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Composition, Seasonality and Distribution of the Ichthyoplankton in the Lower Swan Estuary, South-western Australia

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Abstract

Paired conical nets (0·5 mm mesh) were used to sample ichthyoplankton at three sites in the lower Swan Estuary in each month between May 1986 and April 1987. In all, 3948 fish larvae were caught, representing 32 families and 60 species, of which 29 could be assigned species names. The Clupeidae (20·2%), Engraulididae (10·4%), Callionymidae (8·7%) and Nemipteridae (6·8%) made the greatest contributions to the total larval number, followed by the Pinguepididae (5·8%), Gobiidae (5·8%), Terapontidae (5·7%) and Monacanthidae (5·4%). The most numerous of the identified species were *Engraulis australis* (10·4%), *Hyperlophus vittatus* (8·9%), *Callionymus goodladi* (8·7%) and *Sardinella lemuru* (7·4%). The 11 most abundant of the identified species included 2 that spawn in the estuary (*E. australis* and *Parablennius tasmanianus*) and 2 that spawn at sea but are abundant as juveniles in the estuary (*Pelates sexlineatus* and *H. vittatus*). The remaining 7 species are not common as either juveniles or adults in any region of the Swan Estuary. The larvae of marine species collected just inside the estuary mouth were very similar in size to those collected a further 7·2 km upstream, indicating that they are transported rapidly through the lower estuary, presumably through tidal action. The concentrations of both eggs and larvae of all fish collectively, and the concentrations of larvae of most of the abundant identified species, peaked between late spring and midsummer (November–January).

Introduction

Estuaries in both the northern and the southern hemispheres support a range of marine teleosts (Cronin and Mansueti 1971; Dando 1984; Wållace *et al.* 1984; Potter *et al.* 1990). Since many of these species are represented in estuaries predominantly by their juveniles, estuaries have frequently been referred to as fish nursery areas (McHugh 1967; Haedrich 1983; Claridge *et al.* 1986). Although some of these species migrate into these systems as juveniles (e.g. de Silva 1980; Potter *et al.* 1988*a*, 1990), others enter as larvae (e.g. Misitano 1977; Beckley 1985; Miskiewicz 1986; Whitfield 1989). The upstream movement and retention of larvae within estuaries relies to a large extent on mechanisms involving active and/or passive tidal transport (Weinstein *et al.* 1980; Fortier and Leggett 1982; Norcross and Shaw 1984; Roper 1986; Boehlert and Mundy 1988). The distance that these larvae have to be transported from the spawning areas to their nursery habitats within estuarine systems is least in the case of those species that spawn near or within estuary mouths. Typically, only a few species spawn within the main bodies of estuaries (Haedrich 1983; Dando 1984).

The large Swan Estuary in south-western Australia (Fig. 1) comprises a long, narrow entrance channel leading into wide basins that are fed by tributary rivers. The channel, basins and those parts of the tributaries that become markedly saline in the summer have been termed the lower, middle and upper estuary respectively (Chalmer *et al.* 1976). The

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tidal range in local marine waters is small (0·9 m), with the result that the maximum tidal range even at Fremantle near the bottom end of the lower estuary is only 0·8 m (Riggert 1978).

Recent studies have provided information on the biology of the majority of the more abundant fish species found in the Swan Estuary and the nearby Peel-Harvey Estuary (Chubb *et al.* 1981; Prince *et al.* 1982; Potter *et al.* 1983, 1988*b*; Prince and Potter 1983; Chubb and Potter 1984, 1986; Lenanton *et al.* 1984; Chrystal *et al.* 1985; Nel *et al.* 1985; Lenanton and Potter 1987; Loneragan *et al.* 1987, 1989; H. Gill, unpublished data). However, none of these studies included data on the larval phase in the life cycle of any of these species.

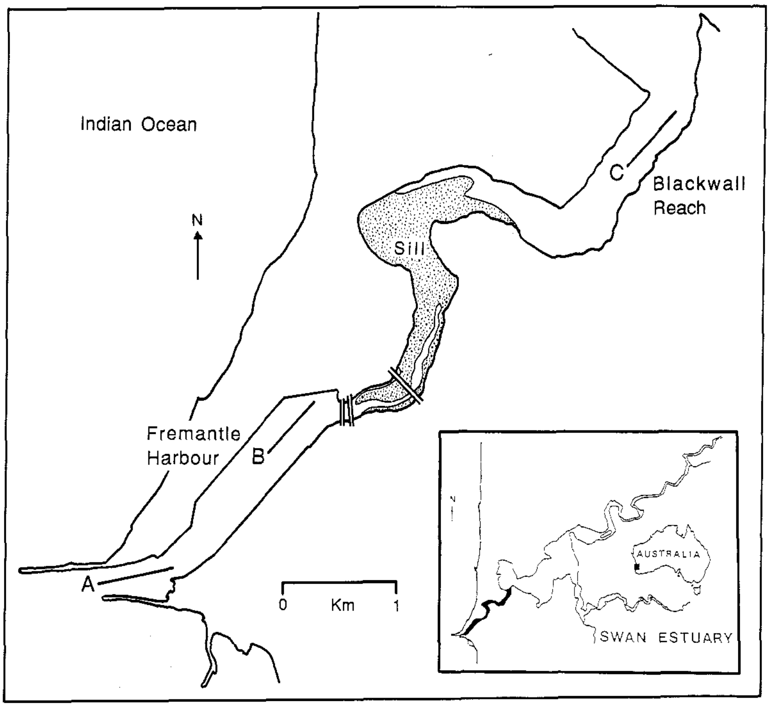

Fig. 1. Location of the three sampling sites (A, B and C) in the lower Swan Estuary.

The present study describes the composition and seasonal changes in the concentration of ichthyoplankton at three sites in the lower Swan Estuary. These data, together with those previously obtained for juvenile and adult fish, are then used to distinguish the species that spawn in or near the estuary mouth from those that breed within the main body of the estuary. The data are also used to determine whether any of the species that spawn at sea, but are abundant as juveniles in the estuary, are transported through the lower estuary as larvae. This paper provides data on part of the first detailed ecological study of the ichthyoplankton within an estuary in Western Australia, and it complements the limited number of comparable studies carried out in estuaries elsewhere in southern Australia (Ramm 1986; Miskiewicz 1987; Steffe and Pease 1988).

Materials and Methods

Study Area

The lower region of the Swan Estuary comprises a narrow channel 7·5 km long and between 200 and 600 m wide (Fig. 1). Fremantle Harbour, which lies near the mouth of the estuary and is dredged to a depth of 11 m, leads into a stretch of water where the presence of a sill greatly reduces the depth. At the top end of the lower estuary lies Blackwall Reach, where the depth ranges from 10 to 16 m. Apart from those along the sill, the banks of the lower estuary are steep, either naturally or through development by humans. There is thus comparatively little shallow water in the harbour and in Blackwall Reach.

