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Biological data for the management of competing commercial and recreational fisheries for King George whiting and Black bream

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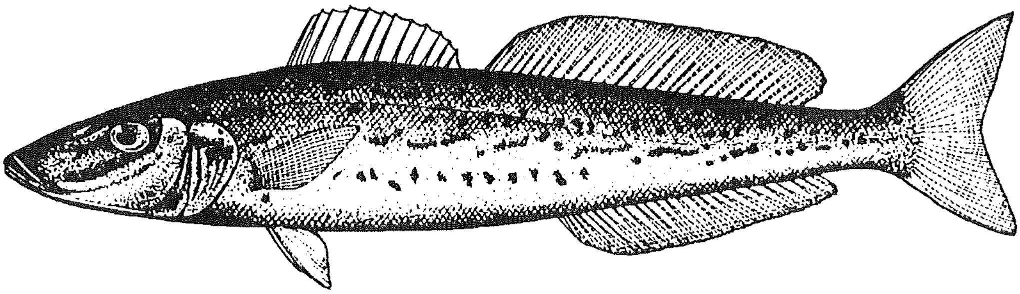
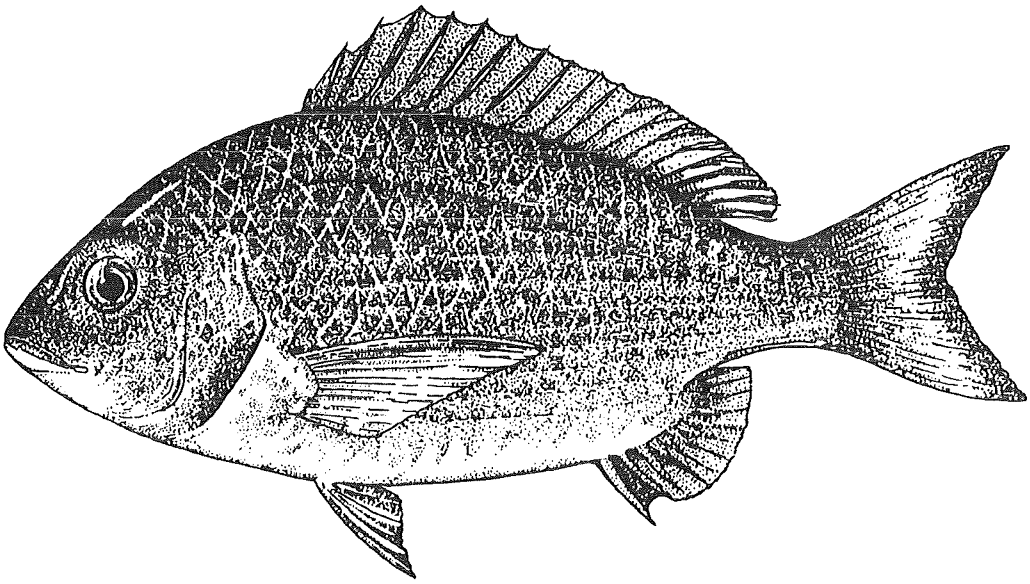


King George whiting (*Sillaginodes punctata*)



Black bream (*Acanthopagrus butcheri*)

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(I) NON-TECHNICAL SUMMARY

The King George whiting is a marine species which uses estuaries as a nursery area, whereas the Black bream spends the whole of its life cycle in estuaries and the lower reaches of rivers. King George whiting and Black bream are both very important commercial and recreational finfish species in south-western Australia. While virtually all of the commercial catch of King George whiting is taken in estuaries, the recreational fishery for this species is based in both estuaries and protected marine waters, such as Cockburn Sound. The fisheries for Black bream are of course entirely restricted to estuaries.

During recent years, the increase that has occurred in the catches of both King George whiting and Black bream has increased the potential for conflict between commercial and recreational fisheries. This point was recognised by the Western Australian Fisheries Department, who then approached us to produce the biological information that is required to develop management policies that will benefit both the commercial and recreational fishers who target these two species.

The main biological information that the Fisheries Department required for developing management policies for King George whiting and Black bream were the growth rate, maximum age, age and length at sexual maturity, spawning period and location, habitat requirements and the selectivity of gill net meshes for these species in south-western Australia. None of this information was available and data on the age of these species elsewhere in Australia were based on counts of growth zones in hard structures, such as scales and otoliths (ear bones), which had not been confirmed as being formed annually.

Our results demonstrate that, in south-western Australia, King George whiting, which can live as long as 13 years and attains lengths in excess of 530 mm, reaches maturity at a length of 400 mm, which is achieved at the end of its fourth year of life. Since King George whiting has a legal minimum size for capture of 250 mm on the lower west coast and 280 mm on the south coast, it is obviously being fished extensively before it first reaches maturity. This is particularly the case with the commercial fishery in estuaries on the lower west coast, in which our results show that these systems are typically only used by King George whiting of lengths up to *ca* 320 mm. Our data also demonstrate that the recreational fishery for this species in marine waters is based on their alternative nursery areas in protected environments and thus largely targets juvenile fish. The effects of the increasing commercial and recreational fishing pressure on King George whiting in their nursery areas is alleviated to some extent by the fact that this species migrates offshore as it increases in size and spawns in winter around reefs, and thus in a location and at a time when fishing pressure is very low. The above data have already been used by Dr R.C.J. Lenanton of the WA Fisheries Department to help resolve a dispute between commercial and recreational fishers regarding allocations of resources.

The results of our study show that Black bream in the main study area, *i.e.* Swan Estuary, reach a maximum age and length of 21 years and 470 mm, respectively, and attain sexual maturity at the end of their second year of life, when they have reached a length of about 220 mm. However, the growth rates of this species in the different estuaries of south-western Australia vary markedly. For example, the growth rate in the Moore River Estuary is so much slower than in the Swan Estuary that the fish in this

system did not reach 180 mm, and thus the typical size for maturity in this estuary, until they were four years old. Since the legal minimum size for capture of Black bream is 250 mm, the representatives of this species typically reach sexual maturity in the Moore River and Swan estuaries, and also estuaries elsewhere in south-western Australia, before they can be legally captured. Our data demonstrate that, in an estuary such as that of the Moore River, where the growth of Black bream is very slow, only a relatively small proportion of this species will reach the minimum legal length of capture.

Black bream has now been shown to spawn mainly in the narrow, upper reaches of estuaries between September and December. This restricted spawning region means that, in the Swan Estuary, the spawning success of Black bream may be deleteriously affected in those years when the algal blooms that occur annually in that part of the system are particularly severe. Genetic studies showed that the Black bream in the different estuaries essentially represent different populations, *i.e.* there is little or no interchange of this species between estuaries.

Our data also show that King George whiting and Black bream are multiple spawners, *i.e.* they spawn more than once in a breeding season. It was thus not possible to estimate the frequency of spawning and therefore obtain an accurate estimate of the real annual fecundity of these species.

Sampling of the fish faunas was carried out in an intermittently closed estuary, *i.e.* Moore River Estuary, and in two permanently-open systems, one of which was moderately eutrophic, *i.e.* Leschenault Estuary, while the other, *i.e.* the Blackwood River Estuary, contained extensive patches of the aquatic angiosperm *Ruppia megacarpa*. While juveniles of marine species extensively used both the Leschenault and Blackwood River estuaries as nursery areas, they were far less abundant in the Moore River Estuary, presumably as a consequence of the closure of the mouth for protracted periods and the presence of the low salinities that characterise even the lower reaches of this estuary. The overall densities of marine fish species declined markedly during the periods of substantial freshwater discharge, which also resulted in a pronounced decline in salinities. The densities of a number of species were greater in areas containing *Ruppia* than in other regions of the estuary which comprised mainly bare sand.

Our extensive sampling of the same areas of the Blackwood River Estuary, that yielded large numbers of Black bream twenty years ago, produced only a single individual. Thus, since this estuary has been subjected to substantial commercial and recreational fishing over that period, it therefore appears that fishing pressure has had a deleterious effect on the abundance of Black bream in this estuary.

All of the data we have collected have been made available to Dr R.C.J. Lenanton of the Western Australian Fisheries Department. Dr Lenanton has already used those data to help resolve a dispute over allocation of King George whiting resources between commercial and recreational fishers. Our results have also been communicated to fishers through talks and articles in angling and professional fishing magazines.

Key Words

King George whiting, Black bream, age, growth, maturity, spawning period, spawning location, habitats, legal size for capture, estuaries, fish communities, environmental influences.

(II) Background

King George whiting and Black bream

The vast majority of the abundant species of fish found in south-western Australian estuaries are either marine species, such as King George whiting (*Sillaginodes punctata*), which use estuaries as nursery areas, or estuarine species, such as Black bream (*Acanthopagrus butcheri*), which complete their life cycle within the estuary or the lower reaches of rivers (Loneragan *et al.* 1986, 1987, 1989, Lenanton and Potter 1987, Loneragan and Potter 1990, Potter *et al.* 1990, 1993). While inshore marine waters are used as nursery areas by King George whiting, the extent of this role has not yet been elucidated.

A total of 68 fishing units take significant catches of King George whiting in Western Australia. Since the majority of the commercial fishery for this species is based in estuarine waters, much of the commercial catch in Western Australia comprises immature fish (R.C.J. Lenanton pers. comm.). During recent years, the recreational fishing pressure on this much sought-after species has increased markedly, both in estuaries and more importantly in inshore marine waters. Black bream is also an important commercial species with as many as 42 fishing units fishing for this species in Western Australia in 1990/91, with the catches supplying both interstate and local markets. This species is also the most sought-after recreational fish in Western Australian estuaries, such as the Swan Estuary (R.C.J. Lenanton pers. comm.).

The question of the ability of some important commercial and recreational finfish fisheries to coexist with minimal conflict in the inshore marine and estuarine waters of south-western Australia must take into account the rapidly increasing demand for these resources by recreational fishers. Indeed, these pressures are already leading to a redistribution of the catch of certain species between commercial and recreational fishers. As a result of these problems, a 1991 report by the Recreational Fisheries Advisory Committee, entitled The Future for Recreational Fishing, stated that "As a priority, southern (Western Australian) estuarine fisheries should be fully evaluated to determine whether there should be a shift in the resource share in favour of recreational (as opposed to commercial) fishing". Despite the importance of King George whiting and Black bream to the commercial and recreational fisheries in Western Australia, there have been no detailed studies of those aspects of the biology of either of these species which would facilitate the development of sophisticated management policies.

Extensive sampling of larvae off the coast of South Australia suggests that in those waters, King George whiting spawns between late February and June, with peak spawning activity occurring in mid-April (Bruce 1989, Cockrum and Jones, 1992). Spawning in South Australia occurs in deeper offshore waters (Cockrum and Jones 1992), with the ocean currents carrying the fertilised eggs and larvae to the shallow nearshore nursery areas (Bruce 1989, Jenkins and May 1994). However, our very preliminary studies on the larvae and juveniles of King George whiting in Western Australia during the late 1980s and early 1990s suggest that this species spawns at an entirely different time along the lower west coast of that state.

The spawning period of Black bream has been estimated as occurring from July to November by Thomson (1957a) and from the entirely different period of early November to July by Holt (1978). However, these results were derived from limited data. Furthermore, it is not known whether spawning occurs in the rivers or the estuary basin.

King George whiting have been aged using growth zones on whole otoliths (Scott 1954) and scales (Caton 1966, Gilmour 1967, Jones *et al.* 1990), and by analysing length-frequency data (Jones *et al.* 1990), while Black bream have only been aged using scales (Thomson 1957b, Hobday and Moran 1983). There have been no published data which has validated that the growth zones on scales or whole otoliths of either of these two species were formed annually.

