The fish fauna and finfish fishery of the Leschenault Estuary in south-western Australia

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Abstract

This paper collates unpublished and published data on the fish faunas of the large basin and Collie River regions of the Leschenault Estuary in 1982/83 and 1993/94, and provides information on the commercial and recreational fisheries in that estuary. The most abundant of the 42 fish species recorded in eight six-weekly samples collected from the nearshore, shallow waters of the basin in 1994, were the long-finned goby *Favonigobius lateralis*, the sandy sprat *Hyperlophus vittatus* and the atherinids *Leptatherina presbyteroides* and *Atherinosoma elongata*; these four species collectively contributing 83.0% to the total number of fish caught. Of the 42 species, 20 were marine species which use the estuary as a nursery area (marine estuarine-opportunists), while 13 complete their life cycles in the estuary, of which seven are also represented by marine populations. The contribution made to the total number of individuals by marine estuarine-opportunists and marine stragglers collectively (32.1%) was far lower than that of species which complete their life cycles in the estuary (67.9%). The presence in shallow waters of large numbers of representatives of species that spawn in the estuary, which parallels the situation found in other south-western Australian estuaries, is probably related to the maintenance of stable conditions and high salinities during late spring and summer when these species, which generally have marine affinities, typically spawn. The composition of the fish fauna of the shallows of Leschenault Estuary differs markedly from that of comparable waters in Koombana Bay into which this estuary discharges. Indeed, the most abundant species in the bay, the flathead sandfish *Lesueurina platycephala*, which contributed *ca* 25% to the total numbers in those marine waters, was never recorded in the estuary. The fish catches in offshore, deeper waters of the estuary basin and Collie River comprised larger species and, unlike the situation in shallow waters, were dominated by marine estuarine-opportunists and the semi-anadromous Perth herring *Nematalosa vlaminghi*. However, the composition of the fish fauna in offshore, deeper waters of the basin differed markedly from that in corresponding waters in the Collie River. This was mainly due to the presence in the basin of far more species and relatively greater numbers of species, such as yellow-eye mullet (*Aldrichetta forsteri*), tailor (*Pomatomus saltatrix*) and Australian herring (*Arripis georgiana*), and to the occurrence in the river of relatively greater numbers of Perth herring and sea mullet (*Mugil cephalus*). Length-frequency data provide strong evidence that, within the estuary, the small species *F. lateralis, L. presbyteroides* and *A. elongata* spawn mainly in summer and typically have a one year life cycle. The small juveniles of the marine species *A. forsteri* and *M. cephalus* are recruited into the estuary between mid- or late autumn and early spring, which is consistent with the fact that the spawning period of these two species is very protracted, extending through autumn and winter. Both of these mugilids were represented in some months by three or more age classes. Recruitment into the estuary of King George whiting (*Sillaginodes punctata*) occurs in spring, while that of yellow-finned whiting (*Sillago schomburgkii*) and prickly toadfish (*Contusus brevicaudus*) takes place in summer and autumn, respectively. This reflects spawning occurring in winter and early spring in the case of the first species and in summer with the second and third species. These three species were apparently represented mainly by only two age classes. While length-frequency data show that *P. saltatrix* also uses the estuary as a nursery area, the modal size classes did not follow such consistent trends throughout the year, possibly reflecting a recruitment, in some years, of the 0+ age class of both the spring and autumn-spawning cohorts. The growth of all of these species essentially ceased during the cold winter months. The feeding mode of each of the most abundant species can be allocated to one of the following categories. (1) herbivores which feed mainly on the algae associated with seagrass, *e.g. Hyporhamphus melanochir, Pelates sexlineatus.* (2) detritivores, *e.g. M. cephalus, N. vlaminghi*. (3) omnivores which feed on algae and a range of invertebrates, *e.g. A. forsteri, Amniataba caudavittata.* (4) lower-order carnivores which feed on small benthic invertebrates, *e.g. A. elongata, F. lateralis, L. presbyteroides, S. punctata, S. schomburgkii, Torquigener pleurogramma*. (5) higher-order carnivores whose prey includes larger and more active invertebrates and fish, *e.g. Argyrosomus japonicus, P. saltatrix*. The former commercial fishers in Leschenault Estuary, who were restricted to fishing in the basin, shifted from gill nets to haul nets in recent years to reduce the amount of bycatch. *Aldrichetta forsteri, M. cephalus, S. schomburgkii* and *S. punctatia* were the main commercial fish species, contributing 55.5, 20.2, 11.1 and 6.6%, respectively, to the total wet weight of all fish species caught between 1981 and 1997. The recreational fishery is dominated by three species of whiting (*S. punctata, S. schomburgkii* and *Sillago burrus)* and tailor *P. saltatrix*.

Keywords: Leschenault Estuary, shallow and deep waters, fish species, size compositions, use of the estuary, recruitment, diets, commercial and recreational fisheries.

Introduction

The estuaries of temperate south-western Australia typically contain a large central basin region, which is fed by tributary rivers, the downstream regions of which are saline. The basin region opens to the sea via a narrow and usually short entrance channel (Hodgkin & Lenanton 1981). Some of these estuaries, *e.g.* the Swan River, Peel Harvey, Leschenault and Nornalup Walpole estuaries, remain permanently open, whereas others such as the Wellstead Estuary and Wilson Inlet become closed, either seasonally or for longer periods through the formation of sand bars at their mouths (Lenanton & Hodgkin 1985). However, the Peel Harvey Estuary used to become closed in some years in the past, but is now kept permanently open through dredging (Bradby 1997). Another category of estuary is provided by that of the Moore River, which does not contain a large central basin and opens intermittently during the year when, as a result of input from artesian springs and/or increased rainfall, the volume of water becomes sufficiently great to breach the bar at its mouth (Young *et al.* 1997). In the case of these south-western Australian estuaries, the narrowness and shallowness of their entrance channels and the large areas occupied by their basins (Lenanton & Hodgkin 1985; Potter *et al.* 1990), together with the presence of a small tidal range in the region (Hodgkin & di Lollo 1958), mean that tidal water movement within their middle and upper reaches is far less pronounced than it is, for example, in the numerous macrotidal estuaries found in temperate regions of the northern hemisphere (*cf* Spencer 1956; Kennish 1986; Stephens & Imberger 1996).

During the last 20-25 years, detailed studies have been carried out on the ichthyofaunas of several estuaries in south-western Australia (see review by Potter & Hyndes 1999). These studies, which employed various techniques to sample different water depths within these estuaries throughout the year, have elucidated the ways in which the compositions of the fish faunas and numbers of the main fish species in the different regions of these estuaries change seasonally and in relation to environmental conditions (*e.g.* Chubb *et al.* 1981; Loneragan *et al.* 1986, 1989; Potter *et al.* 1983, 1988, 1993; Potter & Hyndes 1994; Valesini *et al.* 1997; Young *et al.* 1997). The studies on ichthyofaunal compositions in the different estuaries have been accompanied by studies of the biology of the more numerous fish species in these estuaries, which have helped clarify the ways in which each of those species use estuaries (*e.g.* Chubb *et al.* 1981; Prince & Potter 1983; Chrystal *et al.* 1985; Potter *et al.* 1988; Hyndes *et al.* 1992; Laurenson *et al.* 1993a). The results of each of the various studies have been considered collectively to ascertain the main features of the ichthyofaunas of estuaries in south-western Australia in general and the way in which the particular characteristics of the ichthyofaunas vary according to both the type and location of the estuary, *e.g.* open *vs* closed and lower west coast *vs* south coast respectively (Potter & Hyndes 1999).

A number of marine fish species, such as the sea mullet *Mugil cephalus* and the yellow-eye mullet *Aldrichetta forsteri*, use the permanently-open estuaries on the lower west coast of Australia as nursery areas (*e.g.* Chubb *et al.* 1981; Lenanton *et al.* 1984), thereby paralleling the situation with several marine fish species in estuaries in temperate regions of the northern hemisphere (*e.g.* Haedrich 1983; Claridge *et al.* 1986; Elliott & Dewailly 1996). However, the prevalence of the 0+ age class of these and other marine species tends to be far lower in estuaries on the south coast of Western Australia, a feature that apparently reflects in part a greater distance of these estuaries from the main spawning grounds of those species (Potter & Hyndes 1994). Although those marine fish species, which use estuaries regularly and typically as nursery areas, are sometimes referred to as estuarine-dependent in other regions (Blaber *et al.* 1989; Elliott *et al.* 1990; Kennish 1990; Whitfield 1998), such species in south-western Australia almost invariably also employ as nursery areas those sheltered marine waters that are found, for example, in coastal embayments (Lenanton & Potter 1987). We thus regard the term marine estuarine-opportunist as more applicable for these species in south-western Australia. While the larvae of a few marine estuarine-opportunist species are transported into the lower regions of estuaries in south-western Australia, the larvae of such species are absent or occur in relatively low numbers in the main body (basins) of these estuaries (Neira *et al.* 1992; Neira & Potter 1992a,b, 1994). This contrasts with the situation found in macrotidal estuaries in the temperate regions of the northern hemisphere, where the larvae of certain comparable species capitalise on the strong tidal water movements to enter and then move through those estuaries by using tidal and/or passive transport (Fortier & Leggett 1982; Norcross & Shaw 1984; Boehlert & Mundy 1988). The movement of marine estuarine-opportunists into and through the estuaries of south-western Australia typically occurs at the juvenile stage and is presumably achieved largely through swimming in an upstream direction. The use of the term marine estuarine-opportunist for the above group of species enables such species to be distinguished from the marine stragglers, which occur irregularly and usually in low numbers in estuaries and generally in the regions of high salinity near the estuary mouth.

Although only a few fish species are adapted to completing their life cycles in estuaries, some of these species, such as certain hardyheads (atherinids) and gobies, are particularly abundant in south-western Australian estuaries, which presumably reflects the influence of one or more of the following features. First, the small input of freshwater discharge from tributary rivers in late spring and summer, when rainfall is minimal, combined with a small tidal action, leads at that time to salinities remaining high and stable in these estuaries and to water movement being largely brought about by wind action and changes in barometric pressure. Such stable conditions thus approximate to those in sheltered nearshore, marine waters outside the estuary, which act as the habitat for several small marine fish species (Ayvazian & Hyndes 1995) and are thus ideal for spawning by species with a marine origin. It is also important to recognise that, during the periodic landlocking to which many estuaries in south-western Australia have been subjected, there would have been strong selection pressures, particularly amongst short-lived species, to favour those individuals of any species that could spawn within the estuary. This would help account for the fact that some of the fish species that complete their life cycle in estuaries, such as the cobbler *Cnidoglanis macrocephalus* and the gobbleguts *Apogon rueppellii*, are also represented by genetically-discrete populations in coastal waters (Watts 1991; Ayvazian *et al.* 1994).

The only truly diadromous species in south-western Australia, which therefore requires an estuary to act as a migratory route between the marine and freshwater environments in which it spends different periods of its life cycle, is the pouched lamprey *Geotria australis*. This anadromous species spawns in freshwater and feeds parasitically on fish at sea (Potter *et al.* 1986). However, for convenience, the Perth herring *Nematalosa vlaminghi*, which spends a period feeding at sea but later migrates into its spawning grounds in the upper and reduced salinity areas of estuaries (Chubb & Potter 1984), is referred to as semi-anadromous. The few freshwater fish species that are found in estuaries are usually confined to the upper and brackish reaches of those estuaries (Loneragan *et al.* 1989).

This study has collated published and unpublished data on the fish fauna of the basin and saline, riverine reaches of the Leschenault Estuary and also of Koombana Bay into which that estuary discharges (Anon 1983; Potter *et al.* 1997; Tiivel *et al.*, Murdoch University, unpublished data). These data are then used to demonstrate the ways in which the compositions of the fish faunas in the shallow waters of an estuary can differ markedly from those in shallow, sheltered coastal waters just outside that estuary. The composition of the fish faunas in offshore, deeper waters of both the basin and riverine regions of the estuary, which are likely to contain larger fish than the shallows, have also been determined and compared to ascertain whether certain species are relatively more abundant in one or the other of these two very different environments. Length-frequency data for several of the most abundant species have been analysed in order to determine the times of recruitment, size compositions, probable age compositions and patterns of growth of those species. Data are also provided on the diets of several of the most abundant species. The ichthyofaunal composition and biology of the main fish species in Leschenault Estuary have been compared with those of other south-western Australian estuaries to help place in perspective the role played by that estuary in the life cycle of the main fish species found in that system. The policy of Fisheries Western Australia to buy out the licenses of commercial fishers, through a fisheries adjustment scheme, has now produced a situation whereby all fishers formerly licensed to operate in the Leschenault Estuary no longer have commercial access to this estuary. Nevertheless, catch data for this fishery have been analysed to elucidate the main species that formed the basis of this fishery and how the catches of these species have varied over the years. Preliminary data are also provided on the species composition of the recreational fishery.