Sampling Procedures

Ichthyoplankton samples were taken monthly between May 1986 and April 1987 at site A near the estuary mouth, site B in Fremantle Harbour, and site C in Blackwall Reach (Fig. 1). These three sites were located 0·3, 2·5 and 7·2 km from the mouth of the estuary respectively. Sampling commenced 1–2 h after sunset and was completed at all three sites within the next $1\frac{1}{2}$ h. Samples were taken in the third quarter of each month against the current. It should be noted that tides in the Swan Estuary in any month can be either diurnal or semi-diurnal (Hodgkin and di Lollo 1958) and that water movements brought about by changes in barometric pressure can be greater than those due to tidal action (Spencer 1956). These two features make it difficult to plan in advance a regime that ensures sampling is carried out when water is always flowing in the same direction. Surface and bottom salinities and temperatures were recorded at each site at the time of sampling, using a Yeo–Kal Model 602 salinity/temperature bridge.

Ichthyoplankton was sampled with a pair of 0·5-mm-mesh conical nets joined by a 25-cm-wide aluminium plate and towed from the stern of a power boat. Each net was 2 m long and had a mouth diameter of 0·6 m. The volume of water filtered was measured with a General Oceanics flow-meter fitted at the mouth of one of the nets. At each site in each month, one stepwise oblique tow (Austin 1976) of 10 min duration was made upwards from a depth of 8 m to just below the surface at a speed of approximately 1 m s^{-1}. The average volume of water sampled by each net was 85 m^3. The nets were washed at the end of each tow, and samples were fixed in 5–10% formalin and seawater and stored in 70% alcohol.

Larvae were removed from the samples under a dissecting microscope, identified to the lowest taxonomic level possible, and counted. Identifications of larvae were based on descriptions given in a variety of atlases of larval fishes, including those of Miller *et al.* (1979), Leis and Rennis (1983), Fahay (1983) and Moser *et al.* (1984). The relatively small number of larvae that could not be identified even to family level (including damaged specimens) were placed in the unidentified category (Table 1). Body lengths (i.e. tip of snout to end of notochord in preflexion and flexion larvae, tip of snout to urostyle in postflexion larvae) were measured to the nearest 0·1 mm, using an eyepiece micrometer in a Wild M8 stereomicroscope.

The numbers of *Engraulis australis* eggs, which are easily identifiable (Robertson 1975), and the numbers of eggs of all other fish collectively, were either counted or estimated by subsampling. Concentrations of fish eggs and larvae in each month represent the numbers per 100 m^3 of water recorded for the two nets at each sampling site. The relative contributions of the larvae of the various species to the total number, and the relative contributions of each species at each site to the total catch of those species, were calculated from these concentrations. In other words, these contributions correspond to values calculated after adjustment of the numbers at each site in each month to a constant volume of 100 m^3. The same procedure was adopted for calculating the contributions made by the numbers of eggs at the three sites.

A two-way factorial analysis of variance (ANOVA) without replication was used to test whether the concentrations of all eggs and of all larvae at the three sites were significantly different.

Results

Environmental Conditions

Bottom salinities at sites A and B were always close to the salinity of full-strength sea water (~35 g kg^{-1}). Although the bottom salinity at site C fell slightly to a minimum of 31·5 g kg^{-1} in July, it was always close to or the same as the salinity of full-strength sea water (Fig. 2). In contrast, surface salinity at each site declined markedly in winter. Values at site C fell to 5·4 g kg^{-1} in August before rising sharply over the ensuing months to approach the salinity of full-strength sea water by December. Compared with the situation at site C, the surface salinities at sites A and B, which were similar in each month, started to decline later and recover earlier and did not fall as low (Fig. 2).

Since temperatures at the top and the bottom of the water column at each of the three sites in any given month never differed by more than 1°C, and since differences among sites were similarly small, the temperatures for each month have been plotted as the mean of all bottom and surface temperatures at the three sites (Fig. 2). Mean temperatures in 1986 declined from 17·0°C in May to approximately 15°C in July and August before gradually rising to reach a peak of 23·8°C in February 1987.

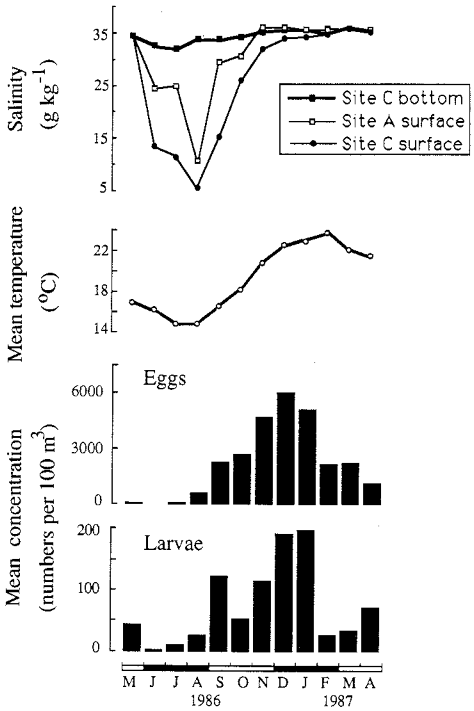

Fig. 2. Salinities, mean temperatures and mean concentrations of fish eggs and larvae based on data collected at sites A, B and C in the lower Swan Estuary between May 1986 and April 1987. Bottom salinities at sites A and B always remained close to the salinity of full-strength sea water (~35 g kg^{-1}) and the surface salinity at site B was similar in each month to that shown for site A. The temperature for each month represents the mean of the surface and bottom values at all three sites. Mean concentrations of fish eggs and larvae were calculated from the respective concentrations of these variables at the three sites.

Species Composition of Larvae

In all, 3948 fish larvae were caught during this study, representing 32 families and 60 species (Table 1). Of the latter, 29 could be assigned to particular species, 7 to genus, and 24 to family (Table 1).

Eight families each contributed more than 5% to the total number of larvae and collectively accounted for 68·9% of that number. The Clupeidae, Engraulididae, Callionymidae and Nemipteridae were the most abundant families, with respective contributions of 20·2, 10·4, 8·7 and 6·8% (Table 1). The Terapontidae, Pinguepididae, Gobiidae and Monacanthidae each contributed between 5·4 and 5·8% to the total number. Contributions greater than 1% were also provided by the Gobiesocidae, Platycephalidae, Sillaginidae, Carangidae, Labridae, Blenniidae and Cynoglossidae (Table 1).

The Clupeidae was represented by 5 species, of which *Hyperlophus vittatus*, *Sardinella lemuru* and *Sardinops neopilchardus* were common (Table 1). The Engraulididae, Callionymidae, Nemipteridae, Terapontidae and Pinguepididae were each represented by single species, namely *Engraulis australis*, *Callionymus goodladi*, *Pentapodus vitta*, *Pelates sexlineatus* and *Parapercis haackei* respectively (Table 1). The Gobiidae and Gobiesocidae each comprised 4 species, the Monacanthidae 3 species.