Influence of environmental variables and eutrophication on fish communities

The estuaries of south-western Australia are characterised by having very narrow entrance channels, which open into large basins that are exposed to only a very small tidal action. The above characteristics have meant that nutrients from surrounding agricultural land have been retained in some of these estuaries and, in some cases, this has resulted in very marked increases in primary and secondary productivity (McComb *et al.* 1981, Lukatelich *et al.* 1987). Differences in the type of primary productivity produced by nutrient input from surrounding agricultural land within different regions of one system have been accompanied by increases in fish abundance in one of those regions and by decreases in fish production in another (Lenanton *et al.* 1984, 1985, Potter *et al.* 1983). The massive growths of *Ruppia megacarpa* that developed as a result of nutrient input in another system has led to an increased diversity of habitat and to a greater abundance of some fish species (Humphries *et al.* 1992, Humphries and Potter 1993).

(III) Need

King George whiting and Black bream

It is essential that management strategies are in place which will enable Fisheries Departments to achieve maximum utilisation of the resource and ensure that the fishery is sustainable. This requires that the spawning potential of the stock is protected through a sound understanding of the age at maturity, time and location of spawning and fecundity, and the degree to which the different stocks of the species in question are independent. The development of management plans is also dependent on a detailed knowledge of the growth rates, mortality and migration rates, and the distribution of the stock, coupled with an understanding of the fishing gear and its impact on the stock.

Additional fishing pressure on certain species is already leading to reduced fish abundance and a greater potential for conflict between and within user groups, *i.e.* between commercial and recreational fishers. For favoured recreational species, such as King George whiting and Black bream, it is clear that strategies need to be developed to avert some of this potential conflict and to ensure that the fisheries are sustainable under increased fishing pressure. There is thus an urgent need for sound biological and mesh selectivity data to produce sophisticated management plans that will ensure that the sustainable and optimum yield of King George whiting and Black bream can be determined. This yield can then be divided equitably between the two different groups of fishers exploiting these two species.

During recent years, there has been both a growing conflict between commercial and recreational fishers for King George whiting and also disputes amongst the former group as to the appropriateness of the current minimum legal size. In west coast regions, the current minimum legal size is 250 mm, while on the south coast it has recently been increased to 280 mm. Such an increase on the west coast would make the fishery unviable, since many King George whiting apparently leave estuaries before they reach 280 mm.

There is also an increasingly intense and serious conflict between commercial and recreational fishers targetting Black bream in estuaries, such as the Blackwood River Estuary, as to which each user group regard as their traditional netting rights for that species (R.C.J. Lenanton pers. comm.). There is even evidence that, as a result of extreme fishing pressure, the size of Black bream in some heavily-fished estuaries is now far smaller than in unexploited estuaries (R.C.J. Lenanton pers. comm.).

If Black bream in different estuaries are confined to each of their respective water bodies, their numbers cannot be supplemented from marine waters or other estuaries when they come under heavy exploitation. The importance of this point is emphasised by the results of a recent study on catch per unit effort for the commercially very important estuarine catfish (*Cnidoglanis macrocephalus*), which likewise spawns within estuaries in south-western Australia (Laurenson *et al.* 1993a, b). These results showed that the fishery for this species in Wilson Inlet undergoes a series of "boom and bust" cycles that reflect the influence of extreme fishing pressures in certain years, combined with the capture of fish before they have reached sexual maturity (Steckis *et al.* 1995). Furthermore, if the circumstantial evidence that Black bream spawns in rivers is correct (Lenanton and Hodgkin 1985, Loneragan *et al.* 1989, Potter *et al.* 1983, Neira *et al.* 1992), the construction of dams and residential developments and the changes brought about by extensive land clearing in the catchment area must be influencing both access to and the quality of spawning habitats, and thus the spawning success of this species.

Reliable information on the age composition and growth of any species is also crucial for management since such data are essential for determining the relationship between age and length at first maturity and the age and length at which fish are collected by different sizes of mesh. While previous studies have used growth zones (annuli) on scales and/or whole otoliths to determine the ages of King George whiting and Black bream, many recent studies have shown that scales and whole otoliths are less reliable tools for ageing fish than sectioned otoliths, particularly for older fish (Beamish 1979, Beamish and McFarlane 1983, Campana 1984, Casselman 1987). Indeed, our recent study on the flathead, *Platycephalus speculator*, in south-western Australia, demonstrated that, unless the otoliths were sectioned, they were often providing an underestimate of the age of older fish by as much as 3-7 years, even though this species does not generally live beyond 12 years (Hyndes *et al.* 1992). Furthermore, there have been no published data which has validated that the growth zones in the scales or otoliths of King George whiting or Black bream have formed annually, a procedure that is considered crucial for accurate ageing studies (Beamish and McFarlane 1983).

There are no published data on the age and growth of King George whiting in Western Australia. In South Australia, the King George whiting reaches maturity at *ca* 300 mm and has been estimated as living up to 15 years (Scott 1954, Jones *et al.* 1990). The estimated growth rates of this species in south-eastern Australia vary greatly between regions (*cf* Scott 1954, Caton 1966, Gilmour 1969), as is also the case for Black bream in eastern Australia (*cf* Butcher 1945, Weng 1971, Hobday and Moran 1983). It is not clear whether the above marked differences in growth reflect differences between populations, due to such features as fishing pressure, genetic differences, density or diet, or whether they arose from variations in the interpretation of growth zones on the scales and otoliths. There is therefore clearly an urgent need to establish the best technique for ageing these two species in order to obtain validated data for determining the age composition and thus the growth rates.

Fish communities in estuaries

The four large estuaries (Swan, Peel-Harvey, Leschenault and Blackwood River estuaries) on the lower west coast of Western Australia each has a commercial and recreational fishery. Two of these systems (Peel-Harvey Estuary and Leschenault Estuary) now contain massive growths of macroalgae. There are now sound data on the species composition of the fish fauna of the first two of these systems, *i.e.* Swan and Peel-Harvey estuaries, and the way in which the fish communities are influenced by normal environmental and man-induced perturbations (e.g. Lenanton 1977, Potter *et al.* 1983, Lenanton *et al.* 1984, 1985, Loneragan *et al.* 1986, 1987, 1989, Loneragan and Potter 1990). However, there are no comparable recent data for the Blackwood River, Leschenault or Moore River estuaries which contain a considerable fishery for Black bream and, in the case for the first two species, also for King George whiting.

(IV) Objectives

The main objective of our studies was to produce sound quantitative data on the biology and mesh selectivity of King George whiting and Black bream, which would enable the Western Australian Fisheries Department to determine management strategies for these species, including in particular estimating the sustainable and optimum yields for both species. This would enable the Department to be able to allocate an equitable share of the resources to the commercial and recreational fisheries. This in turn will necessitate the achievement of the following.

(i) Determine, for both species, the age and size composition and growth of selected populations.

(ii) Determine, for both species, the spawning period and location, the age and length at sexual maturity, and the fecundity and its relationship to body size.

(iii) Determine, for both species, the age at the current minimum legal size for capture and the age and length at which fish are taken in the minimum legal-sized mesh used by the commercial and recreational fisheries.

(iv) Use the above data to estimate the degree to which the different populations are being exploited prior to the attainment of sexual maturity.

(v) Establish whether the growth rates, and size and age at maturity of King George whiting and Black bream are influenced by fishing pressures and/or biological factors, such as density and dietary differences and, in the case of King George whiting, by the type of habitat occupied by the juveniles, *i.e.* estuary or inshore marine waters.

(vi) Determine the habitats occupied by King George whiting and by Black bream at different stages in the life cycles of these species.

(vii) Determine whether different stocks of Black bream are genetically distinct.

(viii) Use the catches taken during sampling in the Moore River Estuary, Leschenault Estuary and Blackwood River Estuary to elucidate the influences of environmental variables and the presence of macrophytes on the fish compositions of these estuaries.

(V) Methods

Sampling regime for King George whiting

A 21.5 m long seine net, comprising 9 and 3 mm woven mesh in the wings and pocket, respectively, was used during the day and night at six-weekly intervals between February and December 1994 to collect King George whiting in the shallow waters (<1.5 m) of Leschenault Estuary and of the basin, channel and Deadwater Lagoon of the Blackwood River Estuary, and also of adjacent marine embayments of both estuaries (Figs 1, 2, 3).

A 120 m long gill net, comprising six 20 m panels with sequential stretched mesh sizes of 38, 51, 63, 76, 89 and 102 mm was used to collect King George whiting from three sites in the deeper waters in each of the riverine, lower and middle regions of Leschenault Estuary and in the riverine and basin regions of the Blackwood River Estuary at seasonal intervals between September 1993 and May 1994 (Figs 2, 3). Due to the very low numbers of King George whiting caught in the larger meshes of the above gill net, a 100 m long gill net, comprising five 20 m panels with sequential stretched mesh sizes of 38, 44, 51, 57 and 63 mm, was used to sample this species in Cockburn Sound in each month between January and September 1995 (Figs 1, 4). Gill nets were set shortly before dusk and collected three hours later.

The 21.5 m seine net was also used to collect King George whiting during the day and night at six-weekly intervals at three sheltered sites and one exposed site in Shoalwater Bay (Figs 1, 4). In addition, a 5.5 m long seine net, comprising 1 mm woven mesh, was used to sample newly-settled larvae and young juveniles in the nearshore waters of both Shoalwater Bay and Cockburn Sound at two-weekly intervals between August and December in 1994 (Fig. 4). Since the above sampling techniques, and also otter trawling in deeper waters, yielded very few fish >350 mm, these large fish were obtained between February 1993 and August 1996 from recreational anglers, who were fishing in deeper waters of the Perth metropolitan region. These anglers kindly supplied frozen, filleted carcasses including the gonads.

Sampling regime for Black bream

A 41.5 m long seine net, with 25 and 9.5 mm stretched mesh in the wings and pocket, respectively, was used to collect Black bream at three sites in the shallow waters of the downstream and middle regions of the Swan Estuary (Figs 1, 5) in each month between September 1993 and April 1995. Black bream were also sampled using a 120 m long gill net, comprising six 20 m panels with sequential stretched mesh sizes of 38, 51, 63, 76, 89 and 102 mm, in deeper waters at each of the above sites, and at three sites in the upstream region, between September 1993 and August 1994 (Fig. 5). Gill nets were set shortly before dusk and collected three hours later. As the results of the first year of the study showed that very few fish were caught in the two smallest meshes, *i.e.* 38 and 51 mm, the panels containing these meshes were removed from the net, and panels containing 115 and 127 mm mesh were added to capture the larger and older individuals. Monthly sampling continued in the same three regions in the following six months. Salinity and temperatures at the surface and bottom of the water column were recorded at the time of sampling. Black bream were also collected by hand line in the upper reaches of the Swan Estuary, both by ourselves and by recreational fishers. Seasonal sampling using the above methods was also carried out in the Moore River Estuary. A maximum of 100 fish collected using the above sampling methods from these two estuaries, as well as from Nornalup-Walpole Estuary, Wellstead Estuary, Bowes River Estuary, Margaret River Estuary and Beaufort River Estuary, was also used for genetic analyses.

Laboratory procedures for King George whiting and Black bream

The total length and weight of each fish was measured to the nearest 1 mm and 0.1 g, respectively, and those gonads which could be identified as either testes or ovaries were assigned to one of eight stages of development that were adapted from those of Laevastu (1965). NB: Since the body and gonads of larger individuals of King George whiting were provided after filleting, the total body weight of these fish could not be recorded and thus the gonadosomatic indices of this species could not be calculated. Ovaries of the larger females of both King George whiting and Black bream collected in each month of the study were used for histological studies. Samples from each calendar month during this study were pooled in order to provide histological data for up to 10 ovaries from each month of the year. The minimum and maximum diameters of 30 oocytes in each section were measured to the nearest 5 µm. Hydrated oocytes were able to be detached from the whole ovaries of Black bream and measured to the nearest 5 µm. Since hydrated oocytes could not be detached from the whole ovaries of King George whiting due to freezing, and had also collapsed as a result of the sectioning process, their diameters could not be measured.