Materials and Methods

Sampling regime in 1993/94

Sites in shallow waters of the basin of the Leschenault Estuary and Koombana Bay (Fig 1) were sampled during the day and night at six-weekly intervals between November 1993 and December 1994, using a 21.5 m long and 1.5 m high seine net (Table 1, see also Potter *et al.* 1997). This net contained two 10 m long wings, each with 6 m of 9 mm mesh and 4 m of 3 mm mesh, the latter leading into a 1.5 m wide bunt which likewise consisted of 3 mm mesh. The net swept an approximately circular area of 116 m^2 from the shoreline. Sampling was also carried out twice in the spring of 1993 and once in each of the ensuing summer, autumn and winter months using a 41.5 m long and 1.5 m high seine net during the day. This second seine net, which consisted of two 20 m long wings of 25 mm mesh and a 1.5 m bunt of 9 mm mesh, swept an area of 274 m^2. Although the lower and middle regions of the basin of Leschenault Estuary could be sampled by the 21.5 m seine net on each sampling occasion, this was not always possible in the upper estuary because the waters in that region sometimes declined to less than the 1.5 m height of this net. Emphasis has thus been placed on the results obtained for shallow waters in the lower and middle regions of the basin. Values for the salinities and water temperatures in the shallows of the basin of Leschenault Estuary and along the shoreline of Koombana Bay are given in Potter *et al.* (1997).

The fish faunas in deeper and more offshore waters at

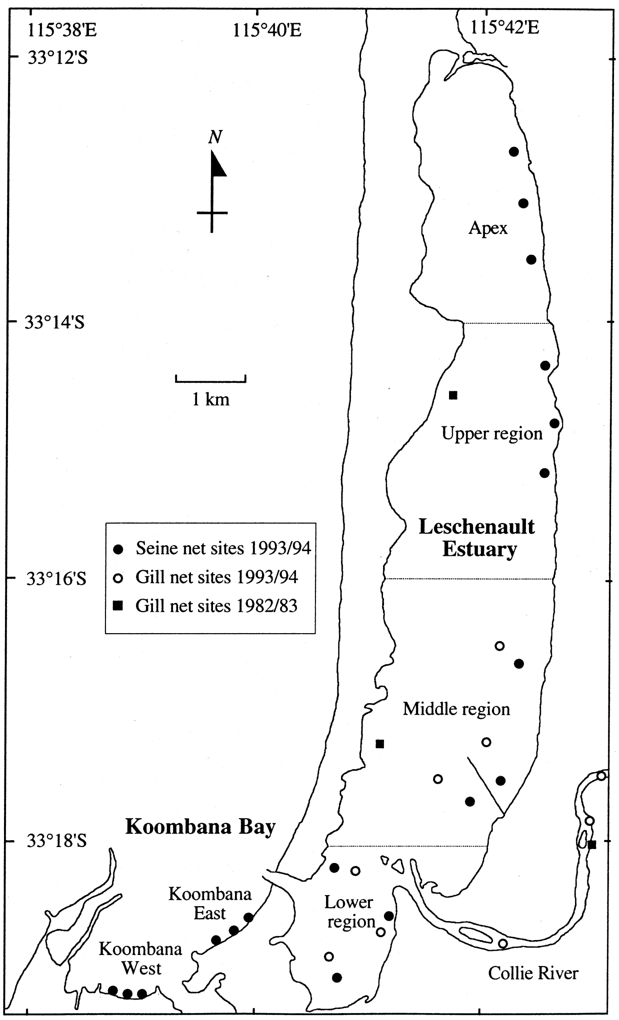

Figure 1. Map of Leschenault Estuary and Koombana Bay, showing the location of the sites sampled using the 21.5 and 41.5 m seine nets and the 120 m long sunken composite gill nets in 1993/94, and employing the 220 m long sunken and floating composite gill nets in 1982/83.

Table 1. Summary of sampling regimes used in the basin and Collie River regions of the Leschenault Estuary in 1993/94 and 1982/83. Numbers in parentheses provide data on the sampling regime in the river on those occasions when it differed from that in the basin. N.B. The rivers were not sampled by seine net in 1993/94. The six shallow water sites in Koombana Bay were sampled using the 21.5 m seine net on the same occasions as the shallow water sites were sampled with the same net in the basin of Leschenault Estuary.

	1993/1994			1982/1983	
	Seine net	Seine net	Gill net (sunken)	Seine net	Gill net (sunken and floating)
Net length	21.5 m	41.5 m	120 m (6 x 20 m panels)	103 m	2 x 220 m (11 x 20 m panels)
Mesh size	3 mm in bunt	9 mm in bunt	38-102 mm	9 mm in bunt	38-100 mm
Area swept (m^2)	116	274		1600	
Number of sites	6	6	6 (3)	10 (5)	2 (1)
Months sampled	Nov 93; Feb, Mar, May, Jun, Jul, Sep, Nov and Dec 94	Sep and Nov 93; Feb, May and Jul 94	Sep and Nov 93; Feb, May and Jul 94	May, Aug and Nov 82; Feb 83	May, Aug and Nov 82; Feb 83

six sites in the basin and at three sites in the saline region of the Collie River of the Leschenault Estuary were sampled using sunken, composite gill nets in each season between the spring of 1993 and winter of 1994, including twice in the first of those seasons (Table 1, Fig 1). The gill nets, which were 120 m long and comprised six 20 m long panels with sequential stretched mesh sizes of 38, 51, 63, 76, 89 and 102 mm, were set immediately prior to dusk and retrieved three hours later.

Sampling regime in 1982/83

The fish faunas of the basin and Collie River regions of the Leschenault Estuary were sampled in May, August and November of 1982 and in February of 1983 using seine and gill nets (Table 1). The seine net, which was 103 m long and 1.5 m high, consisted of two 50 m long wings of 25 mm mesh and a 3 m bunt of 9 mm mesh. Since the lower reaches of the Collie River contain steep banks and could thus not be sampled effectively using seine nets, the use of such nets had to be restricted to regions of this river that were > 4 km above the point that the river discharged into the basin. The net was pulled in a semicircle from the bank, covering in this case an area of 1 600 m^2. The data derived from seine netting at several sites in four seasons in 1982/83 have been used solely for the construction of length-frequency histograms. The composite gill net was 220 m long and consisted of eleven 20 m long panels, with each panel containing a different mesh size, *i.e.* 38, 44, 50, 56, 63, 69, 75, 81, 88, 94 and 100 mm. Two such gill nets were set at dusk for three hours at each site, one being weighted so that it sunk and rested on the estuary floor, while the other was buoyed so that it was suspended from the water surface. In each season, gill netting was undertaken at two sites in the basin and at one site in the river (Table 1, Fig 1).

The methods and dates of sampling in 1993/94 and 1982/83 are summarised in Table 1. The number of each fish species and the total length (to the nearest 1 mm) of each fish caught by the seine and gill nets on each occasion in the two periods were recorded, except when the sample of a species was large, in which case lengths of a random subsample of at least 100 representatives of each species were recorded. The number of each species caught by the 21.5 m seine net has been expressed as a density, *i.e.* number of fish per 100 m^2.

Length-frequency data

Since modes in the length-frequency data, recorded for each of the main larger fish species caught by seine and gill nets in 1993/94 and 1982/83, followed similar monthly trends, the length data collected for those species using both methods in the corresponding months in the two periods have been pooled. However, it should be recognised that, in those months when gill nets were not used, the cohorts of the large representatives of some fish species were not well represented.

Life cycle categories

On the basis of extensive studies of the biology of fish species in south-western Australian estuaries, each fish species collected in Leschenault Estuary and Koombana Bay has been allocated to one of the following life cycle categories, as defined in the introduction, namely marine straggler (S), marine estuarine-opportunist (O), semi-anadromous (SA), those that are found only in estuaries (E) and finally those that can complete the whole of their life cycle in either estuarine or marine environments (E&M). Although the hairy pipefish *Urocampus carinirostris* is abundant in sheltered marine habitats in eastern Australia (Howard & Koehn 1985; Steffe *et al.* 1989), it has never been found in this type of environment in south-western Australia. Thus, in south-western Australia, where this species does occur in estuaries, it is now regarded as estuarine rather than as both estuarine and marine as in Potter *et al.* (1997). While the sea garfish *Hyporhamphus melanochir* spawns in estuaries on the south coast of Western Australia (Neira & Potter 1992a, 1994), it almost certainly spawns only in marine environments on the lower west coast of this state, this difference between regions thus paralleling that of the blue-spotted flathead *Platycephalus speculator* (Hyndes *et al.* 1992). Those marine species that were caught in Koombana Bay, and yet have never been recorded in estuaries in south-western Australia, are referred to as solely marine (SM). Although the southern shovelnose ray *Aptychotrema vincentiana* was recorded in the shallows of Koombana Bay, but not in those of Leschenault Estuary (Potter *et al.* 1997), it has now been recorded in offshore, deeper waters of the basin of this estuary and is thus now considered to be a marine straggler rather than a solely marine species. The percentage contributions of each of the above different life cycle categories, both in terms of number of species and number of individuals, were determined for the shallows of both the lower and middle regions of the basin of Leschenault Estuary and of the western and eastern regions of Koombana Bay, using data derived from samples collected by the 21.5 m seine net at approximately six-weekly intervals in 1994.

Comparison of ichthyofaunal compositions

The mean densities of each fish species in the shallows of the lower and middle basins of Leschenault Estuary and in the western and eastern regions of Koombana Bay during the day and night, which were based on data derived from the catches obtained with the 21.5 m seine net in 1994, were standardised and root transformed and then subjected to classification and ordination using the PRIMER package (Clarke & Warwick 1994). Analyses of similarities (ANOSIM, Clarke 1993) was used to test whether the compositions of the fish faunas differed significantly among the above four regions and between day and night. The catch of each species per 3 hours by gill net in the basin and Collie River regions of Leschenault Estuary were likewise standardised and root transformed and subjected to analysis by classification and ordination. ANOSIM was employed to test whether the ichthyofaunal compositions in the two regions were significantly different.

Commercial and recreational fisheries

Data on the commercial fishery, *i*.e. the total number of boats fishing, the fishing effort (number of days spent fishing using gill and haul nets), and the wet weight of the total catch and of each of the main commercial finfish species in Leschenault Estuary in each year between 1981 and 1997, were extracted from the Fisheries Western Australia Catch and Effort Statistics (CAES). Data on the recreational fishery (Fisheries Western Australia) represent preliminary results of a creel census carried out in Leschenault Estuary during 1998.

Results and Discussion

Ichthyofauna of nearshore, shallow waters

Seine netting carried out at three sites in shallow waters of both the lower and middle regions of the basin of Leschenault Estuary, and at three sites in both the western and eastern regions of Koombana Bay, on eight occasions at six-weekly intervals throughout 1994, yielded 21 192 and 1 770 fish, respectively. After the number of fish caught in each sample had been adjusted to a constant area of 100 m^2 and been summed, the total number of fish recorded for the estuary and bay were 18 269 and 1 527, respectively (Table 2). The number of fish caught in shallow waters was thus approximately twelve times greater in the estuary than in the bay. Analysis of variance demonstrated that the mean overall densities of fish were significantly greater ($P < 0.001$) in the estuary basin than in the bay (Potter *et al.* 1997). Forty two and 34 species were recorded in the estuary and bay, respectively (Table 2). The number of species in shallow waters was significantly greater in both the lower and middle region of the basin than in the eastern region of Koombana Bay, but not in its western region which is more protected (Potter *et al.* 1997).

The most abundant species in the shallow waters of Leschenault Estuary, *i.e.* those contributing > 10% to the total numbers of fish, were the gobiid *Favonigobius lateralis*, the clupeid *Hyperlophus vittatus* and the atherinids *Leptatherina presbyteroides* and *Atherinosoma elongata* (Table 2). The mugilids *Aldrichetta forsteri* and *Mugil cephalus*, the apogonid *Apogon rueppellii*, the sillaginid *Sillaginodes punctata*, the gobiids *Pseudogobius olorum* and *Afurcagobius suppositus* and the atherinid *Leptatherina wallacei* each contributed between 0.8 and 2.8%. The Gobiidae, Atherinidae and Clupeidae were the most abundant families, contributing 37.2, 28.3 and 22.5% to the total numbers of fish, respectively, and thus collectively 88% (Table 3). The Mugilidae, Sillaginidae and Apogonidae were the next most abundant families, contributing 3.6, 2.6 and 2.2%, respectively.