The larvae of the 11 most abundant identified species each contributed more than 1%, and collectively approximately 66%, to the total number of larvae caught. The relative

Table 1. Numbers and relative contributions of the different taxa of larval fish caught in the lower Swan Estuary

Taxa	Number caught	Adjusted numbers[A]	Percentage of total catch	Rank	Percentage of catch from sites A	B	C
Clupeidae							
Etrumeus teres	3	1·2	<0·1		–	100·0	–
Hyperlophus vittatus	317	232·7	8·9	2	46·2	38·0	15·8
Sardinella lemuru	316	194·2	7·4	4	78·6	20·5	0·9
Sardinops neophilchardus	129	98·9	3·8	9	51·5	42·4	6·1
Spratelloides robustus	1	0·6	<0·1		100·0	–	–
Engraulididae							
Engraulis australis[B]	499	272·1	10·4	1	17·9	7·5	74·6
Galaxiidae							
Galaxias occidentalis	1	1·2	<0·1		100·0	–	–
Gobiesocidae							
Species 1	79	56·0	2·1		67·7	30·4	1·9
Species 2	90	52·4	2·0		41·6	55·0	3·4
Species 3	2	1·4	<0·1		–	100·0	–
Species 4	15	9·3	0·4		49·7	49·3	–
Hemiramphidae							
Hyporhamphus sp.	1	1·7	<0·1		100·0	–	–
Atherinidae							
Leptatherina presbyteroides	5	2·7	0·1		–	–	100·0
Atherinomorus ogilbyi	2	1·0	<0·1		50·7	–	49·3
Syngnathidae							
Hippocampus angustus	5	2·4	0·1		80·8	19·2	–
Stigmatopora nigra	25	12·7	0·5		55·9	34·6	9·5
Stigmatopora argus	3	1·7	<0·1		100·0	–	–
Urocampus carinirostris[B]	5	2·6	0·1		33·4	29·3	37·3
Scorpaenidae							
Gymnapistes marmoratus	4	2·3	0·1		52·6	26·4	21·0
Unidentified sp.	1	1·6	<0·1		100·0	–	–
Triglidae							
Unidentified spp. (2)	18	10·6	0·4		71·0	24·2	4·8
Platycephalidae							
Platycephalus spp. (3)	78	45·0	1·7		50·0	34·9	15·1
Pegasidae							
Parapegasus natans	25	20·1	0·8		53·2	34·3	12·5
Terapontidae							
Pelates sexlineatus	183	148·3	5·7	7	49·6	42·4	8·0
Sillaginidae							
Unidentified spp. (2)	179	123·7	4·7		41·8	33·0	25·2
Carangidae							
Pseudocaranx dentex	203	126·1	4·8	8	63·4	29·1	7·5
Sparidae							
Rhabdosargus sarba	15	8·0	0·3		95·3	–	4·7
Gerreidae							
Gerres subfasciatus	2	1·8	<0·1		–	65·5	34·5
Nemipteridae							
Pentapodus vitta	187	178·6	6·8	5	65·2	28·3	6·5

Table 1 (*continued*)

Taxa	Number caught	Adjusted numbers[A]	Percentage of total catch	Rank	Percentage of catch from sites A	B	C
Sphyraenidae							
Sphryraena obtusata	1	1·7	<0·1		100·0	–	–
Labridae							
Unidentified spp. (4)	79	64·9	2·5		48·0	38·6	13·4
Odacidae							
Unidentified spp. (2)	3	1·6	<0·1		29·3	32·3	38·4
Pinguepididae							
Parapercis haackei	227	151·7	5·8	6	65·4	26·4	8·2
Leptoscopidae							
Lesueurina sp.	17	11·1	0·4		63·8	36·2	–
Blenniidae							
Parablennius tasmanianus[B]	116	53·6	1·9	10	15·1	30·3	54·6
Omobranchus germaini	20	18·4	0·7		34·0	59·3	6·7
Tripterygiidae							
Unidentified spp. (2)	43	23·6	0·9		67·6	25·5	6·9
Callionymidae							
Callionymus goodladi	325	229·1	8·7	3	56·8	26·5	16·7
Gobiidae							
Favonigobius lateralis	47	22·3	0·8		38·0	32·9	29·1
Unidentified spp. (3)	223	132·4	5·0		39·3	25·7	35·0
Pleuronectidae							
Ammotretis rostratus	2	0·8	<0·1		54·8	–	45·2
Paralichthyidae							
Pseudorhombus arsius	5	2·4	0·1		60·7	39·3	–
Bothidae							
Arnoglossus sp.	3	1·8	0·1		100·0	–	–
Asterorhombus sp.	2	0·9	<0·1		100·0	–	–
Cynoglossidae							
Cynoglossus broadhursti	52	35·7	1·4	11	65·7	22·8	11·5
Monacanthidae							
Unidentifed spp. (3)	197	140·3	5·4		56·1	27·6	16·3
Diodontidae							
Unidentified sp.	1	0·5	<0·1		100·0	–	–
Unidentified larvae	190	119·1	4·5		57·0	31·9	11·1
Total larvae	3948	2623·4			51·3	29·7	19·0
Engraulis australis eggs	3028	3567·5	4·4		5·0	11·4	83·6
Total eggs	81200	81198·2			45·4	38·9	15·7

[A] Each adjusted number corresponds to the sum of the monthly numbers of larvae at each site after they have been adjusted to a constant volume of 100 m^3 (i.e. it represents the sum of the monthly concentrations at each site when these are expressed as numbers of larvae per 100 m^3). The adjusted numbers were used to calculate the rankings and relative contributions.
[B] Species spawning within the main body of the estuary.

contributions of these species ranged from 10·4% for *E. australis* to 1·4% for *Cynoglossus broadhursti* (Table 1).

Seasonal Abundance of Fish Eggs and Larvae

Apart from in September, the concentrations of eggs and larvae each followed similar seasonal changes at the three sites (Fig. 3). The marked increase in the concentration of larvae at site C in September was due almost entirely to a massive increase in the number of *E. australis* (Fig. 4), and the same was also true for eggs (see below). In view of the general similarity in seasonal trends at the three sites, the monthly concentrations of all fish eggs and larvae at the sites have been pooled to provide an approximation of the overall seasonal trends in the lower estuary (Fig. 2).

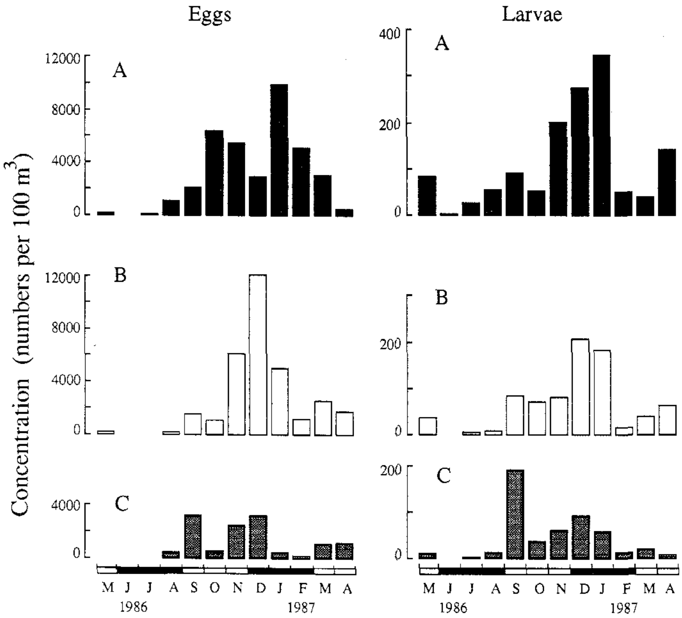

Fig. 3. Concentrations of fish eggs and larvae at sites A, B and C in the lower Swan Estuary between May 1986 and April 1987.