The birth date was assigned to the estimated mid-point of the peak spawning period, which was based on trends shown by gonadal and oocyte development. von Bertalanffy growth curves were fitted to the individual lengths of female and males using the NONLINEAR subroutine in SPSS (SPSS Inc. 1988). The von Bertalanffy equation is $L_t=L_\infty[1-e^{-K(t-t_0)}]$, where L_t is the length at age t (years), L_∞ is the mean of the asymptote predicted by the equation, K is the growth coefficient and t_0 is the hypothetical age at which fish would have zero length, if their growth had followed that predicted by the equation. The mean lengths of both sexes of Black bream at first maturity (L_{50}) was estimated by fitting the logistic function to the proportion of mature fish in each 10 mm length interval by a non-linear technique (Saila *et al.* 1988), using the NONLINEAR subroutine in SPSS (SPSS Inc. 1988). The logistic equation is $P_L=1/[1+e^{(a+bL)}]$, , where P_L is the proportion of fish with mature gonads at length interval L, and a and b are constants. The L_{50}, which is the length at which 50% of the individuals possessed mature gonads, was derived from the equation $L_{50}=-a/b$.

The entire gut was removed from a maximum of 20 individuals from each sampling region in each season for both King George whiting and Black bream, and its contents subjected to microscopic examination. Each dietary item in the guts of both King George whiting and Black bream was identified to the lowest possible taxon and the contribution of each taxon was recorded as its percentage contribution of the total volume of all prey taxa present in each gut (Hyslop 1980). The percentage frequency of occurrence (%F) and the contribution by volume (%V) of each dietary category to the stomachs of all fish were calculated for each species, and for sequential length classes of 50 and 60 mm for King George whiting and Black bream, respectively.

The question of whether or not the Black bream populations from different estuaries are genetically distinct was investigated using starch-gel and cellulose-acetate electrophoresis of different isozymes. Samples of liver and muscle tissue from a subsample of fish from each estuary (see earlier) were used for these procedures.

The relationship between the length of King George whiting and Black bream caught in the different mesh sizes of our gill nets, which span the current legal minimum mesh size for both species, was used to calculate the size of fish most likely to be caught in a given mesh size (Kirkwood and Walker 1986).

Sampling of the fish communities

The fish faunas in the shallows of the Moore River, Leschenault and Blackwood River estuaries were sampled using a 21.5 m long seine net with 9 and 3 mm woven mesh in the wings and pocket, respectively. This net was used at three different sites in each of the mouth, lower and middle regions of the Moore River Estuary, the lower and middle regions of the Leschenault Estuary, and the estuary basin, entrance channel and Deadwater Lagoon of the Blackwood River Estuary (Figs 2, 3, 6). This net was also used to sample the fish faunas at three sites in two regions of Koombana Bay outside the Leschenault Estuary and in a region of Flinders Bay outside the Blackwood River Estuary (Figs 2, 3). A smaller seine net, which was 10.5 m in length with 3 mm woven mesh, was used at three sites in the uppermost riverine region of the Moore River Estuary (Fig. 6). Both nets fished to a depth of 1.5 m. Each site in each estuary and nearby embayment was sampled during both the day and night at six-weekly intervals between February and December 1994, except those in the Moore River Estuary, which were sampled monthly between February 1994 and February 1995. Three sites in the upper and apex regions of Leschenault Estuary were sampled during the day on five occasions between May and December 1994. Salinities and temperatures in the middle of the water column were recorded at the time of sampling.

The fish faunas in the deeper and more offshore waters of both the Leschenault and Blackwood River estuaries were sampled using a gill net which was 120 m long and comprised six 20 m panels, with sequential stretched mesh sizes of 38, 51, 63, 76, 89 and 102 mm. Seasonal sampling was carried out using gill nets in deep water sites over five seasons in the lower, middle and riverine regions of the Leschenault Estuary and over four seasons in the basin and riverine regions of the Blackwood River Estuary (Figs 2, 3). Gill nets were set shortly before dusk and collected three hours later. Salinities and temperatures at the surface and bottom of the water column were recorded at the time of sampling.

Laboratory procedures for fish communities

The total number and wet weight (to the nearest 0.1 g) of each species in each sample were recorded. The total length (TL) of each fish was recorded to the nearest 1 mm, except when the catches were large, in which case the measurements were restricted to a random subsample of 100 individuals. In the case of the fish caught using gill nets, the size of the mesh in which it was captured was also recorded.

Data analyses for fish communities

The numbers of each species in each of the three replicate seine samples from each sampling occasion were expressed as densities, *i.e.* number of fish per 100 m^2. Each species collected from seine and gill net samples was categorised as either a solely marine species (SM), marine straggler (S), marine estuarine-opportunist (O), estuarine species (E), semi-anadromous (A) or freshwater species (F). The various species were allocated to one of the above life-cycle categories on the basis of extensive studies of the biology of fish species in south-western Australian estuaries (see Potter *et al.* 1990, 1993). In the case of the Blackwood and Leschenault studies, where concomitant studies were carried out on the fish faunas of nearby protected marine environments, the estuarine category was further separated into those species capable of spawning in both estuarine and marine environments (E/M) and those which typically spawn only in estuaries (E).

Analysis of variance (ANOVA) was used to determine whether the number of species and the overall density of fish, on the basis of catches obtained using seine nets, differed significantly among regions, sampling occasions and time of day (day and night). Since the overall fish densities were shown by Cochran's C test to be heteroscedastic, they were $\log_{10}(n + 1)$ transformed, which resulted in homoscedasticity. When ANOVA showed a significant difference, the *a posteriori* Scheffe's multiple comparison test was used to determine which values were significantly different at the 0.05 probability level (Underwood 1981).

The densities of fish collected in the day and night using seine nets in different regions of each of the three estuaries were subjected to multivariate analyses. These data were classified by hierarchical agglomerative clustering, using group average linking, and ordinated using non-metric multidimensional scaling techniques in the PRIMER Package (Clarke and Warwick 1994). Prior to classification and ordination, the data were root-root transformed in the case of the Moore River and Blackwood River estuaries, and standardised over the range of densities for each species in the case of the Leschenault Estuary, and the Bray-Curtis similarity measure used to produce the association matrix. Analysis of similarities (ANOSIM) was used to test whether the faunal compositions in the different regions, sampling occasions or time of day were significantly different, while similarity percentages (SIMPER) was employed to determine which species were most responsible for the dissimilarity between groups (Clarke and Warwick 1994). Multivariate dispersion (MVDISP) was used to ascertain the degree of dispersion of the different samples (Somerfield and Clarke 1996).

(VI) Results

Biology of King George whiting

Comparison of age estimates using scales and whole and sectioned otoliths

The ages of approximately a quarter of the King George whiting, whose sectioned sagittal otoliths possessed one and two translucent zones, which were subsequently shown to be annuli (see later), were underestimated by one year using scales (Fig. 7a). Ages were underestimated by as much as two years for three and four year old fish, the underestimates increasing to between six and eight years for eight to 13 year old fish. Comparisons between ages determined from whole and sectioned otoliths of King George whiting demonstrated that, while the ages of all of the one year old fish were estimated correctly using whole otoliths, those of up to 21% of two to five year old fish were underestimated by one year using whole otoliths (Fig. 7b). Ages were underestimated by one or two years in the majority of fish >7 years old, and by as much as four years in an 11 year old fish, when whole otoliths were used. Thus, it is essential to section otoliths of King George whiting in order to obtain accurate estimates of the ages for individuals. The fact that the age of the larger representatives of King George whiting can only be determined accurately using otoliths when these structures had been sectioned, thereby parallels the situation with many other teleost species (*e.g.* Beamish 1979, Campana 1984, Hyndes *et al.* 1992).

Age, size composition and growth

The mean marginal increments in sectioned otoliths with one translucent zone ranged from 0.41 to 0.55 between May and October, but then fell precipitously to 0.11 in November, before gradually increasing to 0.40 by April (Fig. 8). The marginal increments in otoliths with two, three and four to 13 translucent zones followed similar trends and thus also declined markedly between October and November (Fig. 8). The consistency of the strong seasonal trends exhibited by the marginal increments, irrespective of the number of translucent zones, with the values in each case declining markedly only once during a twelve month period, demonstrates that translucent zones are formed annually and can thus be considered to represent true annuli.

Small King George whiting were first caught using seine nets in nearshore waters in early November, in which month their lengths ranged from 25 to 50 mm. By late December, the maximum length had increased to 68 mm. The length range of the corresponding cohort, *i.e.* those comprising fish whose otoliths did not possess a translucent zone, increased to 122 to 298 mm by August to October (Fig. 9). Since the birthdate of King George whiting, represented by the middle of the spawning period, was designated as 1 August (see later section), the members of this cohort had begun to enter their second year of life during the first of these latter three months, *i.e.* they were early 1+ fish. By November, a translucent zone had become discernible at the edge of the otoliths belonging to these fish. The length range of fish possessing one translucent zone in their otoliths ranged from 140-300 mm in November to January, to 240-420 mm between August and October, when they had just commenced their third year of life, *i.e.* they were early 2+ fish (Fig. 9). The oldest female and male King George whiting, which were both 13+, had lengths of 590 and 570 mm, respectively, which were the maxima recorded for the two sexes.

Growth curves derived for female and male King George whiting (Fig. 10) differed significantly ($p<0.05$). The asymptotic lengths (L_∞) for females and males were 535 and 501 mm, respectively, and the growth coefficients (K) were 0.46 and 0.52, respectively (Table 1). The asymptotic lengths (L_∞) and growth coefficients (K) of King George whiting in south-western Australia lay within the range of those of this species in south-eastern Australia. However, these two parameters varied markedly in different localities of that latter region, *i.e.* from 444 to 715 mm and from 0.15 to 0.45, respectively (Scott 1954, Caton 1966, Gilmour 1969, Jones 1980, Jones *et al.* 1990). The variability in the values for both L_∞ and K derived for King George whiting in south-eastern Australian waters reflect either differences in the patterns of growth of this species in different locations, or errors associated with deriving the ages of fish from growth zones in scales or whole otoliths.

Age and length at sexual maturity

For the purposes of determining the length and age of King George whiting at maturity, the data for mature ovaries (stages V-VI) and recovering spent ovaries (stages VII-VIII) have been combined (Fig. 11). During the spawning period, *i.e.* June to September (see later), mature gonads were found in only one female King George whiting in the length range 350 to 399 mm (Fig. 11a). The proportion of female fish with mature ovaries increased sharply to 71% in those of 400 to 449 mm, and to 100% in those >500 mm. Maturity was first attained by females at the end of their third year of life, when almost 30% of fish possessed mature ovaries (Fig. 11b). However, by the end of the fourth year of life, the proportion of mature females had increased markedly to *ca* 90%. A similar pattern was shown by the maturity indices for male fish (data not shown).

The above results indicate that female and male King George whiting both reach maturity at the end of their fourth year of life or when they have attained a length of *ca* 400 mm. Thus, the length at which King George whiting reaches maturity in south-western Australia is far greater than the 320 mm at which it occurs in south-eastern Australian populations of this species (Scott 1954, Caton 1966, Cockrum and Jones 1992).

Minimum legal size and exploitation

An examination of the selectivity of different mesh sizes in gill nets shows that the 38, 51 and 63 mm stretched mesh sizes predominantly capture King George whiting in the length ranges 180-370, 280-470 and 370-550 mm, respectively (Fig. 12). Since commercial fishers in estuaries normally use a mesh size of 51 mm, they potentially target fish with lengths between 280 and 470 mm. However, few fish >320 mm are typically found in estuaries and shallow marine embayments (see earlier), and thus commercial fishers predominantly catch King George whiting with lengths of 280-320 mm.

Since the current minimum legal size for capture of King George whiting in Western Australia is 250 mm on the west coast and 280 mm on the south coast, and this species does not reach maturity until 400 mm, representatives of King George whiting are subject to exploitation by commercial and recreational fishers well before this species attains maturity. Furthermore, the vast majority of the effort for the capture of this species by these user groups is concentrated in estuaries and shallow marine embayments, regions which the juveniles use before they start their size-related offshore movement into deeper areas, where they congregate around reefs (see later). As there is limited fishing effort for King George whiting in these offshore waters, there is only light exploitation of this species after it has attained maturity. Since the vast majority of fishing activity for King George whiting is restricted to the nursery grounds, the fishery for this species is essentially a "gauntlet" fishery. The data produced from the present study on the biology of King George whiting will allow the W.A. Fisheries Department to undertake initial stock assessment, *i.e.* yield per recruit, analyses.