Favonigobius lateralis and *Aldrichetta forsteri* were the only two of the ten most abundant species in the estuary which also ranked amongst the 13 most abundant species in Koombana Bay (Table 2). *Favonigobius lateralis* ranked fifth in the bay and *A. forsteri* second. The most abundant species in shallow waters of the bay was the leptoscopid *Lesueurina platycephala*, which was never caught in the estuary. The third and fourth most abundant species in the bay were the sillaginid *Sillago bassensis*, which was only very occasionally caught in the estuary, and the tetraodontid *Contusus brevicaudus*, which was moderately abundant in the estuary (Table 2).

In terms of number of individuals, the most abundant family in shallow waters of Koombana Bay was the Leptoscopidae, which was represented by a single species and contributed *ca* 25% to the total numbers. The next three most numerous families in the bay by far were the Sillaginidae (18.1%), Mugilidae (16.7%) and Tetraodontidae (15.3%), each of which ranked amongst the seven most abundant families in Leschenault Estuary (Table 3).

Twenty of the 42 fish species caught in the basin of Leschenault Estuary use that estuary regularly and in appreciable numbers as a nursery area (Table 4). The most abundant of these marine estuarine-opportunist species were the sandy sprat *Hyperlophus vittatus*, the mullets *Aldrichetta forsteri* and *Mugil cephalus* and the King George whiting *Sillaginodes punctata* (Table 2). However, approximately 97% of the *H. vittatus* were caught in November 1994 and were represented in that month exclusively by young 0+ fish. Surprisingly, only nine species of marine straggler were recorded in the estuary basin (Table 4), which is far fewer than the numbers of this category found in other estuaries on the lower west coast (see Potter & Hyndes 1999). Thirteen of the fish species caught in the basin complete their life cycle within the estuary and, of these, seven are also represented by marine populations (Table 4).

Table 2. Life cycle categories (SM = solely marine, S = marine straggler, O = marine estuarine-opportunist, E&M = estuarine and marine, E = estuarine), length range, number (N), percentage contribution (%) and ranking by abundance (R) of each species of elasmobranch and teleost caught in the shallows of the lower and middle regions of the Leschenault Estuary and western and eastern regions of Koombana Bay using the 21.5 m seine net between February and December 1994. In this and Tables 3 and 4, the number of each fish species represents the total for all samples, after the number in each sample had been adjusted to a constant density, *i.e.* number of fish per 100 m^2.

Species	Life cycle category	Length range (mm)	Estuary			Bay		
			N	%	R	N	%	R
Favonigobius lateralis	E&M	8-76	6196	33.9	1	124	8.1	5
Hyperlophus vittatus	O	21-57	4109	22.5	2	12	0.8	12
Leptatherina presbyteroides	E&M	11-67	3025	16.6	3	4	0.3	21
Atherinosoma elongata	E	12-87	1840	10.1	4			
Aldrichetta forsteri	O	23-295	509	2.8	5	254	16.7	2
Apogon rueppellii	E&M	15-73	385	2.1	6			
Sillaginodes punctata	O	23-236	374	2.0	7			
Pseudogobius olorum	E	18-60	367	2.0	8			
Leptatherina wallacei	E	21-64	297	1.6	9			
Afurcagobius suppositus	E	15-69	215	1.2	10			
Mugil cephalus	O	23-149	144	0.8	11	2	0.1	26
Gymnapistes marmoratus	O	15-93	107	0.6	12	7	0.5	15
Torquigener pleurogramma	O	81-154	93	0.5	13	6	0.4	16
Contusus brevicaudus	O	22-130	85	0.5	14	228	14.9	4
Sillago burrus	O	18-99	83	0.5	15	11	0.7	14
Haletta semifasciata	S	20-155	75	0.4	16			
Stigmatophora argus	S	51-137	68	0.4	17			
Pelates sexlineatus	O	13-201	67	0.4	18	15	1.0	11
Arripis georgiana	O	41-209	26	0.1	19	48	3.1	7
Urocampus carinirostris	E	39-91	22	0.1	20			
Amoya bifrenatus	E&M	22-129	20	0.1	21			
Siphamia cephalotes	E&M	20-51	18	0.1	22			
Hyporhamphus melanochir	O	66-231	17	0.1	23	6	0.4	16
Scobinichthys granulatus	S	32-73	16	0.1	24	1	<0.1	31
Rhabdosargus sarba	O	16-220	15	0.1	25	2	0.1	26
Atherinomorus ogilbyi	O	46-152	14	0.1	26	51	3.3	6
Gerres subfasciatus	O	12-155	12	0.1	27	2	0.1	26
Enoplosus armatus	S	23-41	10	0.1	28			
Sillago schomburgkii	O	82-256	9	<0.1	29	31	2.0	8
Gonorynchus greyi	O	82-167	8	<0.1	30	2	0.1	26
Sillago bassensis	S	28-183	7	<0.1	31	235	15.4	3
Engraulis australis	E&M	60-76	6	<0.1	32	3	0.2	22
Callogobius mucosus	O	57-96	5	<0.1	33			
Pseudorhombus jenynsii	O	55-263	5	<0.1	33	1	<0.1	31
Ammotretis elongatus	S	23-163	4	<0.1	35	31	2.0	8
Spratelloides robustus	S	24-53	4	<0.1	35	3	0.2	22
Cnidoglanis macrocephalus	E&M	37-445	3	<0.1	37	6	0.4	16
Pomatomus saltatrix	O	32-291	3	<0.1	37	6	0.4	16
Amniataba caudavittata	E	41-163	3	<0.1	37			
Platycephalus speculator	O	79-299	1	<0.1	40	6	0.4	16
Pseudolabrus parilus	S	22	1	<0.1	40			
Cristiceps australis	S	129	1	<0.1	40			
Trygonorhina fasciata	SM	227				1	<0.1	31
Aptychotrema vincentiana	SM	400				1	<0.1	31
Pelsartia humeralis	SM	78-161				29	1.9	10
Arripis truttaceus	O	36-210				3	0.2	22
Lesueurina platycephala	SM	19-101				379	24.8	1
Cynoglossus maculipinnis	SM	82-157				3	0.2	22
Paraplagusia unicolor	SM	32-125				12	0.8	12
Scorpis aequipinnis	S	35-54				2	0.1	26
Total number of species				42			34	
Total number of fish				18269			1527	

Table 3. Number (N), percentage contribution (%) and ranking by abundance (R) of each family of elasmobranch and teleost caught in the shallows of Leschenault Estuary and Koombana Bay using the 21.5 m seine net between February and December 1994.

Families	Leschenault Estuary			Koombana Bay		
	N	%	R	N	%	R
Gobiidae	6803	37.2	1	124	8.1	6
Atherinidae	5176	28.3	2	55	3.6	7
Clupeidae	4113	22.5	3	15	1.0	11
Mugilidae	653	3.6	4	256	16.7	3
Sillaginidae	473	2.6	5	277	18.1	2
Apogonidae	403	2.2	6			
Tetraodontidae	178	1.0	7	234	15.3	4
Scorpaenidae	107	0.6	8	7	0.5	13
Syngnathidae	90	0.5	9			
Odacidae	75	0.4	10			
Terapontidae	70	0.4	11	44	2.9	9
Arripidae	26	0.1	12	51	3.3	8
Hemiramphidae	17	0.1	13	6	0.4	14
Monacanthidae	16	0.1	14	1	0.1	24
Sparidae	15	0.1	15	2	0.1	19
Gerreidae	12	0.1	16	2	0.1	19
Enoplosidae	10	0.1	17			
Gonorynchidae	8	<0.1	18	2	0.1	19
Engraulididae	6	<0.1	19	3	0.2	18
Bothidae	5	<0.1	20	1	0.1	24
Pleuronectidae	4	<0.1	21	31	2.0	10
Plotosidae	3	<0.1	22	6	0.4	14
Pomatomidae	3	<0.1	22	6	0.4	14
Platycephalidae	1	<0.1	24	6	0.4	14
Clinidae	1	<0.1	24	152	10.0	5
Labridae	1	<0.1	24			
Leptoscopidae				379	24.8	1
Cynoglossidae				15	1.0	11
Rhinobatidae				2	0.1	19
Scorpididae				2	0.1	19
Total number of families		**26**			**25**	
Total number of fish		**18269**			**1527**	

Table 4. Number (N) and percentage contribution (%) of species and individuals to each life cycle category collected in the nearshore, shallow waters of Leschenault Estuary and Koombana Bay using the 21.5 m seine net between February and December 1994.

Life cycle category	Estuary		Bay	
	N	%	N	%
Species				
Solely marine	0	0	6	17.6
Marine straggler	9	21.4	5	14.7
Marine estuarine -opportunist	20	47.6	19	55.9
Estuarine & marine	7	16.7	4	11.8
Estuarine	6	14.3	0	0
Total	**42**		**34**	
Individuals				
Solely marine	0	0	425	27.8
Marine straggler	187	1.0	272	17.8
Marine estuarine -opportunist	5684	31.1	693	45.4
Estuarine & marine	9653	52.8	137	9.0
Estuarine	2745	15.0	0	0
Total	**18269**		**1527**	

The number of individuals belonging to species which complete their life cycles within the estuary represented *ca* 68% of the total number of fish caught in the estuary (Table 4). Within this category, the numbers of those species, which are also represented by marine populations, contributed *ca* 53% to the total number of fish, while those that are found exclusively in estuaries contributed 15% (Table 4). The total percentage contribution made by species that complete their life cycles in the estuary is far greater than in the large Swan River and Peel Harvey estuaries to the north, but far less than those in Wilson Inlet and the Nornalup-Walpole Estuary on the south coast (Potter & Hyndes 1999).

The fish caught in nearshore, shallow waters of Koombana Bay contained six species that were never recorded in the estuary and five that only occasionally strayed into the estuary (Table 4). These 11 species collectively accounted for over 45% of the total number of fish caught in the bay. Eighteen of the 20 species of marine estuarine-opportunists found in Leschenault Estuary were also collected in Koombana Bay (Tables 2, 4). The individuals in this life cycle category contributed *ca* 45% to the total number of fish caught in the bay, emphasising that protected marine embayments, such as Koombana Bay, act as alternate nursery habitats to those provided by estuaries. The numbers of individuals of the remaining four species in Koombana Bay, which are represented by both estuarine and marine populations, contributed less than 10% to the total number of fish caught in that embayment (Table 4).

Classification of the mean densities of each species in nearshore, shallow waters during the day and night in 1994, based on data derived from samples collected using the 21.5 m seine net, separated all of the samples from the Leschenault Estuary from all of those from Koombana Bay (Fig 2). There was no tendency for the samples collected during the day and night in either the estuary or the bay to form separate clusters and neither was there any tendency for the samples in the two regions of the estuary to cluster separately. However, the majority of the samples from the western end of Koombana Bay did form a cluster that was discrete from all but two of the samples from the eastern and more exposed region of that bay (Fig 2).

MDS ordination of the same density data separated the samples from Leschenault Estuary from those in Koombana Bay (Fig 3 A). Furthermore, and likewise paralleling the results of classification, the samples from the two estuarine regions were interspersed on the ordination plot (Fig 3 B), whereas those from the two regions in Koombana Bay were relatively discrete (Fig 3 C) and shown by ANOSIM to be significantly different. *Lesueurina platycephala* was far more abundant in the eastern than western regions of the bay, whereas the reverse was true for *Sillago bassensis* and *Aldrichetta forsteri*. As with classification, no differences were found between the compositions of the samples collected during the day and night in either the estuary or the bay.