The concentration of fish eggs followed a very pronounced seasonal trend (Fig. 2). It was very low between May and July (<83 per 100 m^3) but then rose progressively over the ensuing months to reach a peak of 6031 per 100 m^3 in December, before declining to 1133 per 100 m^3 in April. As with fish eggs, the trends shown by the concentration of fish larvae were also seasonal (Fig. 2). Overall mean concentration rose from only 1·5 larvae per 100 m^3 in June to nearly 200 per 100 m^3 in both December and January, but then declined sharply to less than 35 per 100 m^3 in February and March. It then rose to 70 per 100 m^3 in April.

The monthly concentrations of eggs at site C were less than those at sites A and B in all months except September (and August at site B) (Fig. 3). However, it should be recognized that the concentrations at both site B and site C were very low in August (<430 eggs per 100 m^3). The greater concentrations at sites A and B account for the fact that these sites yielded 45·4 and 38·9% respectively of all fish eggs recorded in this study. ANOVA showed that the monthly mean concentrations of eggs differed amongst sites ($P < 0{\cdot}05$).

The mean concentrations of fish larvae at site C were less than those at sites A and B in each month except September (and April at site A; and August at site B). However, it should be noted that the concentrations of larvae were low at each site in both April and August. ANOVA showed that the monthly mean concentrations of larvae differed significantly amongst sites ($P < 0{\cdot}01$).

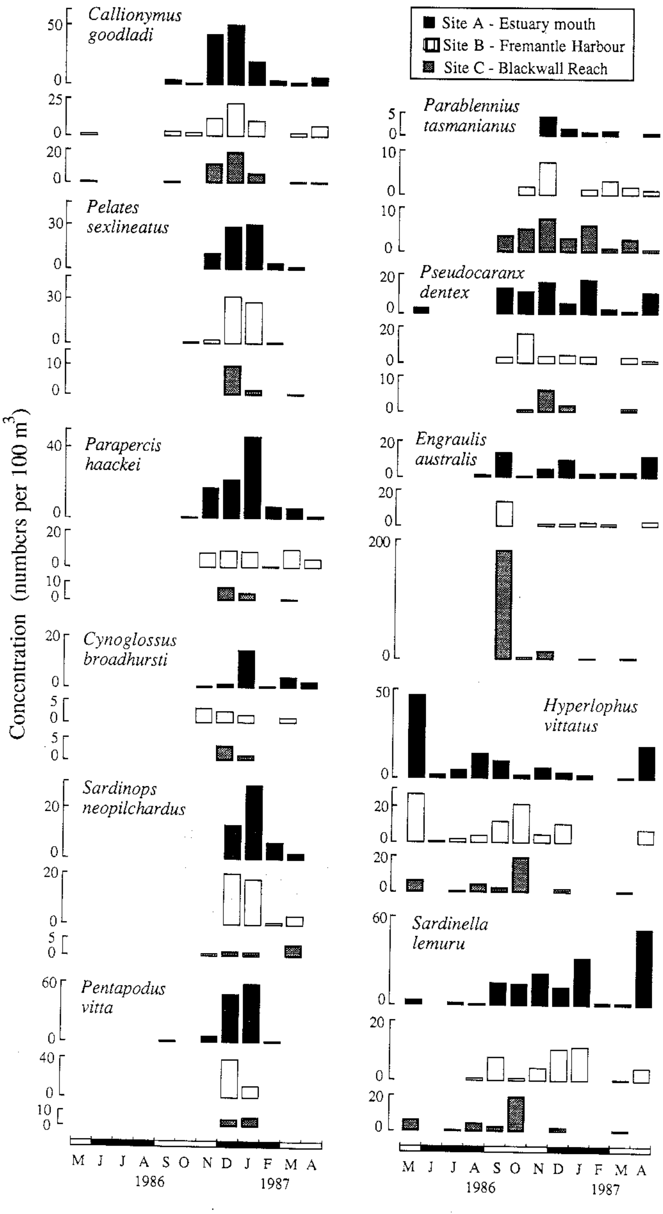

Fig. 4. Concentrations of the larvae of the 11 most abundant identified species at sites A, B and C in the lower Swan Estuary in each month between May 1986 and April 1987.

The percentage contributions of fish larvae at the three sites to the total number of larvae caught at all sites during the 12 months of this study declined from 51% at site A to 30% at site B and 19% at site C (Table 1).

Seasonal Occurrence of Engraulis australis *Eggs*

The large number of *E. australis* eggs collected at site C in September constituted 56·0% of all eggs collected from that site in that month, compared with 22·2% at site B and only

3·8% at site A. Furthermore, the number of *E. australis* eggs collected from site C over all months accounted for 83·6% of the total number of eggs of this species recorded during this study (Table 1). Although *E. australis* eggs were present in samples collected between July 1986 and April 1987, approximately 95% of these were taken in August, September, October and December.

Seasonal Occurrence of Larvae of Main Species

The abundance of 7 of the 11 most abundant identified species, namely *C. goodladi*, *P. sexlineatus*, *P. haackei*, *C. broadhursti*, *S. neopilchardus*, *P. vitta* and *Parablennius tasmanianus*, each followed similar seasonal trends (Fig. 4). Thus, the majority of the larvae of these 7 species were caught between late spring and midsummer, with numbers typically peaking in either December or January. However, the larvae of these 7 species were always represented in samples from at least 5 months and from all but 3 months in the case of *C. goodladi* (Fig. 4).

Most *Pseudocaranx dentex* larvae were obtained between September and January. Although the larvae of *E. australis* were collected mainly in September (77·1%), they were represented in samples from 8 other months (Fig. 4).

In September, the larvae of *E. australis* were exceptionally abundant at site C and constituted 95·4% of the total number of larvae collected from that site. The higher concentrations of fish larvae at sites A and B in May 1986 than in the following 2 months, and in April 1987 than in the preceding 2 months, were largely due to the presence of considerable numbers of the larvae of *H. vittatus* and *S. lemuru*.

The seasonal trend shown by the concentrations of *H. vittatus* larvae was unusual in that it exhibited a bimodal pattern, with peaks in both spring (October) and autumn (April and May). Larval *S. lemuru* appeared in samples from at least one site in all months except June. Although the concentrations of this species were at their greatest in January and April, they were very low in the intervening 2 months (Fig. 4).