Spawning period and location

Since the majority of King George whiting did not reach maturity until the end of their fourth year of life, the following monthly trends shown by gonadal stages have used data from those fish that were 3.4 years old, *i.e.* fish that would be expected to reach maturity in the following spawning period. In order to explore these monthly trends, the data for mature ovaries (stages V-VII) were combined (Fig. 13). The ovaries of all female King George whiting caught between January and May were at either stages III or IV (Fig. 13). Mature ovaries, *i.e.* stages V-VII, were found in over 70% of females by June and in 90% by July and August. The proportion of mature ovaries (stages V-VII) declined to 43% in September, whereas that of recovering/spent ovaries (stage VIII) increased from 9 to 48% between August and September (Fig. 13). Female fish with mature ovaries declined further in prevalence to 3% in November and were not found in December, whereas stage VIII ovaries comprised *ca* 8% in both of those two months (Fig. 13).

In each month, the oocyte diameters for King George whiting exhibited a well-defined mode between 50 and 80 μm, representing the perinuclear oocytes (Fig. 14). Yolk vesicle and yolk granule oocytes first appeared in ovaries in April, when the diameters of these larger oocytes ranged between 220 and 460 μm. However, many of these yolk vesicle and yolk granule oocytes were undergoing atresia. In the following month, the maximum oocyte diameter declined to 150 μm, reflecting the fact that no yolk vesicle or yolk granule oocytes were present. By June, the maximum diameter increased to 460 μm (Fig. 14), as a result of the development of yolk vesicle and yolk granule oocytes. While these large oocytes were abundant between June and August, they were reduced in numbers in September and absent during the remainder of the year (Fig. 14). By October, the few remaining yolk vesicle and yolk granule oocytes were at an advanced stage of atresia.

Hydrated oocytes were found in some ovaries between June and August. Since the ovaries in those months sometimes contained large numbers of post-ovulatory follicles, they had already discharged hydrated oocytes. Furthermore, hydrated oocytes and post-ovulatory follicles were occasionally found in the same ovary. In May, and in November and December, the oocyte diameters never exceeded 120 μm, reflecting the absence of yolk vesicle and granule oocytes.

Since yolk granule oocytes and post-ovulatory follicles, and in some cases also hydrated oocytes, were found in some ovaries of King George whiting, during the spawning period, this species is a multiple spawner, as is also the case with this species in South Australia (Cockrum and Jones 1992) and other whiting species in south-western Australia (Hyndes *et al.* 1996a, b, Hyndes and Potter 1997). We were unable to ascertain the spawning frequency over the spawning period, and therefore also the total annual fecundity of this species.

Since large numbers of yolk granule and hydrated oocytes and post-ovulatory follicles were first found in the ovaries of large female King George whiting in June and were present in ovaries through to September, this species spawns during this four month period. As the advanced oocytes present in ovaries in October and November were usually undergoing atresia, the spawning period of King George whiting rarely extends beyond September. This spawning period contrasts with the situation in south-eastern Australia, where it occurs in autumn and early winter (Bruce 1989, Bruce and Short 1991, Cockrum and Jones 1992). Thus, while the duration of spawning of King George whiting is similar in both regions, it is initiated three months later on the south-western than south-eastern coast of Australia. While most of those King George whiting caught by anglers at depths <10 m were mainly <400 mm in length and <4 years of age, those that were collected at depths from 6-50 m were predominantly greater than this length and age (Fig. 15a, b). Furthermore, those individuals of this species that contained mature or recovering/spent gonads, *i.e.* stages V-VII and stage VIII, respectively, were caught predominantly in and around reefs where waters were >6 m in depth (Fig. 15a, b).

The considerable number of large King George whiting, *i.e.* >400 mm in total length, that were collected near and around reefs, indicates that this species tends to congregate in this habitat after it has migrated offshore from its nearshore nursery grounds. Furthermore, the presence of mature and recovering gonads in the larger members of this species in the areas around reefs indicates that spawning occurs in this habitat. The water depths around these reefs where King George whiting spawns range widely in depth, *i.e.* 6-50 m. This species also apparently moves out into deeper water to spawn in south-eastern Australia (Scott 1954, Caton 1966, Gilmour 1969, Cockrum and Jones 1992).

Juvenile recruitment and habitat requirements

The juveniles of King George whiting migrate into the nearshore waters of marine embayments in south-western Australia in late September, when their standard lengths range from 14 to 24 mm (Fig. 16). Since this size range corresponds closely to that at which King George whiting settles into a benthic habit (Bruce 1995), these 0+ fish would have only recently moved into those nearshore waters. The fact that King George whiting, with standard lengths of 14 to 26 mm, were consistently present in nearshore waters between late September and early November (Fig. 16), indicates that this species moves into and settles in its nearshore nursery grounds predominantly during this period. Thus, King George whiting start entering those nearshore waters approximately three months after spawning is initiated, which corresponds to the period taken by the larvae of this species to be recruited into the nursery areas in South Australia (Bruce 1989, Fowler and Short 1996, B.D. Bruce unpubl. data). The fact that juvenile King George whiting start to be recruited into the shallows far later in the waters of south-western Australia than waters of South Australia, *i.e.* June *vs* September, reflects a far later initiation of spawning, *i.e.* June *vs* March (*cf* Bruce 1989, Fowler and Short 1996, B.D. Bruce unpubl. data).

The densities of King George whiting caught over a 12 month period in the nearshore waters of Shoalwater Bay and Warnbro Sound were significantly greater at the three sheltered sites than at the more exposed site. These results were supported by the fact that this species was caught in four sites sheltered from extreme sea conditions, but not in four nearby and far less protected sites over a further 12 month period. The juveniles of King George whiting remained in nearshore waters (depth <1.5 m) until they reached lengths of *ca* 250-300 mm, and ages of *ca* 1.5 years, after which they migrated out into deeper waters. King George whiting in south-western Australia move offshore at about the same size as this species in south-eastern Australia (Robertson 1977).

While over 500 and 300 King George whiting were caught in the Leschenault and Blackwood River estuaries, respectively, during the period in which these estuaries were sampled, none of this species was caught in marine waters immediately outside these estuaries during that period (see later). As in the marine waters of Shoalwater Bay and Warnbro Sound, all of the fish caught in these estuaries were <320 mm, as was also the case during earlier studies of the Swan and Peel-Harvey estuaries (Potter *et al.* 1983, Loneragan *et al.* 1989). Although King George whiting were present in these last two estuaries, the total number of fish caught when adjusted to constant effort were lower than those in the Leschenault and Blackwood River estuaries. It is thus relevant that sheltered marine embayments, such as Cockburn Sound, are adjacent to the Swan and Peel-Harvey estuaries, whereas no such environment is present outside those other two estuaries. It thus appears that, when sheltered marine regions are present on the lower west coast of Australia, King George whiting is more abundant in those waters than in nearby estuaries whereas the reverse situation pertains when nearshore, marine waters are not protected. Furthermore, King George whiting reach far larger sizes, *i.e* up to 400 mm, in Wilson Inlet and Nornalup-Walpole Estuary on the south coast, where the adjacent marine waters are more exposed than those on the lower west coast. Thus, King George whiting remain in the relatively sheltered environment of those estuaries for a longer period than estuaries on the lower west coast.

Dietary composition of King George whiting

King George whiting found in nearshore and relatively shallow inshore waters most frequently ingested crustaceans, particularly amphipods, carid decapods and copepods, and both errant and sedentary polychaetes (Table 2). Crustaceans and polychaetes contributed 47.6 and 39.5%, respectively, to the overall dietary volume. The most important prey taxa in terms of volume were errant polychaetes (32.9%), which mainly comprised onuphids and lumbrinerids, and amphipods and copepods, which contributed 21.4 and 10.4%, respectively, to the overall dietary volume (Table 2).

These diets are similar to those King George whiting found in other inshore marine waters and permanently open estuaries such as the Leschenault Estuary (Thomson 1957b). However, in the Wilson Inlet on the south coast, which has a different and relatively productive benthic fauna (Platell and Potter 1996), King George whiting has a different dietary composition (P.A. Orr unpubl. data). The diets of this species in that estuary consisted mainly of polychaetes (46% by weight), opisthobranch gastropods (15%), nemertean worms (13%) and bivalve siphons (13%). In contrast, relatively 'high quality' prey such as opisthobranch gastropods and bivalve siphons made only low contributions to the diet of King George whiting of the same size in marine waters. Since the growth rates of King George whiting in estuaries and nearshore marine waters are similar, the markedly different diets in those two types of environment does not appear to lead to differences in the growth rate.

Ontogenetic change was evident for fish ranging from 25-375 mm in length (Fig. 17), of which the smaller fish were found mainly in nearshore waters, and the larger in more offshore and deeper marine waters of Shoalwater Bay and Cockburn Sound. The diets of the smallest individuals were dominated by copepods and amphipods. As fish increased in size, the contribution of copepods declined sharply, while that of amphipods and errant polychaetes increased markedly, with the result that the diets of 125-174 mm fish were dominated by the latter two categories (Fig. 17). Although amphipods made a similar contribution to the diets of the next largest size class (175-224 mm), carid decapods also made a substantial contribution, and together with errant polychaetes, were most important in the diets of both this and the next largest length class. When fish exceeded 275 mm in length, opisthobranch gastropods first appeared in their diet and, together with algae and errant polychaetes, comprised most of the dietary volume of the largest length class (Fig. 17). Two large fish (data not shown), of 544 and 545 mm in length, had a diet which consisted entirely of large sipunculid worms.

Consultation with South Australian Research and Development Institute

Two of us (Glenn Hyndes and Ian Potter) visited SARDI on two separate occasions to discuss our results with Dr K. Jones and Dr A. Fowler. On the first of these visits, Glenn Hyndes attended a workshop on King George whiting, a meeting which proved invaluable in helping us discuss mutual problems in using scales and otoliths to age King George whiting and interpret our results. We particularly welcomed having input from Dr Jones, who has had such a long experience with working with King George whiting.

Biology of Black bream

Salinity and temperature

The mean monthly surface salinities in the downstream region of the Swan Estuary rose progressively from 3.3‰ in September 1993 to 26.8‰ in January 1994 and remained at these relatively high levels until May 1994, after which they fell precipitously to 5.0‰ in June 1994 (Fig. 18). Salinities remained at <5‰ until September 1994 when, as in the previous year, they started to increase progressively. While the mean monthly salinities in the middle and upstream regions followed a similar seasonal trend, there was a later increase, *i.e.* November/December *vs* September, and an earlier decrease, *i.e.* May *vs* June, in salinities in the upstream region (Fig. 18).

The mean monthly temperatures followed similar trends to the salinities, with maximum values of between 25 and 29°C being reached in late-spring and summer and minimum values of *ca* 15°C being attained during the winter months in the downstream and middle regions (Fig. 18). The temperature range was slightly greater in the upstream region (Fig. 18).

The difference between surface and bottom salinities was greatest during two periods in 1994, corresponding to the downstream flush of freshwater in winter and the encroachment of a saltwater wedge in summer. In May, the difference between the surface and bottom salinities was greater than 25‰ at site 9 decreasing to *ca* 6‰ further downstream at site 6. There was no difference between surface and bottom salinities at sites 6 to 9 in June by which time the flush of freshwater had progressed into the middle and downstream regions, where the surface and bottom values differed by *ca* 4‰ at site 4 and *ca* 10‰ at site 1. The encroaching wedge of salt water was evident in the downstream region at sites 2 and 3 in September, with the bottom salinity being *ca* 5‰ greater than that at the surface. The saline wedge extended upstream to site 5 in October and by November was minimal when the surface and bottom salinities differed by less than 2‰.