The pronounced difference between the compositions of the ichthyofaunas of nearshore, shallow waters of Leschenault Estuary and Koombana Bay parallel those recorded between comparable waters in the Blackwood River Estuary and Flinders Bay outside that estuary (Valesini *et al.* 1997). Although part of the reason for the difference between these two regions is the fact that some species are restricted to the estuary, it is also important to recognise

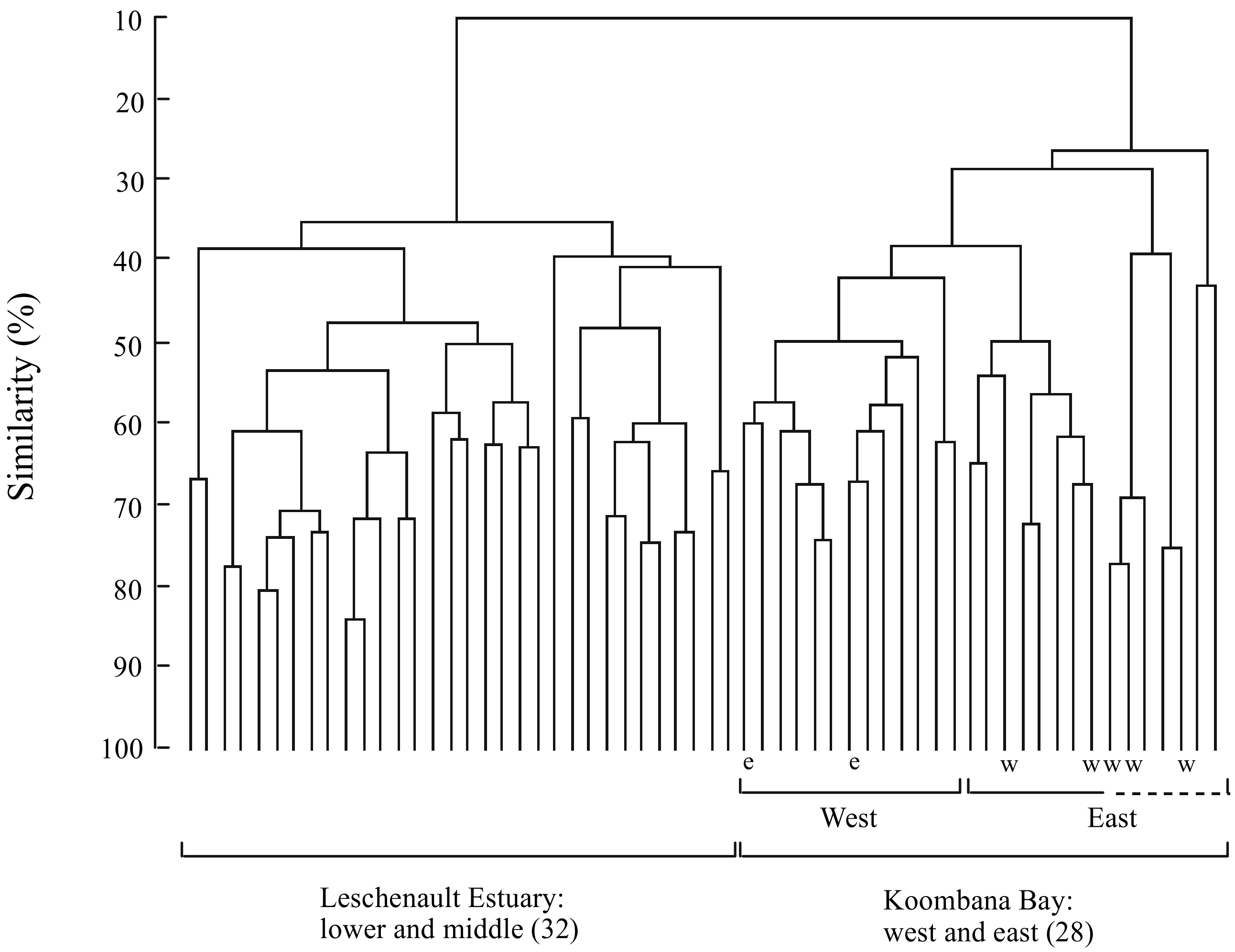

Figure 2. Classification of the mean densities of each fish species during the day and night in nearshore, shallow waters at three sites in both the lower and middle regions of the basin of Leschenault Estuary and at three sites in both the western and eastern regions of Koombana Bay. Here and in Fig 3, the data on densities were derived from samples collected with the 21.5 m seine net at approximately six-weekly intervals between February and December 1994. Numbers in parentheses represent number of samples. The samples from the western and eastern regions of Koombana Bay that fell within the clusters of predominantly the eastern and western regions, respectively, are designated as w and e, respectively. Modified from Potter *et al.* (1997).

that the juveniles of some species, such as *Mugil cephalus*, apparently have a strong preference for estuaries as nursery areas (Lenanton & Potter 1987).

Ichthyofauna of offshore, deeper waters

The total number of fish caught by gill netting seasonally in the basin and riverine regions of Leschenault Estuary in 1993/94, *i.e.* 1 518, was similar to that for those regions in 1982/83, *i.e.* 1 551, when the total amount of effort was similar (Table 1). The total numbers of fish caught in the basin and in the river during those two periods collectively were 1 146 and 1 923 respectively (Table 5). The most abundant species in the basin, *i.e.* the yellow-eye mullet *Aldrichetta forsteri*, contributed 26.9% to the total catch in that region, whereas in the river it ranked fourth and contributed only 2.8% to the total number of fish. The Perth herring *Nematalosa vlaminghi* was the second most abundant species in the basin, where it contributed 18.2%, and was the most numerous species in the river, where it comprised nearly 70% of the total catch (Table 5).

The only other species that contributed more than 10% in the basin was the tailor *Pomatomus saltatrix* with 12.2%, this species also ranking third in the river with a contribution of 3.6%. The sea mullet *Mugil cephalus* was the second most abundant species in the river, where it comprised nearly 20% of the total number of fish, which was far higher than the 3.3% it contributed in the basin. The marked tendency for juvenile *Mugil cephalus* to migrate into the Collie River and thus into waters of reduced salinity parallels the situation recorded for this species in other south-western Australian estuaries (*e.g.* Chubb *et al.* 1981; Potter & Hyndes 1994) and in estuaries elsewhere (*e.g.* Thomson 1957a). The four species of elasmobranch caught in the basin were all collected when salinities were high. One of these species, the eagle ray *Myliobatis australis*, is also often abundant in high salinity regions of the Nornalup-Walpole Estuary (Potter & Hyndes 1994). The three families that contributed most to the total number of fish in offshore, deeper waters of the Collie River, *i.e.* Mugilidae, Clupeidae and Pomatomidae, were the same as in deeper waters in the basin (Table 6). The representatives of no other family contributed over 10% to the total catch in deeper waters of either the river or basin.

Virtually all of the marine species caught by gill netting in deeper waters of the estuary basin and the Collie River were marine estuarine-opportunists (Table 7). The number of individuals of species representing this life cycle category contributed 77.4 and 29.1%, respectively, to those of all fish caught in these two regions. Only four of the species caught by gill net completed their life cycles in the estuary, namely the cobbler *Cnidoglanis macrocephalus*, the Australian anchovy *Engraulis australis*, the black bream *Acanthopagrus butcheri* and the yellowtail trumpeter *Amniataba caudavittata*. Moreover, these four species collectively contributed only 2.5% to the total number of fish caught throughout the estuary (Table 5). In contrast, the semi-anadromous category, represented solely by *N. vlaminghi*, contributed nearly 70% to the total catch in the river and 18.2% in the basin.

The number of species that complete their life cycle in the estuary, and their contribution to the total number of fish present, was far lower in offshore, deeper waters than

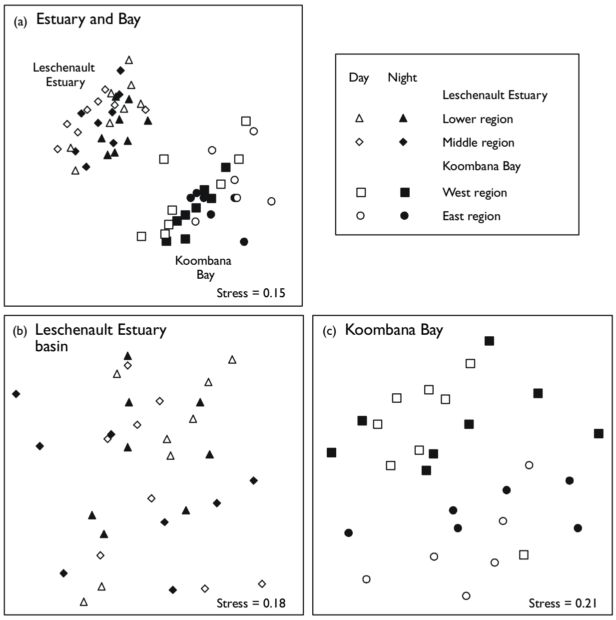

Figure 3. A: MDS ordination of the mean densities in 1994 of each fish species during both the day and night in nearshore, shallow waters of three sites in both the lower and middle regions of the basin of Leschenault Estuary and at three sites in both the western and eastern regions of Koombana Bay. **B** and **C** show separate ordination plots for the samples from the basin and bay, respectively. Modified from Potter *et al.* (1997).

in nearshore, shallow waters (*cf* Tables 4 and 7). This difference reflects the fact that many species belonging to this category are small and essentially confined to the shallows. However, there can be little doubt that, at least *Acanthopagrus butcheri*, which grows to a moderately large size and is relatively abundant in the deeper waters of the river, typically remains for the whole of its life cycle in its natal estuary (Chaplin *et al.* 1998).

Ordination separated the vast majority of the samples from deeper waters of the lower and middle regions of the estuary basin from those in the Collie River (Fig 4), thereby paralleling the results of the classification (not shown). ANOSIM showed that this difference was significant at $P < 0.05$.

Size composition of abundant species

In September 1993, the lengths of the long-finned goby *Favonigobius lateralis* produced a modal class at 45-54 mm (Fig 5). The modal length classes of the corresponding cohort in November 1993 and February 1994 were 40-49 and 40-44 mm, respectively. While this cohort was still represented by fish with a modal length class of 40-44 mm in March, a cohort of smaller fish with a modal length class of 20-24 mm appeared in this month, which clearly represented the new 0+ recruits. The modal length class of the 0+ fish increased to 25-29 mm in May and remained at this size interval during the ensuing late autumn to early spring months, but by November 1994 had increased to 30-34 mm. The strength of the 0+ age class and the accompanying decline in the numbers of the cohort of larger and presumably 1+ fish during the late autumn and winter months strongly indicate that *F. lateralis* typically has a one year life cycle in

Table 5. Life cycle categories (S = marine straggler, O = marine estuarine-opportunist, E&M = estuarine and marine, E = estuarine, SA = semi-anadromous), length range, number (N), percentage contribution (%) and ranking by abundance (R) of each species of elasmobranch and teleost caught using gill nets in offshore, deeper waters of the Leschenault Estuary basin and Collie River and for both of those regions combined, based on data collected in September 1993 to July 1994 and May 1982 to February 1983.

Species	**Life cycle category**	**Length range (mm)**	**Basin**			**River**			**Basin & River**		
			N	**%**	**R**	**N**	**%**	**R**	**N**	**%**	**R**
Aldrichetta forsteri	O	133-324	308	26.9	1	53	2.8	4	361	11.8	3
Nematalosa vlaminghi	SA	104-340	208	18.2	2	1325	68.9	1	1533	50.0	1
Pomatomus saltatrix	O	94-359	140	12.2	3	69	3.6	3	209	6.8	4
Sillago schomburgkii	O	174-282	90	7.9	4	5	0.3	9	95	3.1	5
Arripis georgianus	*O*	*167-274*	*75*	*6.5*	*5*				*75*	2.4	*6*
Pseudocaranx dentex	O	68-298	60	5.2	6				60	2.0	7
Pelates sexlineatus	O	135-197	50	4.4	7				50	1.6	8
Mugil cephalus	O	158-474	38	3.3	8	379	19.7	2	417	13.6	2
Arripis truttaceus	O	145-250	32	2.8	9				32	1.0	10
Myliobatis australis	O	497-1600	32	2.8	9				32	1.0	10
Cnidoglanis macrocephalus	E&M	310-500	27	2.4	11				27	0.9	12
Torquigener pleurogramma	O	111-131	15	1.3	12				15	0.5	16
Engraulis australis	E&M	91-129	14	1.2	13	8	0.4	8	22	0.7	15
Argyrosomus japonicus	O	210-520	13	1.1	14	32	1.7	5	45	1.5	9
Rhabdosargus sarba	O	110-130	9	0.8	15				9	0.3	17
Hyphorhamphus melanochir	O	170-390	8	0.7	16				8	0.3	18
Sillaginodes punctata	O	186-283	8	0.7	16				8	0.3	18
Gerres subfasciatus	O	116-184	5	0.4	18	18	0.9	7	23	0.7	14
Contusus brevicaudus	O	80-249	3	0.3	19	1	<0.1	12	4	0.1	20
Dasyatis thetidis	S	1600-2500	3	0.3	19				3	<0.1	21
Platycephalus laevigatus	S	125	2	0.2	21				2	<0.1	24
Aptychotrema vincentiana	S	700-801	2	0.2	21				2	<0.1	24
Mustelus antarcticus	S	440	1	<0.1	23				1	<0.1	26
Pseudorhombyus jenynsii	S	130	1	<0.1	23				1	<0.1	26
Sillago burrus	S	190	1	<0.1	23				1	<0.1	26
Atherinomorus ogilbyi	O	125	1	<0.1	23				1	<0.1	26
Acanthopagrus butcheri	E	110-354				26	1.4	6	26	0.8	13
Amniataba caudavittata	E	124-128				3	0.2	10	3	<0.1	21
Rhabdosargus sarba	O	144-223				3	0.2	10	3	<0.1	21
Carcharhinus leucas	S	1020				1	<0.1	12	1	<0.1	26
Total number of species				**26**			**13**			**30**	
Total number of fish				**1146**			**1923**			**3069**	

