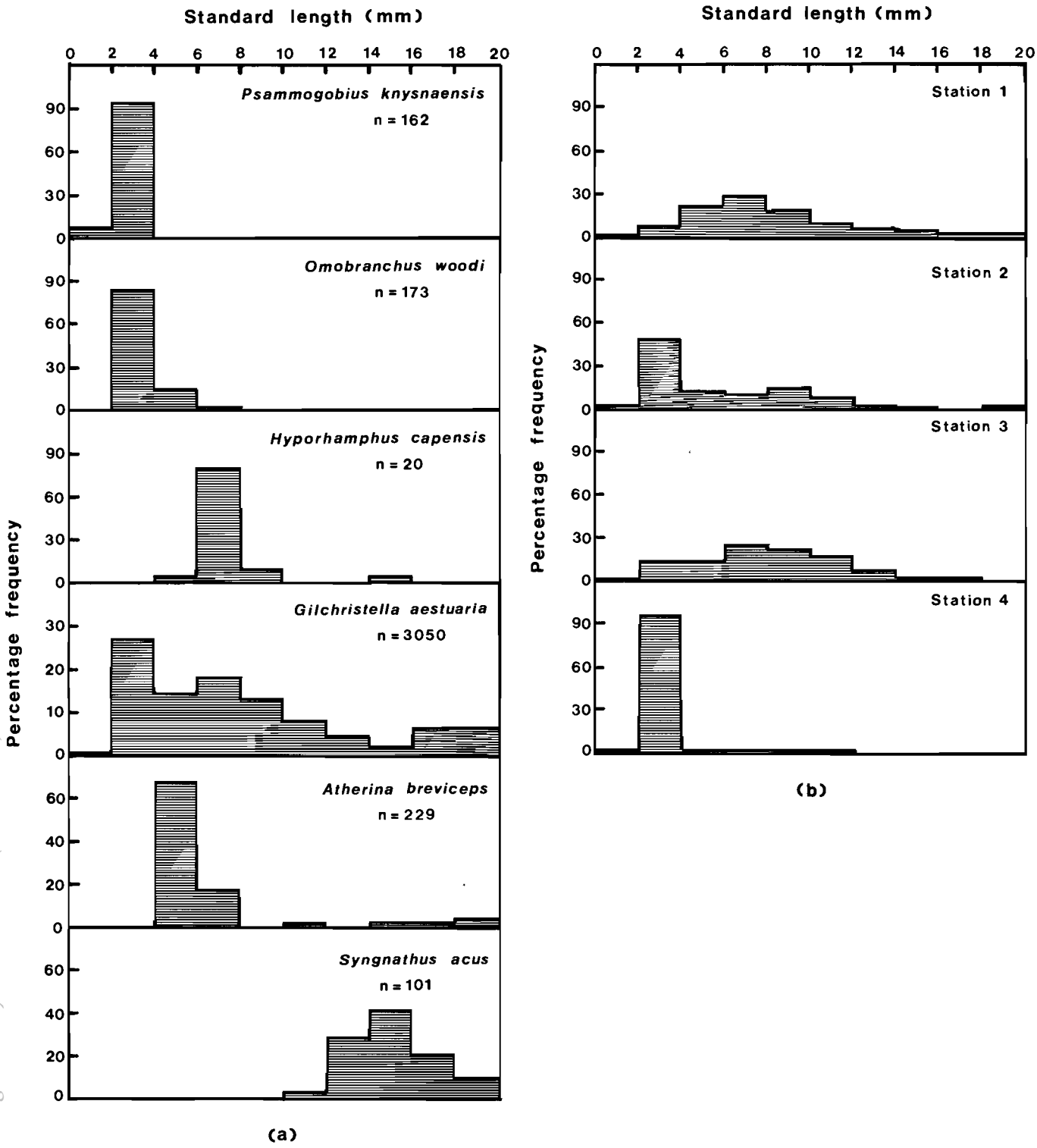

Figure 6 (a) Percentage length composition of the six most abundant ichthyoplankton species from Swartvlei. (b) Percentage length composition of *Gilchristella aestuaria* from Stations 1–4.

Swartkops estuary (Melville-Smith & Baird 1980) and 84% at Swartvlei.

The wide spatial distribution of the dominant ichthyoplankton in Swartvlei (Table 1) reflects the uniformity of epilimnion physico-chemical conditions. Water depth appeared to be a variable which may have influenced *G. aestuaria* distribution patterns. The peak in *G. aestuaria* abundance at littoral shelf Stations 2 and 4 occurred in the 2–4 mm length class, whereas the peak for deep water Stations 1 and 3 was in the 6–8 mm length group (Figure 6b). Spawning by *G. aestuaria* may occur in the vicinity of the littoral shelf and would account for the higher numbers of early larval stages recorded at Stations 2 and 4. Melville-Smith & Baird (1980) suggest that *G. aestuaria* in the Swartkops estuary spawn in the upper reaches and that larvae are most abundant in the upper and middle reaches. A similar situation pertains to Swartvlei, since the lake represents the upper reaches of