Spatial Distribution of Larvae

The concentrations and relative contributions of the larvae of *C. goodladi*, *P. haackei*, *C. broadhursti*, *P. vitta*, *P. dentex*, *S. lemuru*, *P. sexlineatus*, *S. neopilchardus* and *H. vittatus* each declined progressively from site A in the estuary mouth to site B in Fremantle Harbour to site C in Blackwall Reach (Fig. 4, Table 1). In contrast, the concentrations and relative contributions of *E. australis* and *P. tasmanianus* were far greater at site C than at either site A or site B (Fig. 4, Table 1).

Size Composition of Larvae

The lengths of the larvae of *C. goodladi*, *P. sexlineatus*, *P. haackei*, *C. broadhursti*, *P. vitta*, *P. dentex* and *P. tasmanianus* caught at all three sites almost invariably fell within the range 2·0–5·9 mm (Fig. 5). Length–frequency distributions and modal length classes (invariably either 2·0–2·9 or 3·0–3·9 mm) showed that for each of these species its size was similar at the top end of the lower estuary (site C) and the estuary mouth (site A). Although ANOVA showed that the mean lengths of two of these species (*P. haackei* and *P. dentex*) differed significantly ($P > 0{\cdot}05$), it should be recognized that the means at the three sites ranged only from 2·5 to 2·7 mm and from 3·3 to 4·1 mm respectively. Furthermore, in the case of *P. haackei*, the modal length class at each site was identical and pronounced and, with the removal of just the two slightly larger fish, the means were not significantly different. The above statistical differences, which are always likely to occur when there are a large number of measurements and a very small standard deviation, probably do not have any biological significance.

The range of lengths of clupeoid larvae was greater than those of the species mentioned above. Thus, larvae longer than 10 mm were recorded in the cases of *S. neopilchardus*,

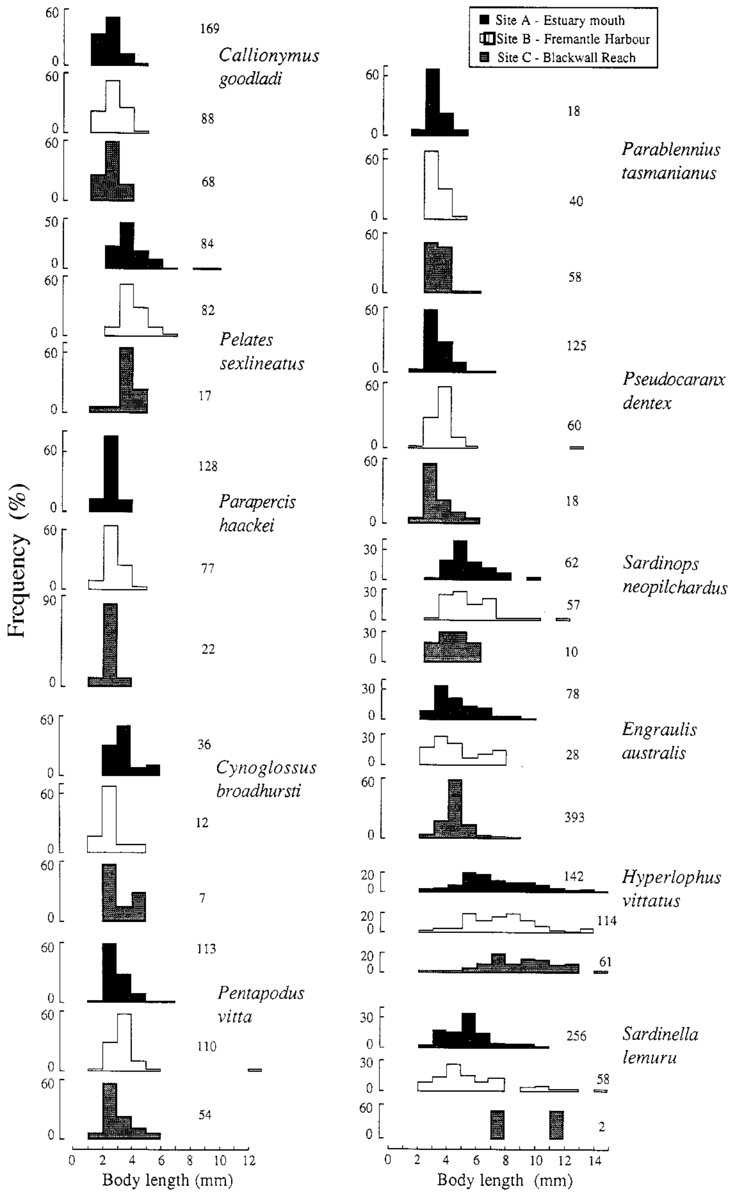

Fig. 5. Length–frequency histograms for the larvae of the 11 most abundant identified species at sites A, B and C in the lower Swan Estuary, based on all length data collected for each species between May 1986 and April 1987.

S. lemuru and *H. vittatus*, and although no larvae of *E. australis* were found that were longer than this, several were longer than 6 mm. ANOVA showed that the mean lengths of *E. australis* and *H. vittatus*, but not those of *S. neopilchardus* and *S. lemuru*, differed significantly amongst sites ($P > 0{\cdot}5$). The median length of *H. vittatus* increased progressively from 6·5 mm at site A to 7·2 mm at site B and 8·9 mm at site C (Fig. 5).

Discussion

Composition of Ichthyoplankton

The major contribution made by the Clupeidae to the ichthyoplankton of the lower Swan Estuary parallels the situation found in other southern-hemisphere estuarine and coastal waters such as the Swartkops Estuary and Algoa Bay in southern Africa (Melville-Smith and Baird 1980; Beckley 1986) and Port Phillip Bay and Lake Macquarie in south-eastern Australia (Jenkins 1986; Miskiewicz 1987). Clupeids are also often the most abundant fish larvae in inshore marine embayments and estuaries of the northern hemisphere (Pearcy and Myers 1974; Houde and Alpern Lovdal 1984; Bourne and Govoni 1988).

The contribution of the Clupeidae during this study (20·2%) was far greater than that of the Gobiidae, which is typically the most abundant family in the ichthyoplankton of many temperate marine embayments and estuaries (Miller 1984). For example, the contribution of the Gobiidae to the larval assemblages of Port Phillip Bay, the Swartkops Estuary and Algoa Bay ranged between 34·2 and 59·4% (Melville-Smith and Baird 1980; Beckley 1986; Jenkins 1986), whereas it accounted for less than 6·0% of the total larvae caught in the lower Swan Estuary. The high ranking of the Engraulididae in the lower Swan Estuary also parallels the situation in Algoa Bay and Lake Macquarie (Beckley 1986; Miskiewicz 1987).

Twelve families accounted for 85·3% of the total number of larvae in the lower Swan Estuary. In contrast, 4 families or less accounted for 85% of the total number of larvae caught in Port Phillip Bay, the Swartkops Estuary, Algoa Bay and Yaquina Bay in Oregon (Pearcy and Myers 1974; Melville-Smith and Baird 1980; Beckley 1986; Jenkins 1986). Furthermore, the contribution by the most abundant family in the lower Swan Estuary (20·2%) was far lower than the 34·2 to 59·4% recorded in the above studies.