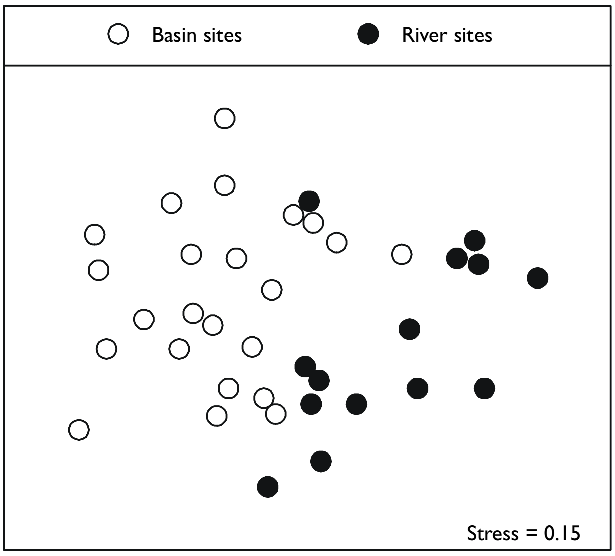

Figure 4. MDS ordination of the catch rates for each fish species in offshore, deeper waters of the basin and Collie River regions of the Leschenault Estuary between September 1993 and July 1994.

Leschenault Estuary. Furthermore, the initial appearance of small 0+ recruits in early autumn indicates that this species spawns in summer. Although the new 0+ age class of *F. lateralis* was not caught by Lenanton (1977) as early as March in the Blackwood River Estuary, the trends exhibited by length-frequency data for this species in that system otherwise closely parallel those described above for the Leschenault Estuary.

As with *Favonigobius lateralis*, the trends exhibited by length-frequency data for *Atherinosoma elongata* (not shown) indicate that this species, which reached a maximum length of only 87 mm (Table 2), also typically has a one year life cycle. This conclusion is based on the fact that the smallest fish, representing 0+ recruits, appeared in samples collected in summer and early autumn, and that the contribution made by larger fish subsequently declined markedly in the immediately ensuing months. These implications that *A. elongata* spawns in summer and has a one year life cycle are consistent with data recorded for this species in the Swan River Estuary (Prince & Potter 1983).

The trends exhibited by length-frequency data for

Leptatherina presbyteroides in the Swan River Estuary were the least well defined of the four smallest species of atherinid in that system (Prince & Potter 1983). The less clear trends for this species were regarded by Prince & Potter (1983) as attributable to the influence of spawning occurring at two different times of the year and/or to the incursion of representatives of marine populations of this species. Length-frequency data for this atherinid show that (1) this species rarely attains 60 mm in length in Leschenault Estuary, (2) its smallest representatives are found in summer and (3) its larger representatives decline in numbers in autumn and early winter. There thus seems every likelihood that, as in the Swan River Estuary, *L. presbyteroides* also typically has a one year life cycle in the Leschenault Estuary.

Table 6. Number (N), percentage contribution (%) and ranking by abundance (R) of each family of elasmobranch and teleost caught using gill nets in offshore, deeper waters of the Leschenault Estuary basin and Collie River and for both of these regions combined, based on data collected in September 1993 to July 1994 and May 1982 to February 1983.

Families	Basin			River			Basin and river		
	N	%	R	N	%	R	N	%	R
Mugilidae	346	30.2	1	432	22.5	2	778	25.4	2
Clupeidae	208	18.2	2	1325	68.9	1	1533	50.0	1
Pomatomidae	140	12.2	3	69	3.6	3	209	6.8	3
Arripidae	107	9.3	4				107	3.5	4
Sillaginidae	99	8.6	5	5	0.3	8	104	3.4	5
Carangidae	60	5.2	6				60	2.0	6
Terapontidae	50	4.4	7	3	0.2	9	53	1.7	7
Myliobatidae	32	2.8	8				32	1.0	10
Plotosidae	27	2.4	9				27	0.9	11
Tetraodontidae	18	1.6	10	1	<0.1	10	19	0.6	14
Engraulididae	14	1.2	11	8	0.4	7	22	0.7	13
Sciaenidae	13	1.1	12	32	1.7	4	45	1.5	8
Sparidae	9	0.8	13	29	1.5	5	38	1.2	9
Hemiramphidae	8	0.7	14				8	0.3	15
Gerreidae	5	0.4	15	18	0.9	6	23	0.7	12
Dasyatididae	3	0.3	16				3	<0.1	16
Rhinobatidae	2	0.2	17				2	<0.1	17
Platycephalidae	2	0.2	17				2	<0.1	17
Atherinidae	1	<0.1	19				1	<0.1	19
Bothidae	1	<0.1	19				1	<0.1	19
Triakidae	1	<0.1	19				1	<0.1	19
Carcharhinidae				1	<0.1	10	1	<0.1	19
Total number of families		21			11			22	
Total number of Fish		1146			1923			3069	

Table 7. Number (N) and percentage contribution (%) of species and individuals to each life cycle category caught using gill nets in offshore, deeper waters of the Leschenault Estuary basin and Collie River and for both of these regions combined, based on data collected in September 1993 to July 1994 and May 1982 to February 1983.

Life cycle category	Basin		River		Basin & River	
	N	%	N	%	N	%
Species						
Marine straggler	6	23.1	1	7.7	7	23.3
Marine estuarine-opportunist	17	65.4	8	61.5	18	60.0
Estuarine & marine	2	7.7	1	7.7	2	6.7
Estuarine	0	0	2	15.4	2	6.7
Semi-anadromous	1	3.8	1	7.7	1	3.3
Total	**26**		**13**		**30**	
Individuals						
Marine straggler	10	0.9	1	0.1	10	0.3
Marine estuarine-opportunist	887	77.4	560	29.1	1447	47.1
Estuarine & marine	41	3.6	8	0.4	49	1.6
Estuarine	0	0	29	1.5	29	0.9
Semi-anadromous	208	18.2	1325	68.9	1533	50.0
Total	**1146**		**1923**		**3069**	

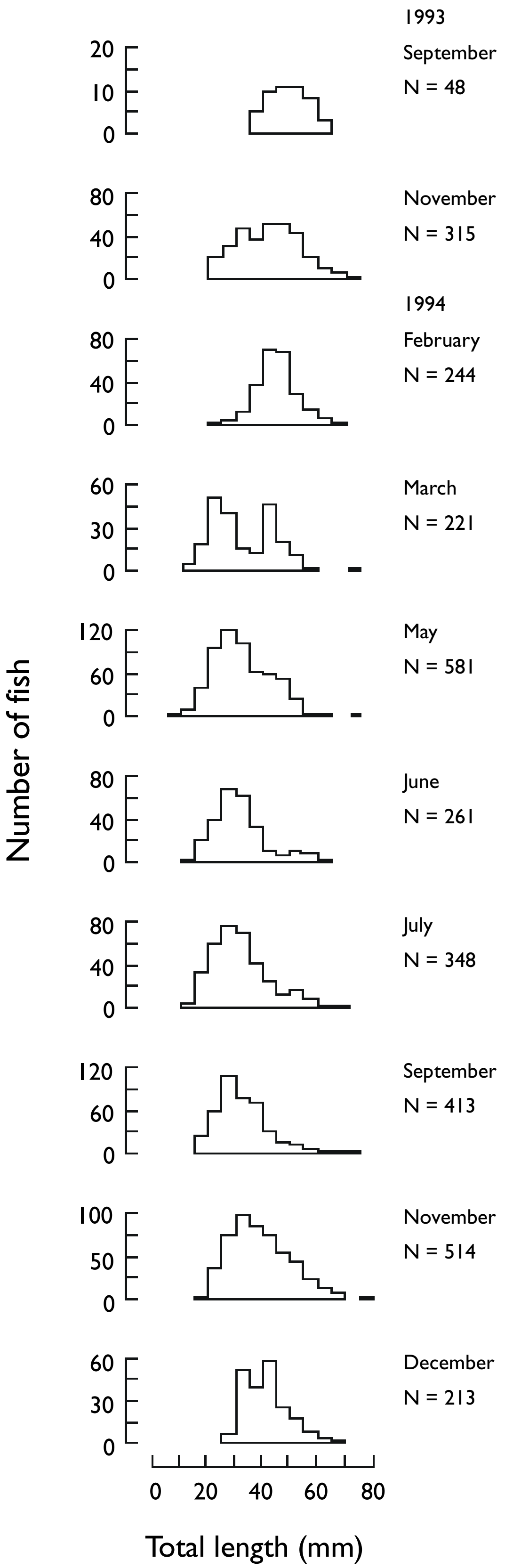

Figure 5. Length-frequency histograms for *Favonigobius lateralis*, derived using data obtained from samples collected by 21.5 and 41.5 m seine nets throughout the nearshore, shallow waters of the basin of Leschenault Estuary between September 1993 and December 1994. The numbers of fish used to construct the histograms for each month are given in italics.

The initial appearance of 0+ recruits of the yellow-eye mullet *Aldrichetta forsteri* in May, in which month their lengths lay between 20 and 49 mm (Fig 6), parallels the situation in the Swan River Estuary (Chubb *et al.* 1981). The presence of small *A. forsteri*, *i.e.*< 30 mm, in samples obtained between May and September is also consistent with the conclusion that, in south-western Australia, this species has a protracted spawning period that extends from early autumn to late winter or even early spring. This essentially parallels the situation elsewhere in south-western Australia (Thomson 1957b; Chubb *et al.* 1981). The modal length class of the 0+ cohort increased from 30-39 mm in May, to 40-49 mm in August, to 50-59 mm in November, and to 130-139 mm in March (Fig 6). There was thus a period of rapid growth between mid-spring and early summer. The pronounced bimodality of the 0+ age class in February, with modal length classes of 70-79 and 120-129 mm, which was a feature of some of the samples of this species collected in the Swan River and Peel Harvey estuaries (Chubb *et al.* 1981; Lenanton *et al.* 1984), was due to the presence of two groups of 0+ fish in February 1983. This implies that two pulses of different-sized new 0+ recruits, resulting from the 1982 spawning season, entered the Leschenault Estuary in 1982/83.

Three well-defined length distributions are present in the length-frequency data for *Aldrichetta forsteri* in May (Fig 6). The first comprised 0+ fish with a modal length of 30-39 mm (see above), compared with 140-149 and 220-229 mm for the second and third groups, respectively. On the basis of ageing studies carried out on *A. forsteri* in the Swan River Estuary (Chubb *et al.* 1981), these latter two groups are assumed to represent the early 1+ and early 2+ age classes, respectively. The modal length class of the presumed 1+ fish did not increase markedly between May and August, but then increased from 180-189 mm in August to 200-209 mm in February (Fig 6). The modal length class of the presumed 2+ fish in August was 220-229 mm and was thus similar to that in May. This age class was not well represented in subsequent months.

As with yellow-eye mullet, the new 0+ recruits of the sea mullet *Mugil cephalus* first appeared in May, in which month the lengths of virtually all of these fish lay between 20 and 39 mm (Fig 6). Small fish, *i.e.* < 30 mm, were also found until September, which essentially parallels the situation for *M. cephalus* in the Swan River and Peel Harvey estuaries (Chubb *et al.* 1981; Lenanton *et al.* 1984). The recruitment of small juvenile sea mullet over these several months is consistent with the conclusion that, in south-western Australia, this species spawns over a protracted period from early autumn to early spring (Thomson 1957b; Chubb *et al.* 1981). The modal length class of the 0+ fish increased from 30-39 mm in May and August to 60-69 mm in November to 70-79 mm in December and 170-179 mm in February (Fig 6). A massive growth of sea mullet over summer has also been recorded for this species in the Swan River Estuary (Chubb *et al.* 1981).