Distribution of Black bream in the Swan Estuary

Since very few Black bream were caught in the main basins and entrance channel of the Swan Estuary during extensive sampling of those regions between 1977 and 1981 (Loneragan *et al.* 1989, Loneragan and Potter 1990), sampling in the present study was restricted to the upper reaches of the Swan Estuary. Seine netting in the shallows of the downstream and middle regions of the upper Swan Estuary yielded small (generally <180 mm) and immature representatives of Black bream. While the vast majority of Black bream were caught in seine nets at the four most downstream sites (1 to 4) in September and October 1993, representatives of this species were absent from the extreme downstream site, but were present in all other sites in November (Fig. 19). Black bream were also absent from the most downstream sites during December and January, with the highest numbers of fish recorded at the extreme upstream sites, *i.e.* sites 5 and 6. Relatively high numbers of this species were caught at the most upstream site 6, and at the downstream sites 2 and 3 during March and April. By May, the numbers of fish caught had decreased, with fish being caught at only site 6. Thereafter, representatives of this species were either absent or present in relatively low numbers throughout the sampling area during the winter months. Similar to the previous year, Black bream were restricted to the sites in the downstream region in September 1994, and were subsequently distributed throughout the downstream and middle regions until December. Furthermore, this species was generally restricted to the more upstream sites between January and March 1994 (Fig. 19).

Black bream were caught in gill nets in the deeper and more offshore waters at sites throughout the downstream, middle and upstream regions of the upper Swan Estuary in September and October 1993 (Fig. 20). During November and December, catches of this species tended to be restricted to the downstream and middle regions. Subsequently, Black bream were caught in low numbers in January, March and April, with the vast majority being caught in the extreme upstream sites in the last two of these months. However, in subsequent months Black bream tended to be caught throughout the three regions. While Black bream were distributed throughout the sampling area in September 1994, when panels with larger mesh sizes were added to the gill nets, the abundances of this species were generally greater at site 3 in the downstream region and sites 4 and 5 in the middle region, than at any other site in October, November and December (Fig. 20). Thereafter catches were restricted to the more upstream sites.

Comparison of age estimates using whole and sectioned otoliths

The ages of 27-67% of all Black bream, whose sectioned sagittal otoliths possessed 1-3 translucent zones, which were subsequently shown to be annuli (see later), were incorrectly estimated using scales, with the majority of fish being overestimated by one year (Fig. 21a). For the majority of fish of between eight and 11 years in age, the ages were overestimated by either one or two years. For one 19 year old fish, the age was overestimated by seven years using scales (Fig. 21a). Comparisons between ages determined from sectioned and whole otoliths of Black bream demonstrates that, although the ages of fish up to six years old were not underestimated using whole otoliths, those of up to 57% of 7-13 year old fish were underestimated by one year using whole otoliths (Fig. 21b). Ages were underestimated by 1-3 years in the majority of fish greater than 10 years old, and by as much as five years in both a 19 and 21 year old fish (Fig. 21b). Thus, as we have shown for King George whiting, it is crucial to section otoliths of Black bream which are greater than six years old, in order to obtain accurate estimates of the ages of individuals of this species.

Age, size composition and growth

The mean marginal increment on the otoliths of Black bream that possessed one translucent zone declined sharply from 0.59 in September and October 1993 to 0.10 in November 1993, before gradually rising to 0.92 in October 1994 (Fig. 22). This trend was repeated in the following year, with the marginal increment declining markedly in November 1994 and then rising progressively over the ensuing months. The mean marginal increment on the otoliths with two and three translucent zones followed similar trends (Fig. 22). As the number of otoliths with four or more translucent zones was small, the data for these otoliths have been pooled and, while the trends in the marginal increment were slightly variable, they still showed the same marked decline to minimal levels in November in both 1993 and 1994 (Fig. 22).

Since a marked decline in the mean values for the marginal increment occurred once only during the year, a single translucent zone is formed each year and can thus be considered to represent an annulus. Since the month in which the marginal increment declines (November) is also the month which has been estimated as corresponding to the middle of the spawning period (see later), fish caught in November with otoliths, for example, having one, two and three translucent zones (annuli), can be considered as having just become one, two and three years old, respectively.

Small representatives of Black bream, which did not possess a translucent zone on their otoliths, were first caught by seine net in shallow waters in September of 1993. The lengths of these 0+ fish, which were produced during the spawning period at the end of 1992, ranged from 81 to 115 mm (Fig. 23). The length range of this 1992 age class increased from 90-125 mm in October to 100-152 mm in November, in which month the otoliths had a single translucent zone visible on the edge of their otoliths. The 1993 year class first appeared in samples in March 1994, at lengths of 67-101 mm, with the corresponding 0+ fish being caught in April at lengths of 76-135 mm. This cohort was subsequently absent until September 1994.

The 1991 year class formed a strong cohort until the end of its third year of life, *i.e.* November 1994. The lengths of this cohort increased from 163-235 mm to 222-325 mm during this period (Fig. 23). Few fish were caught that were four years or older. The oldest female and male Black bream caught were 21+ and 15+, with lengths of 470 mm and 431 mm, respectively. The maximum lengths for females and males were 480 and 475 mm, these being recorded for a 15+ and 14+ fish, respectively.

The von Bertalanffy growth curves for female and male Black bream (Fig. 24), derived using a birth date of 1 November, differed significantly ($p<0.001$). The asymptotic lengths (L_{∞}) were 443 mm for females and 423 mm for males, while the growth coefficients (K) were 0.29 and 0.30, respectively (Table 3).

The asymptotic lengths for Black bream in the Moore River Estuary, were 463 and 342 mm for females and males, respectively. While the asymptotic lengths for particularly the females were similar to those in the Swan Estuary, the growth coefficients, *i.e.* 0.10 and 0.15 for females and males, respectively, were far lower than those for fish in the Swan Estuary (Table 3). The asymptotic lengths, which were generally >400 mm for both the Swan and Moore River estuaries, are far greater than those derived for Black bream in the Gippsland Lakes in Victoria, *i.e.* 240 mm (Hobday and Moran 1983). However, the asymptotic length for Black bream in the Gippsland Lakes was far lower than the maximum lengths of up to 410 mm LCF (length to caudal fork) for Black bream caught in that estuary (Hobday and Moran 1983). Such a discrepancy between these sizes may be due to the use of scales to age Black bream in the study by Hobday and Moran (1983), as the present study showed that the use of scales often overestimated the ages of this species.

Although the asymptotic lengths for Black bream were similar in both the Swan and Moore River estuaries, the growth rate of this species in the latter system was far slower. Indeed, Black bream attain the minimum legal size for capture, *i.e.* 250 mm, before the end of the third year of life, in the Swan Estuary, whereas this length was not reached until the eighth year of life for this species in the Moore River Estuary. Furthermore, while many individuals >250 mm were caught in the Swan Estuary, few individuals greater than the minimum legal size for capture were caught in Moore River Estuary.

Age and length at sexual maturity

For the purpose of determining the length and age of Black bream at maturity, the data for mature, spent and recovering ovaries (stages V-VIII) have been combined (Figs 25, 26). The prevalence of female fish with mature ovaries rose from 5% at 170 mm, to 77% at 220 mm and to 100% at 300 mm. The prevalence of males with mature testes followed similar trends (Fig. 25). The L_{50}, *i.e.* length when 50% of fish first became mature, was 218 mm for females and 212 mm for males (Fig. 25). Very few fish possessing mature gonads were caught until the end of their second year of life, when *ca* 50% were mature (Fig. 26). By the end of the third year of life, *ca* 90% of both females and males possessed mature gonads, and almost all fish at the end of their fourth year of life were mature (Fig. 26). These results indicate that Black bream in the Swan Estuary reach maturity at the end of the second year of life or when they have attained a length of *ca* 215 mm. In the Moore River Estuary, the majority of both female and male Black bream had attained maturity by 180 mm in length, corresponding to *ca* four years of age (data not shown). Since the current minimum legal size for capture of Black bream in Western Australia is 250 mm, this species reaches maturity before attaining that length.

Minimum legal size and exploitation

The selectivity curves using length-frequency data for Black bream in different mesh sizes showed that each mesh size caught a wide length range of this species and that there was a high degree of overlap in the length ranges taken by the different mesh sizes. The lengths of Black bream caught in 38, 51, 63, 76, 89, 102, 115 and 127 mm meshes predominantly ranged from 50-190, 80-230, 120-260, 150-290, 180-330, 220-370, 260-410 and 290-430 mm, respectively. Since the commercial fishers use gill nets with mesh sizes >115 mm to catch Black bream, the vast majority of fish caught would be >260 mm in length, and therefore greater than the minimum legal size at capture, *i.e.* 250 mm. In contrast, recreational fishers often use mesh sizes as small as 76 mm, which catch fish well below 250 mm, they thus potentially catch fish far lower than the minimum legal size at capture. This is particularly relevant for the south-eastern estuaries of western Australia, such as Wellstead Estuary, where Black bream are abundant throughout the estuary basin. However, the majority of recreational net fishers target other species such as the two species of mullet, and often cannot fish in regions where Black bream is most abundant due to the closure of these zones to recreational netting (R.C.J. Lenanton, pers. comm.).

Spawning period and location

The mean monthly GSIs of female Black bream rose sharply from 2.0 in July 1993 to a well-defined peak of 5.8 in October 1993, before declining to 0.6 in January 1994 (Fig. 28). They subsequently remained below 2.2 until August 1994, after which they increased to 8.2 in October 1994 and then fell precipitously to 0.8 in February 1995. The seasonal trends exhibited by male Black bream paralleled those described for females, with mean GSIs reaching maxima of 7.3 and 6.4 in October 1993 and October 1994, respectively (Fig. 28).

The proportion of female Black bream possessing ovaries at stage V (mature) was greatest (>70%) between September and December 1993 and between August and December 1994 (Fig. 29). The high proportion of mature ovaries in these periods accounts for the correspondingly high mean GSIs in these periods (*cf* Fig. 28). In both years, the proportion of stage V ovaries fell sharply after December, the majority of ovaries being at stages II-IV in January to April (Fig. 29). Stage VI (spawning) and stage VII (spent) ovaries were found in most of the months that stage V ovaries were present, the proportion of ovaries at these two stages being greatest in November and December of 1994 and 1995. Stage VIII (recovering) ovaries were usually present in the months after the decline in the proportion of ovaries at stages V-VII, *i.e.* January to March (Fig. 29), when mean GSIs also declined markedly (*cf* Fig. 28). The proportions of the different gonad stages followed similar trends in male Black bream (Fig. 29).

In each month, the oocyte diameters for Black bream exhibited a well-defined modal class that lay between 20 and 80 μm (Fig. 30), representing predominantly the perinuclear oocytes. The maximum diameter of oocytes ranged from 100 μm in April to a maximum of 350 μm in November and December, gradually declining to 310 μm in January, before falling sharply to 180 μm in February/March. In all months, at least some oocytes, representing the secondary phase of growth, were present. The large yolk vesicle and yolk granule oocytes formed a second modal class, ranging from 240-340 μm in May. This mode was absent in subsequent months until August, and thereafter increased in prevalence to a maximum in October and then declined over successive months to a minimum in January (Fig. 30). In those months where the maximum oocyte diameter was lowest, *i.e.* June/July, February/March and April, the majority of ovaries contained yolk vesicle and yolk granule oocytes that had undergone atresia. The diameters of hydrated oocytes, which were measured using whole oocytes that had become detached from the ovary during removal from the fish, ranged from 520 to 810 μm in May and increased to between 700 and 950 μm from October to December (Fig. 30). Since yolk granule and hydrated oocytes and post-ovulatory follicles were prevalent in the ovaries of Black bream between October and December, this species spawns predominantly during this three-month period. Large numbers of post-ovulatory follicles were present in the same ovaries that also contained yolk granule oocytes during the period between October and January, suggesting that, as with King George whiting, Black bream is a multiple spawner, *i.e.* spawns on several occasions over the breeding period. The late-spring to early-summer spawning of Black bream in south-western Australia corresponds closely to the spawning period of this species in south-eastern Australia (Butcher 1945, Harbison 1973).