The lack of extreme dominance in the ichthyoplankton of the lower Swan Estuary by certain families is paralleled by the relatively small contribution (10·4%) made by the most abundant single species (*Engraulis australis*). In contrast, the most abundant species in the ichthyoplankton of Algoa Bay (*Caffrogobius* sp.), the Swartkops Estuary (*Gilchristella aestuaria*) and Yaquina Bay (*Clupea harengus*) contributed 47·6, 31·1 and 56·4% respectively. Furthermore, the number of species recorded in the lower Swan Estuary (60) was greater than those recorded in a number of other studies in the temperate regions of the southern hemisphere. Thus, the numbers of species obtained from inshore marine areas of eastern Australia, South Africa and New Zealand ranged between 27 and 45 (Brownell 1979; Crossland 1982; Beckley 1986; Jenkins 1986; Steffe and Pease 1988). Moreover, in the Swartkops Estuary in southern Africa and Whangateau Harbour in New Zealand, only 17 and 31 larval fish species respectively were recorded (Melville-Smith and Baird 1980; Roper 1986).

Distribution of Larvae

The data presented in this paper show that the larvae of the 11 most abundant of the identified fish species caught in the lower Swan Estuary can be separated into two broad categories, namely those for which the concentrations were greater at site C than at sites A and B, and those for which the opposite situation pertained. The first group were represented by *E. australis* and *Parablennius tasmanianus*. The presence of greater concentrations of their larvae at site C at the top of the lower estuary than at sites A and B several kilometres downstream in the estuary mouth suggest that these two species spawn within the main body of the estuary. Such a view is consistent with the high numbers of larval *E. australis* and *P. tasmanianus* that were caught concomitantly in the wide, open reaches of the middle Swan Estuary (Neira, unpublished data). In this context, it is relevant that *E. australis* is known to spawn in estuaries elsewhere in Australia (Blackburn 1950; Arnott and McKinnon 1985; Ramm 1986).

The second group of larvae (i.e. those whose concentrations were greater at sites A and B than at site C) comprised 9 marine species, of which 7 are moderately to very abundant as juveniles and/or adults in the nearby large marine embayment of Cockburn Sound (Dybdahl 1979). These species were *Sardinops neopilchardus*, *Pelates sexlineatus*, *Pseudocaranx dentex*, *Pentapodus vitta*, *Parapercis haackei*, *Callionymus goodladi* and *Cynoglossus broadhursti*. The extensive catches of juvenile and adult *Hyperlophus vittatus* taken outside the estuary demonstrate that this species is also abundant in local marine waters (Potter *et al.* 1989). The ninth species whose larvae were more abundant at sites A and B than at site C was *Sardinella lemuru*, which is frequently found schooling in the marine waters and estuary mouths of south-western Australia (Hutchins and Thompson 1983).

Two possible explanations could account for the progressive and usually marked decline in the numbers of the larvae of the above marine species between the estuary mouth and the top of the lower estuary. For example, it could reflect progressively reduced spawning by these marine teleosts in an upstream direction. Alternatively, it may represent an upstream dispersion of larvae from spawning areas in either local inshore marine environments or the estuary mouth. Since the juveniles of all 9 species above, except *H. vittatus* and *P. sexlineatus*, are not abundant in either the Swan or the Peel-Harvey Estuaries (Potter *et al.* 1983; Loneragan *et al.* 1989), the second of these two alternatives appears to be more likely for at least the majority of species. Although the tidal amplitude in the lower estuary is small, Spencer's (1956) study suggests that the tidal movement of water through the narrow lower estuary would be sufficiently strong to account for the transport of larvae from the estuary mouth to Blackwall Reach. The fact that the size ranges and modal lengths of each of the abundant marine species, except *H. vittatus*, were similar at sites A, B and C implies that such dispersion occurs rapidly. However, it should also be noted that there is a net upstream movement of salt water over the sill between late spring and midsummer (Spencer 1956), the time when the numbers of most of the marine species reached a maximum.

The progressive increase in the median length of *H. vittatus* from site A to site C suggests that some larvae of this marine species were retained within the estuary. Since *H. vittatus* is also abundant as juveniles in south-western Australian estuaries (Potter *et al.* 1983; Loneragan *et al.* 1989), such retention would have the advantage of allowing the larvae of *H. vittatus* to transform into juveniles within the estuary, after which they would then be able to pass rapidly into their typical estuarine nursery habitats. However, if retention mechanisms exist, it seems likely that they would benefit only a small proportion of those *H. vittatus* larvae that are spawned in or near the estuary mouth. This view is based on the observation that the concentration of *H. vittatus* larvae at site C declined markedly in the early winter (June), when freshwater discharge increased sharply, and rose conspicuously in midspring (October), when this discharge was falling rapidly. In other words, a relatively small number of larval *H. vittatus* were transported towards the top of the lower estuary during the winter/early-spring part of the relatively protracted spawning period that this species is believed to have (Potter *et al.* 1983).

The larvae of the majority of the abundant taxa that could not be assigned to particular species were also apparently representatives of marine teleosts. This view is based on the fact that this group contained gobiesocids, labrids, sillaginids and monacanthids, whose species typically do not breed within the Swan Estuary (Loneragan *et al.* 1989). Indeed, neither gobiesocids nor labrids have been recorded during extensive sampling of the Swan Estuary for juvenile and adult fish (Loneragan *et al.* 1989).

A striking feature to emerge from the current study was the fact that *H. vittatus* and *P. sexlineatus* were the only two of the several marine species found in abundance in the Swan Estuary that were represented as larvae in the lower estuary. This implies that the other abundant marine species enter the estuary as juveniles. The large sizes at which *Cnidoglanis macrocephalus* (>70 mm) and *Torquigener pleurogramma* (>40 mm) typically first start to become abundant in the Swan Estuary (Nel *et al.* 1985; Potter *et al.* 1988*b*) support this concept. Furthermore, these latter species become abundant as juveniles in the Swan Estuary some months after spawning occurs. While many *Mugil cephalus* and *Aldrichetta forsteri* in the length range of 18–30 mm have been caught in the estuary (Chubb *et al.* 1981), the larvae of these species were not taken in our plankton tows. The absence of larvae of both of these mullet species in the plankton tows is consistent with the fact that mugilids typically migrate actively into estuaries as juveniles (de Silva 1980; Powles 1981). The capture of only very small numbers of the larvae of marine species such as *Leptatherina presbyteroides*, *Atherinomorus ogilbyi* and *Gerres subfasciatus*, which are abundant as juveniles in the Swan Estuary (Prince *et al.* 1982; Loneragan *et al.* 1989), also implies that these species usually enter the estuary as juveniles.