On the basis of ageing studies carried out on *Mugil cephalus* in the Swan River Estuary (Chubb *et al.* 1981), the second well-defined size group present in some months represented the 1+ age class (Fig 6). The modal length class of this cohort increased from 180-189 mm in May and August to 190-199 mm in November. The size of the 0+ fish in

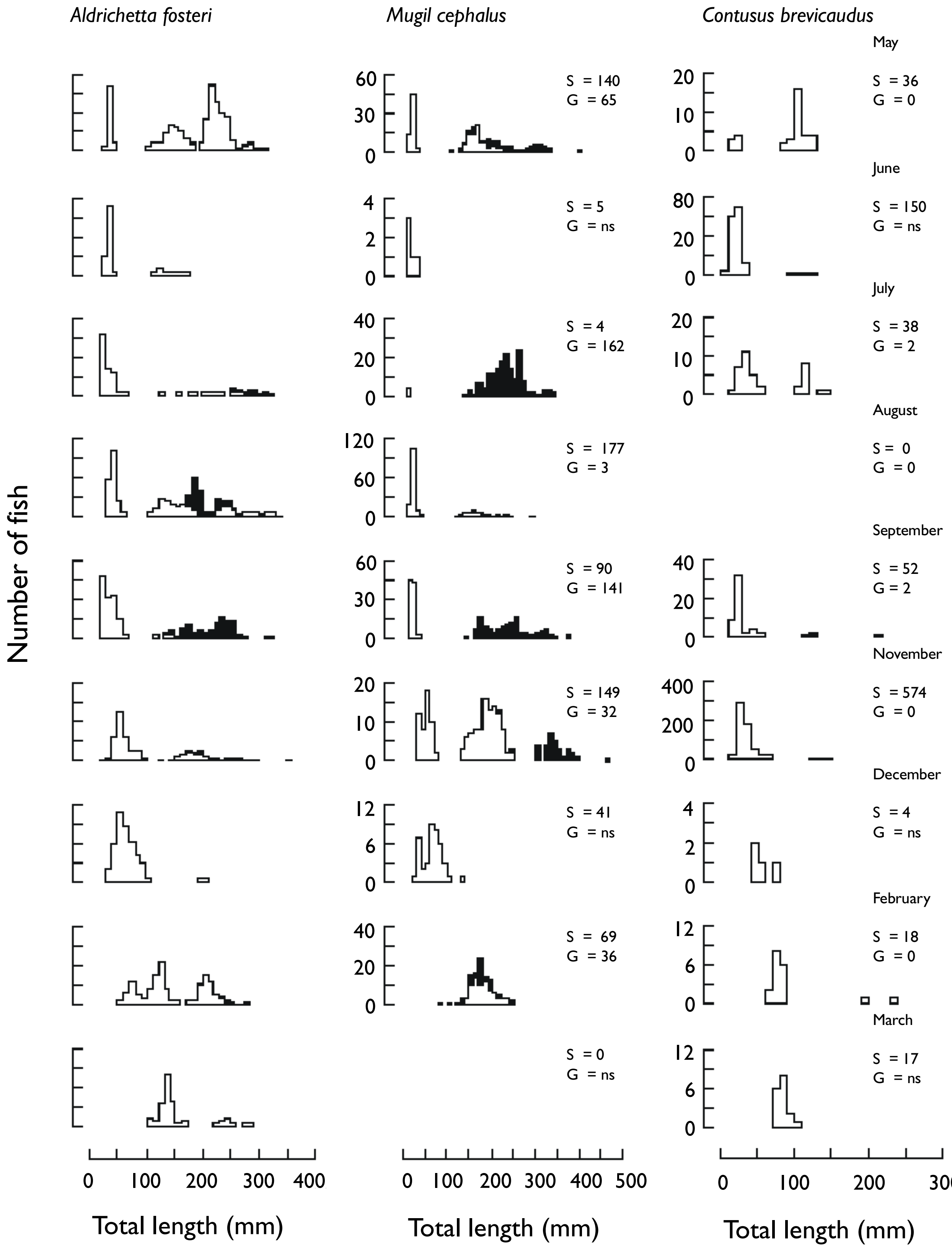

Figure 6. Length-frequency histograms for *Aldrichetta forsteri*, *Mugil cephalus* and *Contusus brevicaudus*. In this and Figs 7 and 8, data for the corresponding months of the year using both seine and gill nets in the basin and river regions of Leschenault Estuary in 1993/94 and 1982/83 have been pooled. In this and Figs 7-9, the numbers in italics for each month refer to the numbers of fish caught using seine (S; □) and gill (G; ■) nets. ns, not sampled. Data are provided only for these months in which an appreciable total number of fish were caught.

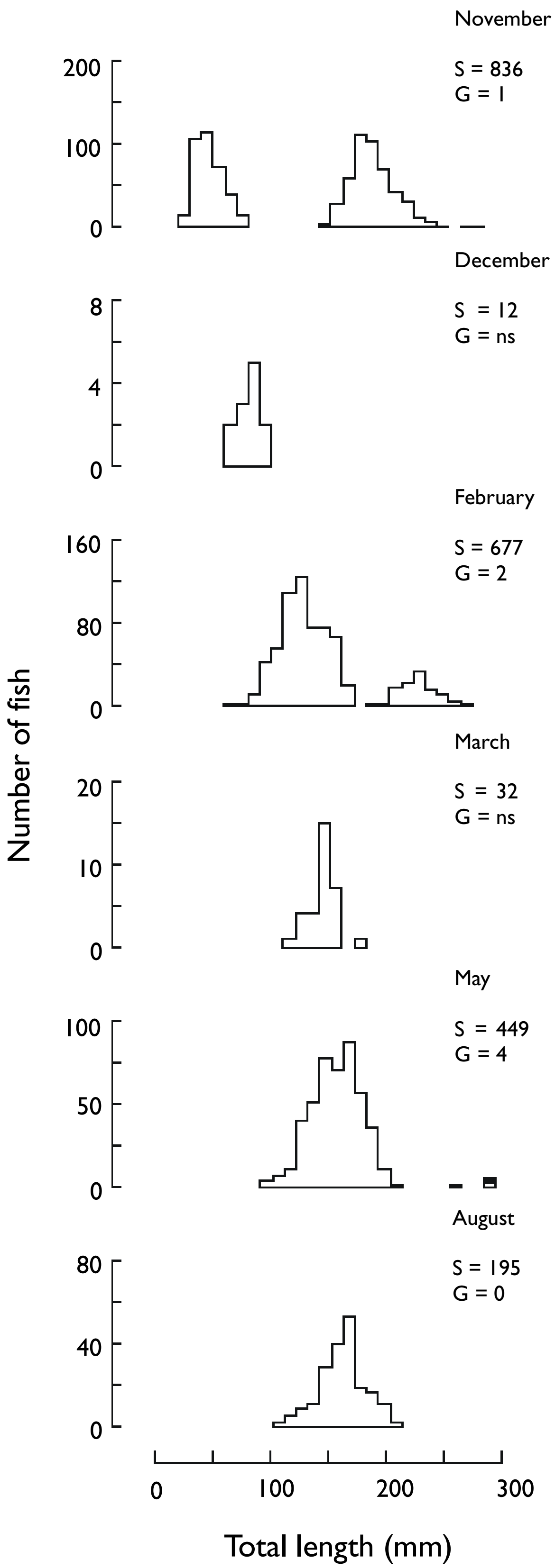

Figure 7. Length-frequency histograms for *Sillaginodes punctata*, caught by seine (S; ☐) or gill net (G; ■). ns, not sampled.

May is slightly less than that of the corresponding age class in both the Swan River and Peel Harvey estuaries in that month (Chubb *et al.* 1981; Lenanton *et al.* 1984). The third size group, with modal length classes between 310 and 340 mm in May, September and November, presumably represents the 2+ age class (Fig 6).

The new 0+ recruits of the prickly toadfish *Contusus brevicaudus* first appeared in May at lengths of only 20-39 mm (Fig 6), which implies that this species spawns in late summer and/or early autumn. The modal length class of the corresponding cohort remained between 30 and 49 mm from May to November, after which it increased to 80-89 mm in February and 110-119 mm in May and 120-129 mm in July. Assuming that spawning occurs in late summer, the fish in July would have been nearly 18 months old. The two largest fish by far were those with lengths of 199 and 239 mm, which were caught in February and were probably about two years old.

The first small 0+ recruits of the King George whiting *Sillaginodes punctata* appeared in the samples collected in November (Fig 7). These juveniles were small, ranging in length from 20 to 79 mm and producing a modal class at 40-49 mm (Fig 7). The latter size interval encompasses the modal length class recorded by Hyndes *et al.* (1998) for 0+ recruits of this species in the same month in coastal waters further north. The initial appearance of small 0+ recruits in Leschenault Estuary in November is consistent with the fact that, in south-western Australia, this species spawns between June and September (Hyndes *et al.* 1998). The modal length class of the 0+ age class increased from 40-49 mm in November to 120-129 mm in February and 140-149 mm in March (Fig 7). The modal length class of the corresponding cohort in August, now representing early 1+ fish, was 160-169 mm and was thus the same as that of the 0+ age class in May, demonstrating that *S. punctata* undergoes little growth during winter. The modal length class of 1+ fish increased from 160-169 mm in August to 170-179 mm in November and 220-229 mm in February (Fig 7). The largest King George whiting caught was 280 mm.

Two well-defined size groups were present in the length-frequency data for *Sillago schomburgkii* collected in February, May and August, the first having lengths ranging from 40-109 mm (Fig 8). Although the modal length class in February, *i.e.* 80-89 mm, was greater than in May and August, *i.e.* 60-69 mm, it should be recognised that the modal length class was skewed to the left in the latter two months. On the basis of ageing studies carried out on yellow-finned whiting in coastal waters further north (Hyndes & Potter 1997), this cohort clearly represents the 0+ recruits that result from the December to February spawning season of this species. The modal length classes of the group of larger *S. schomburgkii*, which are assumed to represent predominantly 1+ fish (see Hyndes & Potter 1997), increased from 150-159 mm in February to between 200 and 229 mm in May, August and November (Fig 8). The lengths of the presumed 1+ fish in other months are comparable to those recorded for this age class in coastal waters further north (Hyndes & Potter 1997).

Length-frequency data demonstrate that the lengths of the vast majority of the Perth herring *Nematalosa* *vlaminghi* that were caught in Leschenault Estuary in each month produced a modal class of *ca* 250 mm, except in February, when there also was a group of smaller fish with a modal length class of 160-169 mm (Fig 8). The situation in Leschenault Estuary thus contrasts markedly with that in the Swan River Estuary, where most of the fish are less than 200 mm in length and where a strong cohort of 0+ *N. vlaminghi* is frequently present (Chubb & Potter 1986). The data for the Swan River Estuary demonstrate that, during spring and summer, the sexually-maturing *N. vlaminghi* migrate into the saline reaches of the Swan River (upper Swan River Estuary) where spawning occurs. The 0+ fish then disperse downstream in the upper estuary and thence into the large basins that constitute the middle estuary (Chubb & Potter 1984). Since there are few areas of shallow banks in the lower reaches of the Collie River, and this river opens directly opposite to and not far from the very short entrance channel of the estuary, it is proposed that, unlike the situation in the Swan River Estuary, the 0+ *N. vlaminghi* soon move out of Leschenault Estuary and into marine waters. Moreover, this species apparently does not return to the Leschenault Estuary until it has reached the size at which sexual maturity is attained.

Any interpretation of the length-frequency data for the tailor *Pomatomus saltatrix* in south-western Australia must take into account the fact that the monthly trends exhibited by gonadosomatic indices (Lenanton *et al.* 1996) and the recruitment patterns of the 0+ age class (Lenanton *et al.*, Fisheries WA, unpublished data) provide strong circumstantial evidence that this species spawns twice annually in this region. The first spawning apparently peaks in early summer, while the second appears to peak in mid- to late autumn. It is thus proposed that the group of small fish with a modal length class of 50-59 mm in February (Fig 8) was the product of a summer spawning. The modal length class of the corresponding cohort was 60-69 mm in May and 80-89 mm in August and November. However, the mode of the 0+ cohort in November 1982 was skewed slightly to the left and was thus not fully representative in that month. The lack of recruitment of small fish, *i.e.* < 60 mm, in both August and November implies either that the autumn-spawning group had limited success in 1983 or that conditions were not conducive for recruitment of the 0+ age class into the Leschenault Estuary in that year. Since none of the fish in Leschenault Estuary were aged, it is not possible to determine whether or not the well-defined modes for larger fish were related to pulses of recruitment from either the product of an autumn or spring spawning cohort or of both cohorts.