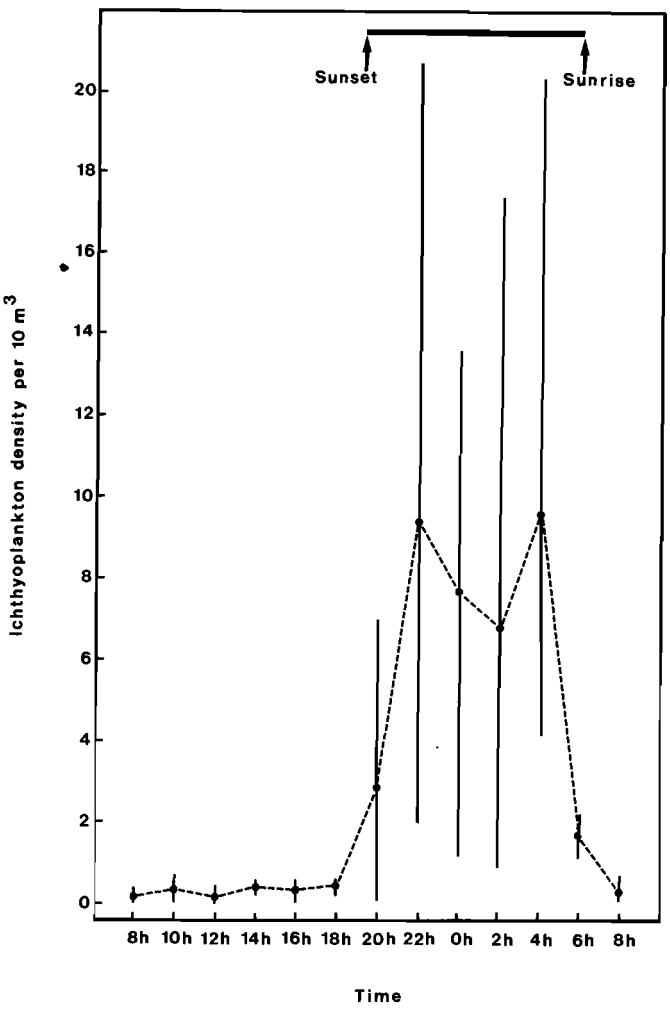

Figure 7 Surface densities ($\bar{x}$ and range) of ichthyoplankton at Stations 1–3 during a 24 h sampling period (4/2/88–5/2/88).

the system, with *G. aestuaria* larvae seldom recorded in the lower estuary (Whitfield 1989).

Mean annual densities of ichthyoplankton were higher in the Swartkops estuary (334 individuals 100 m^{-3}) compared to Swartvlei (38 individuals 100 m^{-3}). However, the abundant goby and blenny larvae in the Swartkops estuary may have represented a transient population, since both Beckley (1985) and Whitfield (1989) found that although spawning by these species occurs within the estuarine environment, large numbers of early larvae are passively swept out of the Swartkops and Swartvlei estuaries on the ebb tide. In contrast, the absence of tidal fluctuations within Swartvlei and the narrow link with the estuary (Figure 1), suggest that fish larvae in this part of the system are residents dependent upon the lake for survival.

Another possible reason for the relatively low Swartvlei larval densities is the oligotrophic status of waters in the lake (Robarts 1976) which may result in depressed ichthyoplankton food resources. According to Coetzee (1981) Swartvlei yielded the lowest mean zooplankton biomass (4 mg dry mass m^{-3}) of the five Wilderness lakes studied. Turner, Woo & Jitts (1979) showed a direct link between phytoplankton primary production, densities of zooplankton and the abundance of fish larvae. Evidence from Swartvlei with its low primary productivity, low zooplankton biomass and low ichthyoplankton densities tends to support this hypothesis.

The highest densities of fish larvae in Swartvlei were recorded during summer (Figures 4 & 5), which also coincided with peaks in zooplankton abundance (Coetzee 1981). Melville-Smith & Baird (1980) and Melville-Smith (1981) found that in eastern Cape estuaries fish larvae were most abundant between October and March , with low numbers recorded during the remainder of the year. Similar seasonal patterns in estuarine ichthyoplankton abundance have been recorded in both the northern and southern hemisphere e.g. Mexico (Flores-Coto, Barba-Torres & Sanchez-Robles 1983), New Zealand (Roper 1986), Australia (Jenkins 1986) and Portugal (Duarte 1987).

Diel changes in estuarine ichthyoplankton abundance have been documented by several authors (e.g. Bridger 1956; Fore & Baxter 1972; Eldridge 1977) but little information (Melville Smith, Baird & Wooldridge 1981; Beckley 1985) is available from southern African estuaries. Results from this study show a highly significant ($p < 0{,}001$) increase in the abundance of larval fishes in the upper metre of the water column between sunset and sunrise (Figure 7). This event may be linked to the vertical migration pattern of zooplanktonic prey organisms (e.g. *Acartia natalensis* and *Pseudodiaptomus hessei*) in Swartvlei, which concentrated in surface waters of the lake at night (Coetzee 1981).

Acknowledgements

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