Seasonal Changes in Ichthyoplankton

The data in this paper show that the total numbers of both fish eggs and larvae follow a highly seasonal trend, with peak numbers occurring in late spring and early summer. In view of this strong seasonal trend in total numbers, it is hardly surprising that the concentrations of the larvae of 7 of the 11 most abundant identified species peaked at this time. The fact that the larvae of these 7 species reached maximum concentrations between November and January and were small (<5 mm), provides strong evidence that peak spawning by these species must occur over a similar period. The occurrence of maximum larval concentrations between November and January, prior to the attainment of maximum mean monthly water temperatures (February), parallels the situation recorded by Beckley (1986) in Algoa Bay in South Africa, Roper (1986) in Whangateau Harbour (an estuary) in New Zealand, and Jenkins (1986) in Port Phillip Bay in Victoria. Although the majority of the larvae of most species was usually caught within 2–3 months, the larvae of some species were present over many months. This implies that although spawning may peak at a particular time, the breeding period of these species is protracted.

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References

Arnott, G. H., and McKinnon, A. D. (1985). Distribution and abundance of eggs of the anchovy, *Engraulis australis antipodum* Gunther, in relation to temperature and salinity in the Gippsland Lakes. *Australian Journal of Marine and Freshwater Research* **36**, 433–9.

Austin, H. M. (1976). Distribution and abundance of ichthyoplankton in the New York Bight during the fall in 1971. *New York Fish and Game Journal* **3**, 58–72.

Beckley, L. E. (1985). Tidal exchange if ichthyoplankton in the Swartkops Estuary mouth, South Africa. *South African Journal of Zoology* **20**, 15–20.

Beckley, L. E. (1986). The ichthyoplankton assemblage of the Algoa Bay nearshore region in relation to coastal zone utilization by juvenile fish. *South African Journal of Zoology* **21**, 244–52.

Blackburn, M. (1950). A biological study of the anchovy, *Engraulis australis* (White), in Australian waters. *Australian Journal of Marine and Freshwater Research* **1**, 3–84.

Boehlert, G. W., and Mundy, B. C. (1988). Roles of behavioral and physical factors in larval and juvenile fish recruitment to estuarine nursery areas. *American Fisheries Society Symposium* **3**, 51–67.

Bourne, D. W., and Govoni, J. J. (1988). Distribution of fish eggs and larvae and patterns of water circulation in Narragansett Bay, 1972–1973. *American Fisheries Society Symposium* **3**, 132–48.

Brownell, D. L. (1979). Stages in the early development of 40 marine fish species with pelagic eggs from the Cape of Good Hope. *Ichthyological Bulletin of the J.L.B. Smith Institute of Ichthyology* **40**, 1–84.

Chalmer, P. N., Hodgkin, E. P., and Kendrick, G. W. (1976). Benthic faunal changes in a seasonal estuary of south-western Australia. *Records of the Western Australian Museum* **4**, 383–410.

Chrystal, P. J., Potter, I. C., Loneragan, N. R., and Holt, C. P. (1985). Age structure, growth rates, movement patterns and feeding in an estuarine population of the cardinalfish *Apogon rueppellii*. *Marine Biology (Berlin)* **854**, 185–97.

Chubb, C. F., and Potter, I. C. (1984). The reproductive biology and estuarine movements of the gizzard shad, *Nematalosa vlaminghi* (Munro). *Journal of Fish Biology* **25**, 527–43.

Chubb, C. F., and Potter, I. C. (1986). Age, growth and condition of the Perth herring, *Nematalosa vlaminghi* (Munro) (Doromatinae), in the Swan Estuary, south-western Australia. *Australian Journal of Marine and Freshwater Research* **37**, 105–12.

Chubb, C. F., Potter, I. C., Grant, C. J., Lenanton, R. C. J., and Wallace, J. (1981). Age structure, growth rates and movements of sea mullet, *Mugil cephalus* L., and yellow-eye mullet, *Aldrichetta forsteri* (Valenciennes), in the Swan–Avon river system, Western Australia. *Australian Journal of Marine and Freshwater Research* **32**, 605–28.

Claridge, P. N., Potter, I. C., and Hardisty, M. W. (1986). Seasonal changes in movements, abundance, size composition and diversity of the fish fauna of the Severn Estuary. *Journal of the Marine Biological Association of the United Kingdom* **66**, 229–58.

Cronin, L. E., and Mansueti, A. J. (1971). The biology of the estuary. In 'A Symposium on the Biological Significance of Estuaries'. (Eds P. A. Douglas and R. H. B. Stroud.) pp. 24–39. (Sport Fishing Institute: Washington, D.C.)

Crossland, J. (1982). Distribution and abundance of fish eggs and larvae from the spring and summer plankton of north-east New Zealand, 1976–78. New Zealand Ministry of Agriculture and Fisheries Research Bulletin No. 24.

Dando, P. R. (1984). Reproduction in estuarine fishes. In 'Fish Reproduction: Strategies and Tactics'. (Eds G. W. Potts and R. J. Wootton.) pp. 155–70. (Academic Press: London.)

de Silva, S. S. (1980). Biology of juvenile grey mullet: a short review. *Aquaculture* **19**, 21–36.

Dybdahl, R. E. (1979). Technical report on fish productivity: an assessment of marine faunal resources of Cockburn Sound. Western Australian Department of Conservation and Environment Report No. 4.

Fahay, M. P. (1983). Guide to the early stages of marine fishes occurring in the western North Atlantic Ocean, Cape Hatteras to the southern Scotian Shelf. *Journal of Northwest Atlantic Fishery Science* **4**, 1–423.

Fortier, L., and Leggett, W. (1982). Fickian transport and the dispersal of fish larvae in estuaries. *Canadian Journal of Fisheries and Aquatic Sciences* **39**, 1150–63.

Haedrich, R. L. (1983). Estuarine fishes. In 'Estuaries and Enclosed Seas'. (Ed. B. H. Ketchum.) pp. 183–207. (Elsevier: Amsterdam.)

Hodgkin, E. P., and di Lollo, V. (1958). The tides of south-western Australia. *Journal of the Proceedings of the Royal Society of Western Australia* **41**, 42–54.

Houde, E. D., and Alpern Lovdal, J. (1984). Seasonality of occurrence, foods and food preferences of ichthyoplankton in Biscayne Bay, Florida. *Estuarine, Coastal and Shelf Science* **18**, 403–19.

Hutchins, B., and Thompson, M. (1983). 'The Marine and Estuarine Fishes of South-western Australia: A Field Guide for Anglers and Divers.' (Western Australian Museum: Perth.)

Jenkins, G. P. (1986). Composition, seasonality and distribution of ichthyoplankton in Port Phillip Bay, Victoria. *Australian Journal of Marine and Freshwater Research* **37**, 507–20.

Leis, J. M., and Rennis, D. S. (1983). 'The Larvae of Indo-pacific Coral Reef Fishes.' (New South Wales University Press/University of Hawaii Press: Sydney/Honolulu.)

Lenanton, R. C. J., and Potter, I. C. (1987). Contribution of estuaries to commercial and recreational fisheries in temperate Western Australia and the concept of estuarine dependence. *Estuaries* **10**, 28–35.