The spawning of Black bream in the Swan Estuary typically occurs in the narrow, upper reaches of this system. Spawning was initiated when temperatures and salinities had increased to *ca* 20°C and 15‰ throughout the water column of that region of the estuary, *i.e.* October. Sequential monthly catches of Black bream in the Swan Estuary show that this species moves into the downstream and middle regions of the upper Swan Estuary during the spring months, when the salinity of these regions increases, as is also the case for this species in south-eastern Australian estuaries (Sherwood and Backhouse 1982).

Genetic structure of Black bream

In Western Australia, as in South Australia, Black bream may occasionally be washed out from estuaries to the sea during heavy flooding. The extent of migration among the local populations that occupy spatially-isolated estuaries in south-western Australia is currently unknown. Over the past 18 months, we have been using allozymic data to investigate the extent to which the populations of Black bream in different estuaries may be genetically isolated.

Samples of Black bream have been collected from eight estuaries, which together cover much of the range of this species in Western Australia (Fig. 1). The genetic analyses can be divided into two parts: (1) a preliminary analysis that was used to identify allozymic loci that display scorable genetic variation in Black bream and, (2) the use of those identified variable loci to document patterns of genetic variation within and among estuarine populations. Both starch-gel and cellulose-acetate electrophoretic methods were used to assay individuals from at least three, and usually six, different estuaries for a total of 50 enzyme systems. These assays revealed 37 presumptive loci that could be reliably scored. Of these 37 loci, 32 were monomorphic, 2 were marginally polymorphic (*Adh* and *Pgm-1*), and 3 were polymorphic (*Gpi, Ldh* and *Mdh-1*) and were thus subjected to more detailed analysis.

With the exception of a rare third allele for *Gpi*, which was found in just one local population (Moore River Estuary), each of the three polymorphic loci were represented by the same two alleles over the entire sampling range. Nevertheless, each locus exhibited significant allele frequency variation among samples ($p<0.001$). These significant differences were reflected by high values of FST. The mean FST value for the three loci was 0.14, while values for individual loci ranged from 0.57 (*Gpi*) to 0.29 (*Mdh-1*). NB: FST provides a measure of the extent of genetic subdivision among local populations. Broadly speaking, values less than 0.01 indicate panmixis, *i.e.* population mixing, while values between 0.01 and 0.10 indicate moderate levels of genetic differentiation and values of 0.10 or greater indicate marked population subdivision.

Although the sample from Bowes River Estuary in the northern region was very different from all other samples (Fig. 31) and contributed greatly to the high FST values (without Bowes River Estuary, the mean FST was only 0.07), we otherwise found no clear evidence of a geographic or other pattern to the allele frequency. Of the samples from the more southerly populations, those from each of Margaret River and Nornalup-Walpole estuaries were particularly distinctive, while the remainder formed a relatively homogeneous genetic grouping. However, although statistically significant allele frequency differences were found for each pairwise comparison of these relatively homogeneous samples ($p<0.05$), these differences often involved only one of the three sampled loci (usually either *Mdh-1* or *Ldh*). Nevertheless, even these single locus differences contrast with the virtually identical genetic compositions shown by two samples collected from the Moore River Estuary in 1994 and 1996 (Fig. 31).

In conclusion, our results indicate that, while Black bream shows no allelic substitutions, there is significant allele frequency divergence at allozyme loci over its range in south-western Australia. The apparent absence of allelic substitutions probably reflects a common and relatively recent evolutionary origin of the individual estuarine populations, while the allele frequency divergence is likely to reflect, in part, very limited gene exchange among the spatially-isolated local populations. In other words, the amount of movement of Black bream between estuaries is likely to be very limited. However, we detected extremely variable degrees of genetic differentiation and our data, which are based on variation on only three polymorphic allozyme loci, do not clearly resolve the relative contributions of gene flow, genetic drift and selection to population differentiation. Future studies employing more variable genetic markers (mitochondrial DNA markers) are required to document properly the genetic structure of Black bream in Western Australia and in particular to investigate the true extent of, and basis for, genetic differentiation among populations that form relatively homogeneous allozymic groupings.

Dietary composition of Black bream

In the Swan Estuary, Black bream most frequently ingested detrital material, molluscs, algae and crustaceans (Table 4). In terms of the dietary volume, detrital material, molluscs and algae were most important, contributing 33.1, 23.2 and 22.7% to the overall dietary volume, respectively, With the exception of amphipods and mussels (*Xenostrobus* spp.), which contributed 21.2% and 6.5% to the diet, respectively, no other dietary category contributed more than 5% to the overall dietary volume.

In those estuaries where Black bream grows at a relatively fast rate, such as the Swan Estuary, diets may be dominated by mussels. In the Moore River Estuary, where the Black bream grow much more slowly, the diets are dominated by algae (G.A. Sarre unpubl. data). The differences in the growth rates of Black bream in these two estuaries may be related to differences in their diets. However, the densities of this species in the Moore River Estuary were far greater than in the Swan Estuary (G.A. Sarre unpubl. data) and therefore the slower growth rates in the former estuary may also be related to high densities of this species in that system.

Black bream in the upper reaches of the Swan Estuary did not exhibit very pronounced ontogenetic changes in their diet (Fig. 32). Thus, the diets of the smallest individuals were not clearly dominated by any dietary category, and comprised mainly algae, molluscs such as mussels, detrital material, amphipods and errant polychaetes. Although the diets of the next largest individuals contained these same categories, the contribution of molluscs had increased and remained between 15 and 35% in the diets of almost all of the larger length classes (Fig. 32). Amphipods were seldom consumed by fish larger than 170 mm in length. Diets of fish ranging from 170 to 349 mm in length were composed mainly of detrital material and molluscs, with small contributions made by algae. In the diets of the very largest fish (350-410 mm) only detrital material and algae were present (Fig. 32). However, other dietary studies of the Black bream in this system (A.N. Kanandjembo unpubl. data) indicate that many of the larger fish, *i.e.* >400 mm, almost exclusively consume mussels.

Composition of the fish communities of Moore River Estuary

Bar breaching, salinity and temperature

Between February 1994 and February 1995, the estuary was continuously open for 18, 5 and 23 days in May/June, early July and November 1994, respectively. During the first and last of these periods, the discharge of freshwater was sufficiently strong and continuous to produce a prominent channel in the bar. On several other occasions, increases in freshwater led to the mouth becoming intermittently open for periods that ranged from a few hours to one or two days. On these occasions, the channel produced in the bar was relatively shallow, *i.e.* <1 m. The mouth remained permanently closed at times in both June and July 1994 and between late November 1994 and February 1995.

Mean monthly salinities in the shallows at the mouth of the Moore River Estuary during the day, which were almost invariably the same as those recorded at night on the same day, declined gradually from 6.6‰ in February 1994 to 2.7‰ in April (Fig. 33). Following the breaching of the bar in early May, salinities rose to 6.1‰ in the middle of that month and then to 11.3‰ in June, before declining progressively to 2.5‰ in August. Salinities again rose sharply, after the sand bar had been breached early in November, reaching 25.0‰ on an incoming tide at night. Salinities declined markedly to 7.8‰ in December and *ca* 5‰ in January and February 1995 (Fig. 33).

Mean monthly salinities in the shallows of the lower, middle and upper regions of the estuary followed similar trends to those exhibited at the mouth of the estuary, but, in each month, declined progressively with distance from estuary mouth (Fig. 33). Mean salinities in the lower estuary rose above 7.0‰ in only three months (February, November and December 1995) and always remained below 4.5‰ in the middle and upper estuary.

Mean water temperatures in each month were almost invariably greater during the day than at night in each of the four regions of the estuary (Fig. 33). During the day, mean monthly water temperatures at the mouth of the estuary declined gradually from 23.7°C in February to a minimum of 15.6°C in June and July, before rising over the following two months to peak at 26.4°C in December (Fig. 33). While mean water temperatures in the middle and upper regions of the estuary followed the same seasonal trends as those in the lower estuary, they did rise to higher levels in these regions than in the mouth and lower region of the estuary in summer, *i.e.* 29.9 *vs* 26.4°C (Fig. 33).

The results of this study show that the pattern of opening and closing of the mouth of the Moore River Estuary, on the lower west coast of Australia, differs from that exhibited by seasonally closed estuaries in south-western Australia. In those estuaries, which are predominantly located on the south coast, the estuary becomes open when the heavy seasonal rainfall that occurs in this region during winter and early spring, results in freshwater building up to a sufficient level in the basin to cause the bar at the estuary mouth to be breached (Lenanton and Hodgkin 1985). In contrast, freshwater passes from the estuary of the Moore River into the sea at different times in the year, sometimes largely as a result of a considerable input of freshwater from artesian springs. The passage of water to the sea, which is therefore sometimes not directly related to seasonal rainfall, occurred occasionally for a few hours to two days and twice for at least 18 days. However, it was only during the latter two most protracted periods of opening, *i.e.* in late May to mid-June and in November, that the sand bar became sufficiently scoured out to produce a channel that was sufficiently deep to allow reasonable volumes of sea water to enter the estuary when freshwater discharge receded and thus produce a conspicuous increase in salinity within the estuary. On the second of those occasions, the mean salinity rose markedly from 4.9 to 25.0‰ inside the mouth and from 2.7 to 7.4‰ in the lower estuary, and even increased conspicuously in the middle estuary. The fact that the mean monthly salinity in the lower region of the Moore River Estuary never rose above 7.4‰ at any time in turn reflected the limited volume of saltwater entering the estuary, as a result of a combination of a small opening to the estuary mouth, the strong pressure of freshwater input and the small astronomic tidal action that characterises the region (Hodgkin and di Lollo 1956). The marked decline in salinities that occurred even in the estuary mouth, when it remained closed during the low rainfall period of late November to February, was largely due to the input of artesian springwater, but at a rate which was insufficient to breach the bar at the estuary mouth.

Faunal composition

A total of 91373 fish were caught in the shallows of the Moore River Estuary between February 1994 and February 1995, which, after the numbers in each sample from each site had been adjusted to 100 m^2, corresponds to a total of 105491 fish (Table 5). The samples contained 27 species, representing 17 families. The eight most abundant species each contributed more than 1.0% to the total number of fish and together accounted for 98.5% of that number. *Aldrichetta forsteri* was the only one of these eight species whose mean length exceeded 100 mm (Table 5).

The atherinid *Leptatherina wallacei* was by far the most abundant species, contributing 74.8% to the total number of fish (Table 5). The gobiid *Pseudogobius olorum* and the sparid *Acanthopagrus butcheri*, which contributed 8.8 and 5.4%, respectively, were the only other species to comprise more than 2.5% of the total catch. *Leptatherina wallacei*, *P. olorum* and *Favonigobius lateralis*, which do not grow to a large size, made a smaller contribution to biomass than to the number of fish. Indeed, the contribution of the first of these species to biomass was well under a third of its contribution in terms of numbers (Table 5). Conversely, *Aldrichetta forsteri, A. butcheri* and *Mugil cephalus*, which reach far larger sizes, each made far greater contributions to biomass than to the numbers of fish.

Number of species and densities in different regions

ANOVA showed that the number of fish species in the Moore River Estuary differed significantly among regions and months and between day and night (Table 6, Fig. 34). The interactions between region and month and between month and time of day were also significant. In the case of number of species, the mean squares were far higher for time of day than for region, which in turn were greater than those for month or the interaction terms. The number of species was significantly higher at night than in the day in the mouth and lower, middle and upper estuarine regions (Fig. 34). The mean monthly number of species in these four regions ranged from 3.7 to 8.3 at night, compared with 1.3 to 7.0 during the day (Fig. 34). The number of species was significantly greater in the lower region than at the mouth of the estuary and was significantly greater in both of these regions than in the middle and upper regions. This accounts for the negative correlation between number of species and distance from estuary mouth (Table 7). The maximum mean monthly number of species recorded in either the day or night in these four regions were 7.7, 8.3, 7.0 and 6.7, respectively (Fig. 34).