The patterns just described for the length-frequency data for 0+ *Pomatomus saltatrix* in Leschenault Estuary contrast with those recorded for the Peel Harvey Estuary further north (Potter *et al.* 1983). Thus, while, as in the Leschenault Estuary, there were some small *P. saltatrix* in the Peel Harvey Estuary in February, there was, in that latter system in that month, also a second and larger group, with lengths ranging from 60-109 mm and having a modal length class of 90-99 mm, which was not represented in the Leschenault Estuary. Since this latter group clearly corresponded to the cohort that was recruited into the Peel Harvey Estuary in December, when the lengths ranged from 30-49 mm, it is believed to represent the product of an autumn rather than summer spawning. Thus, in February, the 0+ age class of *P. saltatrix* in the Peel Harvey Estuary was represented by a small group of fish that had apparently been spawned in summer and a larger group of larger fish that appeared to have been spawned in autumn. Furthermore, the growth of the 0+ cohort that appeared in the Peel Harvey Estuary in December, and which was apparently the result of an autumn spawning, was far more rapid than that described above for the 0+ age class that appeared in Leschenault Estuary in February, and which was apparently the product of an early summer spawning. Thus, in the case of that 0+ age class in the Peel Harvey Estuary, the modal length class increased rapidly from 50-59 mm in December to 90-99 mm in February and to 120-129 mm in March.

Virtually all of the sea garfish, *Hyporhamphus melanochir*, that were obtained during 1993/94 and 1982/83, were collected in May 1983. The 296 representatives of this species caught in that month constituted three well-defined size categories, with modal length classes of 110-119, 240-249 and 350-359 mm (Fig 9), which probably represent the 0+, 1+ and 2+ age classes, respectively.

Diets of fish

Chalmer & Scott (1984) showed that the Leschenault Estuary contained a range of benthic invertebrates, which were dominated by an abundance of bivalve molluscs, polychaetes and amphipods. They also showed that, on the basis of the diets of fish collected from both the Leschenault and nearby Peel Harvey estuaries, relatively large volumes of bivalve molluscs were consumed by species such as *Cnidoglanis macrocephalus*, *Gerres subfasciatus*, *Aldrichetta forsteri* and *Torquigener pleurogramma* and that polychaetes constituted an important component of the diets of *Sillaginodes punctata*, *Sillago schomburgkii*, *Arripis georgiana* and *A. forsteri*. Appreciable numbers of small crustaceans, such as amphipods and isopods, were ingested by *C. macrocephalus*, *A. caudavittata*, *A. forsteri* and *T. pleurogramma*, while larger crustaceans, such as the decapods *Palaemonetes australis* and *Alpheus* spp, were consumed by *A. caudavittata*, *S. schomburgkii*, *Pomatomus saltatrix* and *Argyrosomus japonicus* (formerly *Argyrosomus hololepidotus*). The last two species also fed on small fish, particularly *Engraulis australis*, and chironomid larvae constituted an important component of the diet of *A. forsteri*.

On the basis of their analyses of the gut contents of the above species, Chalmer & Scott (1984) considered that the feeding modes of the fish they examined in Leschenault Estuary comprised the following four main categories, namely (1) herbivores, (2) omnivores, (3) lower-order carnivores and (4) higher-order carnivores (Table 8). Since *Mugil cephalus* and *Nematalosa vlaminghi* feed predominantly on detritus (Thomson 1957c), a further category for detritivores is added to that list of four categories (Table 8).

The above fish species examined by Chalmer & Scott (1984) all grew to a relatively large size in Leschenault Estuary. On the basis of work carried out in the Swan River Estuary and Wilson Inlet, the far smaller species *Favonigobius lateralis* would be expected to feed mainly on polychaetes and amphipod crustaceans, together with some detritus (Gill & Potter 1993; Humphries & Potter 1993).

Studies in those other two estuaries also suggest that, in Leschenault Estuary, the atherinid *Atherinosoma elongata* would probably feed largely on benthic prey, such as polychaetes and certain crustaceans, *e.g. Palaemonetes australis*, and on detritus, whereas the other small atherinid *Leptatherina presbyteroides* would probably feed on planktonic crustaceans, such as calanoid and harpacticoid copepods, terrestrial insects, larval bivalves and foraminiferans (Prince *et al.* 1982; Humphries & Potter 1993).

Commercial fishery

The number of commercial fishing boats that were operating annually in Leschenault Estuary between 1981 and 1997 declined from a maximum of 21 in 1982 to 6 or 7 boats in 1993 to 1997 (Fig 10 a). This decline in the number of boats fishing between the early 1980s and mid 1990s is a direct consequence of the long term policy of Fisheries Western Australia to allow the level of participation by commercial fishers in the Leschenault Estuary to undergo

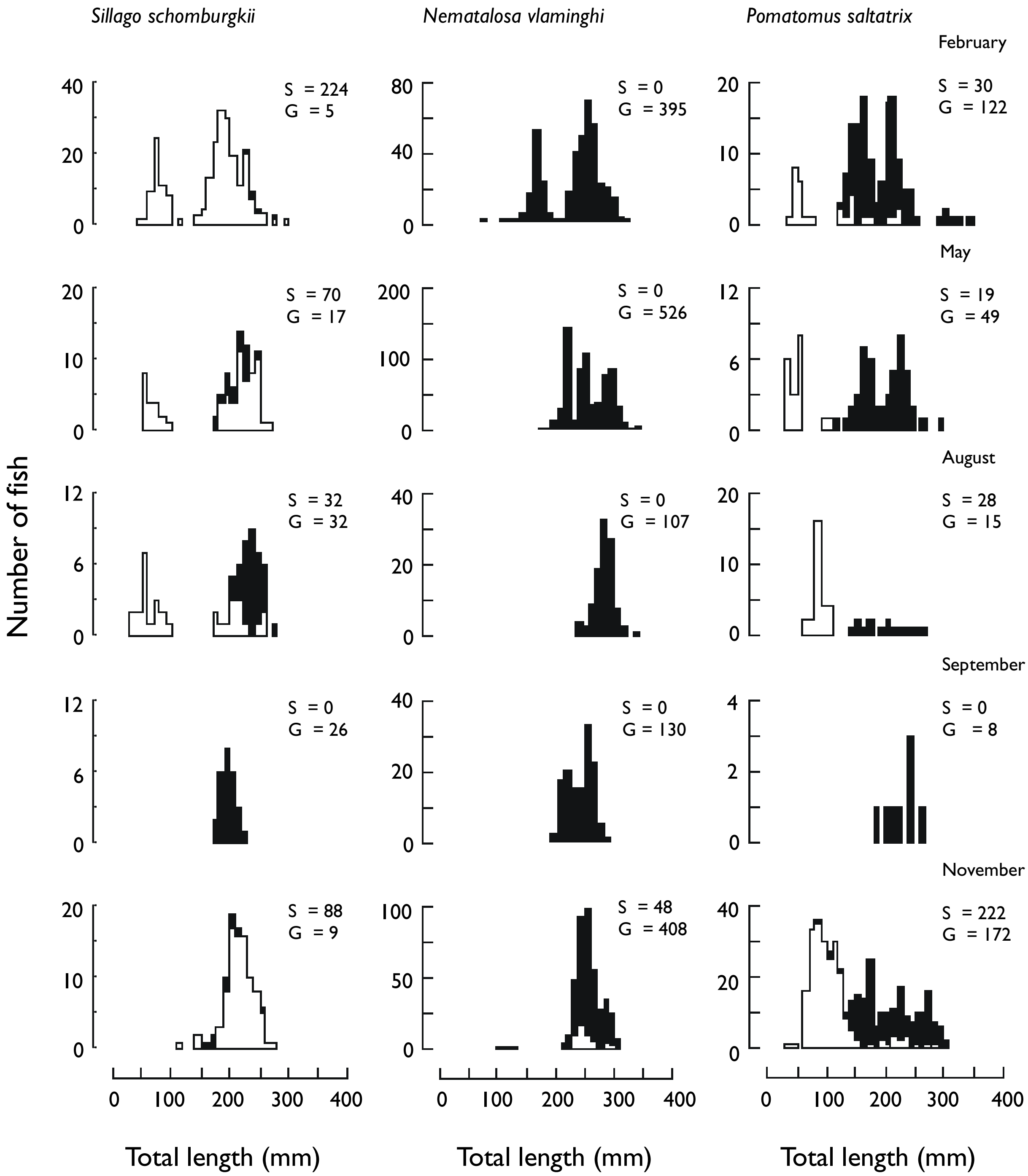

Figure 8. Length-frequency histograms for *Sillago schomburgkii*, *Nematalosa vlaminghi* and *Pomatomus saltatrix*, caught by seine (S; ☐) and gill net (G; ■).

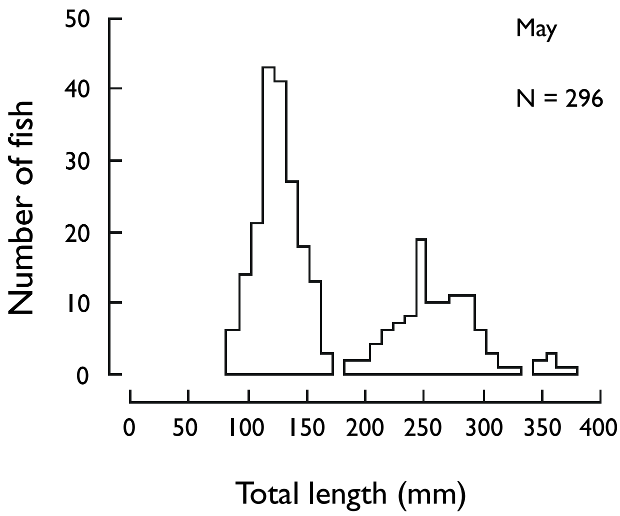

Figure 9. Length-frequency histograms for *Hyporhamphus melanochir* derived from samples collected by seine and gill nets in the basin of the Leschenault Estuary in May 1982.

a progressive reduction. In other words, the license of a commercial fisher is allowed to lapse when that fisher decided to leave the industry.

The amount of gill net effort reported in the years between the early 1980s and 1997 declined markedly and progressively from its maximum of 831 boat days in 1981 to less than 90 boat days in 1991 to 1997 (Fig 10 B). The amount of annual haul net effort between 1981 and 1987 was essentially the same as that of gill net effort, *i.e.* with annual values ranging from 375 to 780 boat days. However, unlike the situation with gill net effort, the haul net effort did not decrease after 1987, remaining above 500 boat days in these subsequent years. The fact that haul net effort greatly exceeded that of gill net effort during the 1990s reflects a deliberate policy, that was instigated by the commercial fishers, to use a technique that would both reduce the amount of bycatch and overcome the problems posed to other users of the estuary by nets being left unattended overnight in the water.

When gill and haul net effort were combined, the resultant total effort reported by commercial fishers can be seen to have declined from greater than 1 300 boat days between 1981 and 1984, to about 850 boat days in all but one year between 1985 and 1990 and then to less than 700 boat days in subsequent years (Fig 10 C). The substantial decline in both the number of boats operating and total fishing effort is reflected in the total reported catch of finfish species. Thus, the wet weight of catch was typically greater than 150 000 kg in 1981 to 1985, compared with *ca* 10 000 kg in 1986 to 1992 and *ca* 85 000 kg in 1993 to 1997 (Fig 10 D).

The catches of the main commercial fish species in Leschenault Estuary were derived from statutory monthly returns sent to Fisheries Western Australia. Discussions with commercial fishers suggest that, prior to 1989, some of the catches obtained in Koombana Bay for some species in a minority of months may have been inadvertently coded as having been taken in Leschenault Estuary and that the catches of yellow-eye mullet *Aldrichetta forsteri* and sea mullet *Mugil cephalus* within the estuary may, in some cases, have been confused. However, it is clear from discussions with commercial fishers that the ranking, in terms of weight of catch that is given for the different species in Table 9 and the overall trends shown for the annual catches of those species in Fig 11, are broadly valid.

Six species of finfish, *i.e. Aldrichetta forsteri*, *Mugil cephalus*, *Sillago schomburgkii*, *Sillaginodes punctata*, *Cnidoglanis macrocephalus* and *Hyporhamphus melanochir*, were caught in Leschenault Estuary by commercial fishers in each of the 17 years between 1981 and 1997 (Table 9). *Nematalosa vlaminghi* and *Pomatomus saltatrix* were caught in most of those years and *Acanthopagrus butcheri* was caught in nine of those years.