Lenanton, R. C. J., Potter, I. C., Loneragan, N. R., and Chrystal, P. J. (1984). Age structure and changes in abundance of three important species of teleost in a eutrophic estuary (Pisces : Teleostei). *Journal of Zoology (London)* **203**, 311–27.

Loneragan, N. R., Potter, I. C., and Lenanton, R. C. J. (1987). The fish and fishery of the Swan Estuary. In 'Swan River Estuary: Ecology and Management'. (Ed. J. John.) pp. 178–201. (Curtin University: Perth.)

Loneragan, N. R., Potter, I. C., and Lenanton, R. C. J. (1989). The influence of site, season and year on the contributions made by marine, estuarine, diadromous and freshwater species to the fish fauna of a temperate Australian estuary. *Marine Biology (Berlin)* **103**, 461–79.

McHugh, J. L. (1967). Estuarine nekton. In 'Estuaries'. (Ed. G. H. Lauff.) vol. 83, pp. 582–620. (American Association for the Advancement of Science: Washington, D.C.)

Melville-Smith, R., and Baird, D. (1980). Abundance, distribution and species composition of fish larvae in the Swartkops Estuary. *South African Journal of Zoology* **15**, 72–8.

Miller, J. M., Watson, W., and Leis, J. M. (1979). An atlas of common nearshore marine fish larvae of the Hawaiian Islands. University of Hawaii Sea Grant Program Miscellaneous Report.

Miller, P. J. (1984). The tokology of gobioid fishes. In 'Fish Reproduction: Strategies and Tactics'. (Eds G. W. Potts and R. J. Wootton.) pp. 119–54. (Academic Press: London.)

Misitano, D. A. (1977). Species composition and relative abundance of larval and post-larval fishes in the Columbia River estuary, 1973. *Fishery Bulletin (US)* **75**, 218–22.

Miskiewicz, A. G. (1986). The season and length at entry into a temperate Australian estuary of the larvae of *Acanthopagrus australis, Rhabdosargus sarba* and *Chrysophrys auratus* (Teleostei : Sparidae). In 'Indo-pacific Fish Biology: Proceedings of the 2nd International Conference on Indo-pacific Fishes'. (Eds T. Uyeno, R. Arai, T. Taniuchi and K. Matsuura.) pp. 740–7. (Ichthyological Society of Japan: Tokyo.)

Miskiewicz, A. G. (1987). Taxonomy and ecology of fish larvae in Lake Macquarie and New South Wales coastal waters. Ph.D. Thesis, University of New South Wales, Sydney.

Moser, H. G., Richards, W. J., Cohen, D. M., Fahay, M. P., Kendall, A. W., Jr, and Richardson, S. L. (1984). 'Ontogeny and Systematics of Fishes.' (American Society of Ichthyologists: La Jolla, California.)

Nel, S. A., Potter, I. C., and Loneragan, N. R. (1985). The biology of the catfish *Cnidoglanis macrocephalus* (Plotosidae) in an Australian estuary. *Estuarine, Coastal and Shelf Science* **21**, 895–909.

Norcross, B. L., and Shaw, R. F. (1984). Oceanic and estuarine transport of fish eggs and larvae: a review. *Transactions of the American Fisheries Society* **113**, 153–65.

Pearcy, W. G., and Myers, S. S. (1974). Larval fishes of Yaquina Bay, Oregon: a nursery ground for marine fishes? *Fishery Bulletin (US)* **72**, 201–13.

Potter, I. C., Loneragan, N. R., Lenanton, R. C. J., Chrystal, P. J., and Grant, C. J. (1983). Abundance, distribution and age structure of fish populations in a Western Australian estuary. *Journal of Zoology (London)* **200**, 21–50.

Potter, I. C., Gardner, D. C., and Claridge, P. N. (1988*a*). Age composition, growth, movements, meristics and parasites of the whiting, *Merlangius merlangus*, in the Severn Estuary and Bristol Channel. *Journal of the Marine Biological Association of the United Kingdom* **68**, 295–313.

Potter, I. C., Cheal, A. J., and Loneragan, N. R. (1988*b*). Protracted estuarine phase in the life cycle of the marine pufferfish *Torquigener pleurogramma. Marine Biology (Berlin)* **98**, 317–29.

Potter, I. C., Beckley, L. E., Whitfield, A. K., and Lenanton, R. C. J. (1990). Comparisons between the roles played by estuaries in the life cycles of fishes in temperate Western Australia and Southern Africa. *Environmental Biology of Fishes* (in press).

Powles, H. (1981). Distribution and movement of neustonic young of estuarine dependent (*Mugil* spp., *Potatomus saltatrix*) and estuarine independent (*Coryphaena* spp.) fishes off south-eastern United States. *Rapports et Procès-Verbaux des Réunions, Conseil International pour l'Exploration de la Mer* **178**, 207–9.

Prince, J. D., and Potter, I. C. (1983). Life cycle duration, growth and spawning times of five species of Atherinidae (Teleostei) found in a Western Australian estuary. *Australian Journal of Marine and Freshwater Research* **34**, 287–301.

Prince, J. D., Potter, I. C., Lenanton, R. C. J., and Loneragan, N. R. (1982). Segregation and feeding of atherinid species (Teleostei) in south-western Australian estuaries. *Australian Journal of Marine and Freshwater Research* **33**, 865–80.

Ramm, D. C. (1986). An ecological study of the ichthyoplankton and juvenile fish in the Gippsland Lakes, Victoria. Ph.D. Thesis, University of Melbourne.

Riggert, T. L. (1978). 'The Swan River Estuary Development, Management and Preservation.' (Swan River Conservation Board: Perth.)

Robertson, D. A. (1975). A key to the planktonic eggs of some New Zealand marine teleosts. New Zealand Fisheries Research Division Occasional Publication No. 9.

Roper, D. S. (1986). Occurrence and recruitment of fish larvae in a northern New Zealand estuary. *Estuarine, Coastal and Shelf Science* **22**, 705–17.

Spencer, R. S. (1956). Studies in Australian estuarine hydrology. II. The Swan River. *Australian Journal of Marine and Freshwater Research* **7**, 193–253.

Steffe, A. S., and Pease, B. C. (1988). Diurnal survey of ichthyoplankton abundance, distribution and seasonality in Botany Bay, New South Wales. *Proceedings of the Linnean Society of New South Wales* **110**, 1–10.

Wallace, J. H., Kok, H. M., Beckley, L. E., Bennett, B., Blaber, S. J. M., and Whitfield, A. K. (1984). South African estuaries and their importance to fishes. *South African Journal of Science* **80**, 203–7.

Weinstein, M. P., Weiss, S. L., Hodson, R. G., and Gerry, L. R. (1980). Retention of three taxa of postlarval fishes in an intensively flushed tidal estuary, Cape Fear River, North Carolina. *Fishery Bulletin (US)* **78**, 419–36.

Whitfield, A. K. (1989). Ichthyoplankton interchange in the mouth region of a southern African estuary. *Marine Ecology—Progress Series* **54**, 25–33.

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