The mean densities of fish differed significantly among regions and months and between day and night (Table 6, Fig. 35). The mean squares of each of these main effects were greater than those for each of the two-way interactions, which were also significant. Region was the most important main effect (Table 6). The maximum mean monthly densities of fish at the mouth of the estuary and in the lower, middle and upper estuarine regions, in either the day or night, were 787, 2078, 1315 and 2473 fish per 100 m^2, respectively (Fig. 35). The densities of fish were significantly greater in the lower, middle and upper regions than at the mouth of the estuary and were also significantly greater in the upper estuary than in the lower estuary. Overall densities were thus positively correlated with distance from estuary mouth (Table 7). Densities in the upper estuary were significantly greater at night than during the day. The mean monthly densities in this region ranged from 139 to 2473 fish per 100 m^2 at night, and from 53 to 1187 fish per 100 m^2 during the day (Fig. 35).

The densities of *Leptatherina wallacei, Pseudogobius olorum, Acanthopagrus butcheri, Aldrichetta forsteri, Mugil cephalus* and *Afurcagobius suppositus* differed significantly among regions and months and between night and day (Tables 6, 8). The mean squares were by far the greatest for region for the first two species and for time of day for *A. butcheri* and *M. cephalus*. Region and time of day were both important for *A. forsteri* and *A. suppositus*. In the case of each species, the mean squares were far higher for the most important of these terms than for the corresponding interaction terms (Table 6). The densities of *L. wallacei* were significantly higher in the lower, middle and upper estuarine regions than at the mouth of the estuary and, like those of *P. olorum, A. butcheri, M. cephalus* and *A. suppositus*, were positively correlated with distance from estuary mouth (Table 7). In this context, it is worth noting that the numbers of four of the above five species were greatest in the upper estuary, even though this region could not be sampled in four of the 13 months (Table 8). Conversely, the densities of *A. forsteri* were significantly greater in the estuary mouth than in the lower, middle and upper regions and were negatively correlated with distance from estuary mouth (Tables 7, 8). The densities of *A. butcheri, A. forsteri, M. cephalus, A. suppositus* and of *L. wallacei* were significantly greater at night than during the day. Densities differed significantly among months and time of day for *Amniataba caudavittata* and among regions and months for

Favonigobius lateralis, the regional effect being particularly strong for the last species (Table 6). Densities of *A. caudavittata* were significantly higher in January and February of 1995 than in all other months and were also significantly higher during the day than at night. Densities of *F. lateralis* decreased progressively from the mouth to the middle and upper regions of the estuary (Tables 7, 8).

The overall density was inversely correlated with salinity and positively correlated with distance from estuary mouth (Table 7). In contrast, the number of species was not correlated with salinity and was inversely correlated with distance from estuary mouth (Table 7). The densities of *Leptatherina wallacei*, *Pseudogobius olorum*, *Acanthopagrus butcheri* and *Afurcagobius suppositus* were inversely correlated with salinity, whereas those of *Aldrichetta forsteri* and *Favonigobius lateralis* were positively correlated with salinity, which is consistent with the respective positive and negative correlations of these two groups with distance from estuary mouth (Table 7). Salinity was selected in the multiple regressions relating the overall density and the densities of *F. lateralis* and *A. suppositus* to both salinity and distance from the estuary mouth. Distance from estuary mouth was selected in comparable multiple regressions for the number of species, overall density and the densities of seven of the eight species (Table 7).

Contributions of different life-cycle categories

The fish caught in the Moore River Estuary contained two species of marine straggler, 15 species of marine estuarine-opportunist, seven species that complete their life cycle within the estuary, one semi-anadromous species and two freshwater species (Table 9). The three most abundant species, *i.e. Leptatherina wallacei, Pseudogobius olorum* and *Acanthopagrus butcheri,* each complete their life cycles within the estuary, as also do *Amniataba caudavittata* and *Afurcagobius suppositus,* which are likewise abundant in this system (Table 9). Marine estuarine-opportunists contributed 48.2% to the number of species, but only 4.8% to the number of fish. In contrast, although estuarine species contributed only 33.3% to the total number of species, they comprised 94.8% of the total number of fish (Table 9). The total number of fish increased progressively in an upstream direction and was thus greatest in the upper estuary (Table 9), even though this region could not be sampled in four months, due to the shallowness of the water.

One of the two marine stragglers caught in the Moore River Estuary, *Contusus brevicaudatus*, was represented by a single fish netted at the mouth of the estuary (Tables 5, 9). In contrast, 297 individuals of the second marine straggler, *Sillago vittata*, were caught. However, all but 13 of these were likewise collected from the mouth of the estuary (Table 8). The contribution of marine estuarine-opportunists to the number of species declined progressively from 52.2% at the mouth of the estuary to 22.2% in the upper region (Table 9). The percentage contribution of the number of individuals of this life-cycle category to the total catch fell in a similar manner, declining from 16.8% at the mouth of the estuary to 3.2% in the upper estuary. These trends for marine estuarine-opportunists are partly attributable to the fact that *Sillago schomburgkii* and *Sillago burrus* were rarely caught upstream of the lower region (Table 8), while other less abundant species in this life-cycle category, namely *Pomatomus saltatrix*, *Atherinomorus ogilbyi*, *Pseudorhombus jenynsii* and *Leptatherina presbyteroides*, were restricted to the estuary mouth. The contribution made by estuarine species to the number of species increased progressively from 34.8% at the mouth of the estuary to 66.7% in the upper region (Table 9). Likewise, the percentage contribution of individuals in this category rose from 80.7% at the mouth of the estuary to over 90% in each of the lower, middle and upper regions, reflecting in particular the trends exhibited by the densities of *P. olorum* and *L. wallacei* (Table 8). Indeed, 98.3% of the fish caught in the middle region of the Moore River Estuary belonged to species that spawn in the estuary (Table 9). The single semi-anadromous species, *Nematalosa vlaminghi*, was represented by only 12 fish. The two freshwater species, which were represented by 17 individuals in the upper region, nine in the middle region and one in the lower region, contributed <0.1% to the total number of fish (Table 9).

Classification and ordination

Classification separated the fish samples from the Moore River Estuary into two major groups (A and B) and nine outliers (Fig. 36). Eight of the nine outliers and all but one of the large number of samples comprising group A came from the mouth and lower estuary (Fig. 36). While one subgroup of seven samples in group B also came exclusively from the mouth and lower estuary, all of the large number of other samples in group B were collected from the middle and upper estuary. Samples also tended to separate on the basis of whether they were obtained during the day or night. Thus, the nine outlying samples, together with one group of six samples (five of which were from the lower estuary), and the majority of the samples in a group of 16 from the mouth and lower, middle and upper estuary, were collected during the day (Fig. 36). In contrast, the vast majority of a group of 32 samples collected from the lower and middle estuary, and one group containing nine samples from the middle and upper estuary, represented night-time collections.

The results of the MDS ordination complemented those produced by classification (*cf* Figs 36, 37). Thus, samples from the mouth tended to form a group which abutted that containing samples mainly from the lower region, which in turn was distinct from those of the middle and upper regions (Fig. 37). The relative dispersion values were greater for samples taken during the day than at night in all four regions of the estuary and were greater in the estuary mouth in both the day and night than in the other three regions at the corresponding time of day (Table 10). The far greater dispersion of the samples in the day than at night is well illustrated by the far wider distribution of their corresponding points for each region on the ordination plot (Fig. 37). ANOSIM demonstrated that the composition of the samples from each region differed significantly from that in each of the other regions during the day, and the same was true for the mouth and lower regions at night.

SIMPER showed that, in comparison with the middle and upper regions, the mouth and lower regions were characterised by greater densities of *Favonigobius lateralis*. The middle region was distinguished from the mouth and lower regions by the presence of much higher densities of *Pseudogobius olorum* and *Afurcagobius suppositus*, while differences between the middle and upper estuary were mainly due to the presence of greater densities of *P. olorum* in the former region.

Night-time samples were characterised by a greater abundance of *Mugil cephalus, Aldrichetta forsteri, Acanthopagrus butcheri* and *Afurcagobius suppositus*, while day-time catches were characterised by a greater abundance of *Amniataba caudavittata*.

Influence of bar breaching on marine species

Although the bar at the mouth of Moore River Estuary was only sufficiently scoured out on two occasions to allow substantial volumes of saltwater to enter this estuary, a total of 17 marine species were collected from this estuary, all but two of which also used estuaries opportunistically. The marine estuarine-opportunists included two species of mullet, *Mugil cephalus* and *Aldrichetta forsteri*, and two species of whiting, *Sillago schomburgkii* and *Sillago burrus*, all four of which were represented predominantly by their juvenile stages. The presence of numbers of these four marine estuarine-opportunist species in an intermittently closed estuary, such as that of the Moore River, emphasises that, when these species are young, they will capitalise on any opportunity to exploit the type of protected and productive environment that is provided by estuaries. The capture of only two species of marine straggler in the shallows of the Moore River Estuary contrasts with the situation in the shallows of the permanently open Swan Estuary just to the south, where this life-cycle category was represented by 37 species (Loneragan *et al.* 1989). The extreme paucity of marine stragglers in the Moore River Estuary may reflect the restrictive influence of the bar on fish movements. Alternatively, since such species may often be stenohaline, they would have been unable to survive in the very low salinities that characterised even the mouth of this system in all but one short period during the 13 months of the present study.

Some species, such as *Sillago schomburgkii*, the most abundant of the three whiting species, were no longer caught in the months immediately following the breaching of the bar in May, presumably due to their emigration from the estuary. In contrast, the two species of mullet, *i.e. Mugil cephalus* and *Aldrichetta forsteri*, were well represented in the system in the ensuing months. Indeed, small juveniles of *M. cephalus*, measuring only 20-40 mm, appeared in samples in May and June after the mouth had opened. Since the 0+ age class of *A. forsteri* first appeared in numbers in September, when the bar was only transiently open, they presumably entered when water levels at the mouth were low and saltwater intrusion was limited. In contrast to whiting species, considerable numbers of the two mullet species penetrated the middle and upper estuary, where salinities never rose above 4.5‰, thereby demonstrating their ability to survive in very low salinities. However, the relative extent of penetration upstream was very much greater with *M. cephalus* than *A. forsteri*, reflecting the marked tendency for the former species to migrate into low salinity, riverine regions (Thomson 1957c, De Silva 1980, Chubb *et al.* 1981, Blaber 1987, Potter and Hyndes 1994). The movement of marine species in and out of the estuary mouth, when the opportunity affords, accounts in part for the far greater variability in the samples of this region than in those of other regions within the estuary. In the case of the seasonally closed Beaufort River Estuary on the south coast of Western Australia, the opening of the bar led to a more than doubling of the number of fish species due to the entry of juveniles of certain marine teleosts (Lenanton and Hodgkin 1985).

The clupeid *Nematalosa vlaminghi*, which migrates from the sea into upper estuarine areas to breed (Chubb and Potter 1984), is found in the Moore River Estuary, but its numbers in this estuary are very much lower than in the Swan Estuary (Loneragan and Potter 1990). The low abundance of *N. vlaminghi* presumably reflects the inhibitory effect that would be posed to the migration of larger fish by the transient nature and usually small size of the opening.

Contributions of estuarine species

Although marine estuarine-opportunists were found in the Moore River Estuary, sometimes in appreciable numbers, the fish fauna of this estuary, in terms of number of individuals, was dominated by species that complete their life cycles within estuaries. Indeed, one estuarine species, *Leptatherina wallacei* accounted for three quarters of the total number of fish caught in this estuary. Furthermore, four of the five most abundant species belong to this life-cycle category and collectively contribute all but 8.7% of all fish caught. The dominance of estuarine species is further emphasised by the fact that they collectively contributed 94.8% to the total number of fish caught in the shallows of the Moore River Estuary, which is far higher than in the shallows of other permanently open estuaries, such as the Peel-Harvey (29.2%) and Swan (17.7%), which are located just to the south of this estuary (Loneragan *et al.* 1986, 1989). However, the contributions made by estuarine species in the Moore River Estuary on the lower west coast of Australia is less than in both the permanently open Nornalup-Walpole Estuary (98.4%) and the seasonally closed Wilson Inlet (98.5%) on the southern coast of Western Australia (Potter *et al.* 1993, Potter and Hyndes 1994). The lower contribution of estuarine species to the ichthyofauna of this lower west coast estuary than to those of south coast estuaries, even when they are permanently open, reflects the far greater prevalence of the 0+ age class of marine estuarine-opportunists along the lower west coast, presumably in turn reflecting a far more extensive spawning of these species in this region (Potter *et al.* 1993, Potter and Hyndes 1994, Ayvazian and Hyndes 1995).