In terms of wet weight, *Aldrichetta forsteri* was the most important commercial finfish species in Leschenault Estu-

Table 8. Modes of feeding of the main fish species in Leschenault Estuary and their major dietary components.

Mode of feeding	Species	Major dietary components
Herbivores	*Hyporhamphus melanochir, Pelates sexlineatus*	Green and brown algae
Detritivores	*Mugil cephalus, Nematalosa vlaminghi*	Bottom sediment, detritus
Omnivores	*Aldrichetta forsteri, Amniataba caudavittata*	Algae, bivalve molluscs, isopods, decapods, *e.g. Palaemonetes australis*, insect larvae, *e.g.* chironomids, polychaetes
Lower-order carnivores	*Favonigobius lateralis, Leptatherina presbyteroides Atherinosoma elongata, Sillaginodes punctata, Gerres subfasciatus, Torquigener pleurogramma, Sillago schomburgkii, Cnidoglanis macrocephalus,*	Small crustaceans, *e.g.* amphipods, and large crustaceans, *e.g. Palaemonetes australis* and *Alpheus* spp, bivalve molluscs, polychaetes
Higher-order carnivores	*Argyrosomus japonicus, Pomatomus saltatrix*	Juveniles of other fish species, smaller fish species, *e.g. Engraulis australis,* and larger crustaceans, *e.g. Palaemonetes australis*

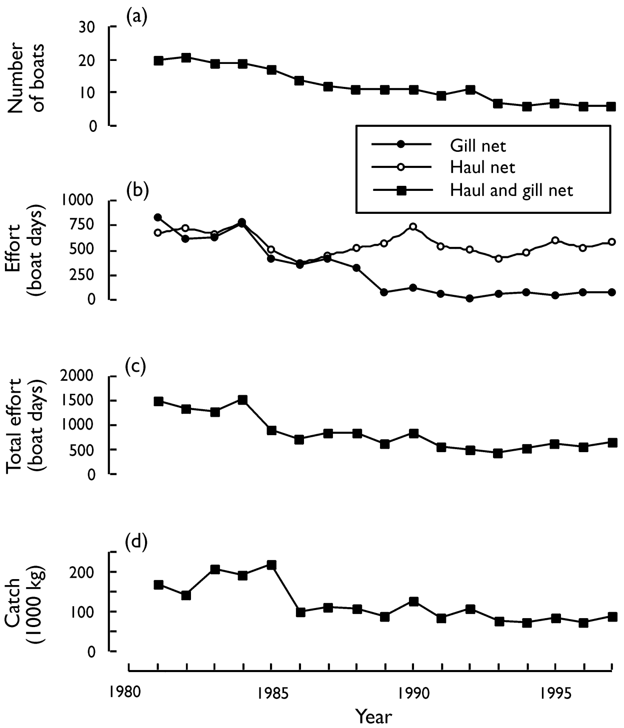

Figure 10. Data on the commercial fishery in the basin of the Leschenault Estuary in each year between 1981 and 1997. (A) number of boats fishing, (B) number of days spent fishing using gill and haul nets, (C) total effort and (D) total catch of finfish.

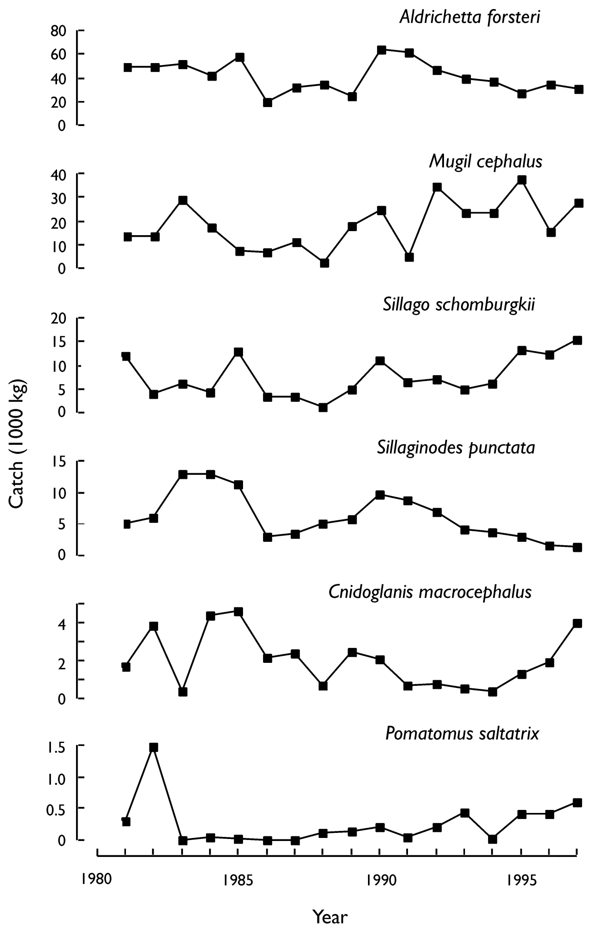

Figure 11. Total annual catches of the main finfish species in the Leschenault Estuary between 1981 and 1997.

ary, with a mean annual catch of 65 255 kg and a contribution of *ca* 56% to the total wet weight of all finfish caught in the 17 years between 1981 and 1997 (Table 9). The next most important species during those years were *Mugil cephalus*, *Sillago schomburgkii*, *Sillaginodes punctata* and *Nematalosa vlaminghi*, with mean annual contributions of between 3.6 and 20.2% to that total wet weight. *Cnidoglanis macrocephalus* contributed only 2.0% to the total wet weight over the above period and *Pomatomus saltatrix*, *Hyporhamphus melanochir* and *Acanthopagrus butcheri* each contributed less than 0.5% (Table 9).

The maximum annual catches of the three species that contribute most to the total catch were *ca* 65 000 kg for *Aldrichetta forsteri* in 1990, *ca* 37 000 kg for *Mugil cephalus* in 1995 and *ca* 16 000 kg for *Sillago schomburgkii* in 1997 (Fig 11). The annual catches of each of the other three main fish species varied markedly between 1981 and 1997. The annual catches of *Sillaginodes punctata* and *Cnidoglanis macrocephalus* reached maxima of *ca* 13 500 and 4 500 kg, respectively.

The decline undergone by catches of *Aldrichetta forsteri* during recent years contrasts with the maintenance of the catches of *Mugil cephalus* during that same period (Fig 11). This difference in trends reflects the fact that, while there has been a decline in the demand for mullets in general as bait for the rock lobster industry, there has still been a demand for sea mullet (but not yellow-eye mullet) as a food fish. During recent years, the catches of *Sillaginodes punctata* have declined while those of *Sillago schomburgkii* have risen, reflecting a targetting of the latter species due to a shortage of the former species. This decline in the catches of *S. punctata*, which contrasts with the situation elsewhere in south-western Australia, may be related to the deleterious effects that would almost certainly have been caused to fish nursery areas both by dredging in the harbour and through the deposition of dredge spoil along the coast northwards to the estuary mouth. The consistently relatively low catches of *C. macrocephalus* in most years since 1986 probably reflect the effects of strong fishing pressure on this species, coupled with the deleterious effects of a legal minimum length below the age at first maturity (Laurenson *et al.* 1993a,b), a situation which parallels that found in some other estuaries in south-western Australia (Steckis *et al.* 1995).

Recreational fishery

The preliminary data derived from a creel census carried out by Fisheries Western Australia demonstrated that the catches of recreational fishers in Leschenault Estuary during 1998 were dominated by the three species of whiting (*Sillaginodes punctata*, *Sillago schomburgkii* and *Sillago burrus*) and tailor (*Pomatomus saltatrix*). The next most abundant species were Australian herring (*Arripis georgiana*) and tarwhine (*Rhabdosargus sarba*). Smaller catches of several other species, including juvenile Australian salmon (*Arripis truttaceus*) and skipjack or southern trevally (*Pseudocaranx dentex*) and sizeable, incidental catches of toadfishes or pufferfishes (*Contusus brevicaudus* and *Torquigener pleurogramma*) were also obtained.

Table 9. List of main finfish species caught commercially in Leschenault Estuary, together with the numbers of years they were caught between 1981 and 1997, the total catch and mean annual catch (± 1se) for those years and the percentage contribution of each species to the total catch over that period.

Species	Years	Total catch, all years *(kg)*	Mean annual catch *(kg per year)*	Contribution *(%)*
Aldrichetta forsteri	17	1 109 343	65 255 (± 7875)	55.5
Mugil cephalus	17	404 248	23 779 (± 2547)	20.2
Sillago schomburgkii	17	220 762	12 986 (± 1833)	11.1
Sillaginodes punctata	17	132 332	7 784 (± 1208)	6.6
Nematalosa vlaminghi	13	71 448	5 496 (± 2040)	3.6
Cnidoglanis macrocephalus	17	39 485	2 323 (± 383)	2.0
Pomatomus saltatrix	16	7 759	485 (± 239)	0.4
Hyporhamphus melanochir	17	6 859	403 (± 75)	0.3
Acanthopagrus butcheri	9	5 106	567 (± 217)	0.3

Conclusions

The collation of unpublished and published data in this paper shows that Leschenault Estuary is used as a nursery area by several marine fish species, including *Hyperlophus vittatus*, *Aldrichetta forsteri*, *Mugil cephalus*, *Sillago schomburgkii*, *Sillaginodes punctata*, *Sillago burrus*, *Pomatomus saltatrix*, *Gymnapistes marmoratus*, *Contusus brevicaudus* and *Torquigener pleurogramma*. The nursery function provided by this estuary parallels that afforded to certain marine species by comparable areas in estuaries elsewhere in south-western Australia (Potter & Hyndes 1999) and in temperate regions of the northern hemisphere (Haedrich 1983; Dando 1984; Kennish 1990). However, unlike the situation frequently found in temperate holarctic estuaries, such as that of the Severn River in England (Claridge *et al.* 1986), the 0+ age class of these species in south-western Australian estuaries remains strongly represented throughout the year in Leschenault Estuary. Furthermore, the above species are also usually well represented throughout the year by the 1+ and also sometimes the 2+ and even older age classes. This parallels the situation in estuaries such as the Peel Harvey and Swan River estuaries to the north (Chubb *et al.* 1981; Lenanton *et al.* 1983; Potter *et al.* 1983) and in the Blackwood River Estuary to the south (Lenanton 1977). Estuaries provide excellent fish nursery areas because their high productivity (Schelske & Odum 1961) facilitates particularly rapid growth rates, which thereby soon makes juvenile fish less susceptible to predation (Kennish 1990). The high productivity of estuaries would also be of value to those species that spend the whole of their life cycles in estuaries. Furthermore, estuaries contain relatively far fewer large piscivorous predators than the natal environments of marine fish species (Blaber & Blaber 1980). The extensive growths of seagrasses in Leschenault Estuary, and particularly of *Halophila*, would also provide protection for small species from any potential predators. The high abundance of certain estuarine-spawning species in the shallows of Leschenault Estuary, together with the restriction of *Lesueurina platycephala* to the shallows of Koombana Bay, where it was relatively very abundant, help account for the marked differences in the compositions of the fish fauna in the shallows of the estuary and the bay.

The work of Chalmer & Scott (1984) demonstrated that Leschenault Estuary contains an abundance of the type of benthic fauna that forms a major component of the diets of fish species in this estuary, *e.g.* nereidid polychaetes, the bivalve *Arthritica semen* and amphipods of the genus *Paracorophium*. There are also extensive beds of seagrass (mainly *Halophila* species) which, together with the profuse algal covering, provide an abundance of food for herbivorous invertebrates and fish and result in the production of large amounts of detritus which constitutes an important component of the diets of certain benthic invertebrates and some teleost fish. Since the densities of potential invertebrate prey are far greater in Leschenault Estuary than Koombana Bay (P Chalmer, unpublished data), it seems highly relevant that the overall density of fish in shallow waters is far greater in the estuary than the bay.

Although the shallow waters of estuaries provide important nursery areas for certain marine fish species, the contribution of such fish to the total number of fish in these waters was less than half that of those species which complete their life cycle in the estuary, *i.e.* 32.1 *vs* 67.9%. The presence in Leschenault Estuary of very large numbers of individuals of estuarine species, such as the gobies *Favonigobius lateralis*, *Pseudogobius olorum* and *Afurcagobius suppositus*, the atherinids *Leptatherina presbyteroides*, *Atherinosoma elongata* and *Leptatherina wallacei*, and the gobbleguts *Apogon rueppellii*, is probably attributable to the presence of high and stable salinities during summer, when spawning occurs, and to the influence of landlocking and/or the limited exchange with the sea during the recent geological past (see introduction).

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