Regional and diel variations in faunal composition

Classification showed that the composition of the fauna in the mouth and lower estuary differed from those in the middle and upper estuary. Ordination also demonstrated that the faunal composition changed progressively from the mouth to the lower estuary and then to the middle and upper estuary. This progressive shift can be attributed mainly to the sequential marked decline in the number of marine species in an upstream direction on the one hand, and to a progressive rise in the number of individuals representing estuarine species along this axis on the other hand. Although the ordination points for the middle and upper estuary overlapped, the degree of variation among samples was far greater in the latter region, which may reflect the changes in water levels of this region.

Composition of the fish communities of Leschenault Estuary

Salinity and temperature

Since mean monthly salinities and water temperatures were very similar between day and night, and between the eastern and western regions of Koombana Bay, the data for these variables have been pooled. Mean monthly salinities in the middle region of the Leschenault Estuary declined gradually from 34‰ in February to 29‰ in June and then sharply to a minimum of *ca* 23‰ in July, before rising progressively to *ca* 35‰ in November and December (Fig. 38). While salinities in the lower region followed a similar trend, they decreased to values below 25‰ far earlier than those in the middle estuary, and remained low for a longer period, *i.e.* June to September (Fig. 38). Salinities in Koombana Bay showed little variation between months, remaining above *ca* 30‰ throughout the sampling period (Fig. 38).

The trends shown by mean monthly temperatures were very similar in the middle and lower regions of the estuary, with values in both regions remaining above 25°C until March, and declining progressively to a minimum of *ca* 15°C in July (Fig. 38). Temperatures then increased steadily to between 25 and 27°C in those two regions in December. Although temperatures in Koombana Bay followed similar seasonal trends to those in the estuary, they never exceeded 25°C or fell to values lower than 17°C (Fig. 38).

Faunal composition of shallow waters

Totals of 21192 and 1770 fish, represented by 42 and 34 species, respectively, were collected by seine net from the shallows of the middle and lower regions of Leschenault Estuary and Koombana Bay, respectively, between February and December 1994 (Table 11). This corresponded to a total of 18269 fish in the estuary and 1526 fish in the bay, after the numbers in each sample had been adjusted to an area of 100 m^2 (Table 11).

The most abundant species collected in the estuary, *i.e.* those that contributed more than 1% to the total number of fish, included the estuarine/marine species *Favonigobius lateralis, Leptatherina presbyteroides* and *Apogon rueppellii*, the marine estuarine-opportunist species *Hyperlophus vittatus, Aldrichetta forsteri* and *Sillaginodes punctata*, and the estuarine species *Atherinosoma elongata, Pseudogobius olorum, Leptatherina wallacei* and *Afurcagobius suppositus*. Only two of the above species, namely *A. forsteri* and *F. lateralis,* ranked amongst the most abundant in Koombana Bay (Table 11). Other species that made a substantial contribution to the total catch in Koombana Bay included the solely marine species *Leseurina platycephala, Ammotretis elongatus* and *Pelsartia humeralis*, the marine straggler *Sillago bassensis* and the marine estuarine-opportunists *Contusus brevicaudatus, Atherinomorus ogilbyi, Arripis georgianus, Sillago schomburgkii* and *Pelates sexlineatus*. These species were either absent or collected in relatively low numbers in Leschenault Estuary (Table 11).

Life-cycle categories

The fish collected throughout the Leschenault Estuary comprised 42 species, of which nine were marine stragglers, 18 were marine estuarine-opportunists, 10 were estuarine/marine species and five were estuarine species (Table 12). In terms of the number of individuals, the marine stragglers contributed only 1.0% to the total catch, whereas the marine estuarine-opportunist and estuarine/marine categories represented

31.0 and 53.1%, respectively, and the estuarine category contained 14.9% of the total number of fish collected (Table 12).

With the exception of the marine stragglers, similar numbers of species belonging to each life-cycle category were found within both the middle and lower regions of the estuary (Table 12). Thus, the marine estuarine-opportunists were represented by 17 and 18 species and the estuarine/marine category by eight and nine species in the middle and lower regions, respectively, while the estuarine category was represented by five species in both regions. However, only four marine straggler species were recorded in the middle region, while nine species belonging to this group were collected from the lower region (Table 12). Of the 18 and 20 species caught at sites in the apex and upper regions of the Leschenault Estuary on five sampling occasions, the marine estuarine-opportunists were represented by seven and nine species, the estuarine category by four and three species, and the estuarine/marine category by four and five species for the respective regions (data not shown). Three marine straggler species were caught in each of these two regions.

The total number of individuals collected in the middle region of the estuary was more than twice that in the lower region, *i.e.* 12312 *vs* 5957 (Table 12). This is mainly due to the far greater contribution of marine estuarine-opportunists to the total numbers in the middle region. The marine estuarine-opportunist and estuarine/marine categories each contributed *ca* 40% to the total catch in the middle region, while the former category contributed only 13.1% and the latter category over 80% to the total number of individuals in the lower region of the estuary (Table 12). Individuals belonging to the estuarine category made a far greater contribution to the fish fauna of the middle than the lower region, *i.e* 19.2 and 6.1%, respectively, whereas the marine stragglers were represented by <1.5% of the total number of fish in both regions (Table 12). Marine estuarine-opportunists contributed 2.7 and 17.1% to the total catch in the apex and upper region, respectively, while the estuarine/marine category contributed 83.4 and 67.2% to the catch for each respective regions (data not shown). The estuarine category contributed *ca* 14% to the total catch of these two regions, while the contribution of marine stragglers was negligible.

The 34 species caught in Koombana Bay comprised six solely marine, five marine stragglers, 17 marine estuarine-opportunists and six estuarine/marine species (Table 12). The majority of individuals collected in the bay were represented by marine estuarine-opportunists, *i.e.* 44.5%, while individuals belonging to the solely marine category also made a substantial contribution to the total catch, *i.e.* 27.9%. Marine stragglers contributed 17.8% and the estuarine/marine category 9.8% to the total number of individuals (Table 12).

A greater overall number of species was recorded in the western and relatively protected region of Koombana Bay than in the eastern and more exposed region, *i.e.* 32 *vs* 22 species (Table 12). This was attributed mainly to the far higher number of marine estuarine-opportunist species collected in the former region, *i.e.* 17 *vs* 11. The remaining life-cycle categories were represented by a similar number of species in each region of the bay. Thus, the solely marine category was represented by three and five species and the estuarine/marine category by four and six species in the eastern and western regions of Koombana Bay, respectively. Four marine straggler species were recorded in both of these regions of the bay (Table 12).

With respect to the number of individuals, the solely marine and marine estuarine-opportunist categories dominated the fish fauna in the eastern and more exposed region of Koombana Bay, contributing 46.7% and 38.5% to the total catch, respectively (Table 12). Marine estuarine-opportunists made by far the greatest contribution to the total number of individuals collected in the western and more protected region of Koombana Bay, *i.e.* 47.3%, while the members of the solely marine species represented only 19.0%. The contribution made by marine stragglers and the estuarine/marine categories to the total catch in the eastern region of Koombana Bay was also relatively lower than in the western region of that bay, *i.e.* 12.9 *vs* 20.1% and 1.9 *vs* 13.6%, respectively (Table 12).

Number of species and densities in different regions

ANOVA showed that the number of species in the Leschenault Estuary and Koombana Bay differed significantly among both regions and months (Table 13, Fig. 39). The interactions between region and month and between region and time of day were also significant, but the mean squares for the main effects were considerably higher than those for the interaction terms (Table 13). Scheffé's *a posteriori* test showed that the numbers of species were significantly greater in both of the estuarine regions and in the western region of Koombana Bay than in the eastern and more exposed region of that bay. Furthermore, the numbers of species were significantly greater in the middle region of the estuary than in the lower estuary and the western region of Koombana Bay. These points are illustrated by the fact that the mean monthly numbers of species during both the day and night were usually greater than four in both of the estuarine regions and in the western region of Koombana Bay, but almost always less than four in the eastern region of the bay (Fig. 39). Additionally, the number of species often exceeded eight in the middle estuary, but was invariably less than this value in the lower estuary and the western region of Koombana Bay (Fig. 39). Scheffé's *a posteriori* test also showed that the numbers of species were significantly higher in November than in July and September.

The total densities of fish differed significantly among regions and months and between day and night (Table 13, Fig. 39). However, the mean square for region was far higher than that for both month and time of day (Table 13). The interactions between region and month, region and time of day and time of day and month were also significant, but these mean square values were considerably less than for the main effects (Table 13). Scheffé's *a posteriori* test showed that the densities of fish captured in both estuarine regions were significantly higher than those in both regions of Koombana Bay. This difference was emphasised by the fact that the mean monthly densities of fish during both the day and night were mostly greater than 55 fish per 100 m^2 in both the middle and lower estuary, whereas they were almost always less than 35 fish per 100 m^2 in both regions of Koombana Bay (Fig. 39).

Classification and ordination

Classification of the mean densities of each species, collected during the day and night in each region and month, clearly separated the samples obtained from the estuary from those collected in Koombana Bay (Fig. 40). Within each of these two major clusters, there were no clear groupings of samples from either region within the estuary or bay, or from certain periods of the year, or time of day (Fig. 40). The results of the MDS ordination complemented those of classification (*cf* Figs 41, 41), producing two distinct groups representing the samples from the Leschenault Estuary and also those from Koombana Bay (Fig. 41). As was found for classification, there were no apparent groupings in the ordination plot for the different regions in the estuary or bay, different months or between day and night.

Faunal composition in deeper waters

A total of 1304 fish representing 22 species was collected by gill nets in the deeper waters of Leschenault Estuary and the lower reaches of the Collie River between September 1993 and July 1994 (Table 14). Of the species caught by gill nets, one species was anadromous, 15 were marine estuarine-opportunists, three were species that complete their life cycles in the estuary and three species were marine stragglers (Table 14). The anadromous species *Nematalosa vlaminghi* contributed 35.7% to the total catch, while the marine estuarine-opportunists *Mugil cephalus, Aldrichetta forsteri* and *Pomatomus saltatrix* contributed 29.5, 8.1 and 7.2%, respectively (Table 14).

Faunal composition of Leschenault Estuary

The fish fauna in the shallows of Leschenault Estuary was dominated by small teleosts, such as *Favonigobius lateralis*, *Leptatherina presbyteroides* and *Atherinosoma elongata*, which are able to complete their entire life cycles in estuaries, and in the case of the first two of these species, also in protected marine waters (Prince and Potter 1983, Potter *et al.* 1990). Thus, estuarine-spawning teleosts, which contributed between 59 and 97% to the total catch in different regions of Leschenault Estuary, dominate the fish fauna in the shallows of this estuary. The high prevalence of these estuarine-spawning fish in Leschenault Estuary thereby parallels the situation in the shallow waters of other estuaries in south-western Australia, such as the Swan and Peel-Harvey estuaries on the west coast and Nornalup-Walpole Estuary and Wilson Inlet on the south coast of that region (Loneragan *et al.* 1987, Loneragan and Potter 1990, Potter *et al.* 1990, 1993, Potter and Hyndes 1994).

Over 60% of the species found in Leschenault Estuary comprised marine species, with the majority of these entering estuaries as juveniles and using the estuarine environment as a nursery ground. Representatives of these marine estuarine-opportunist species also made a substantial contribution to the total number of fish in the shallows of Leschenault Estuary, in which the juveniles of species such as *Hyperlophus vittatus*, *Aldrichetta forsteri*, *Sillaginodes punctata* and *Mugil cephalus* enter in relatively large numbers. Since larger individuals of *A. forsteri* and *M. cephalus*, *i.e.* ≥1+ age class, were regularly caught in gill nets in the deeper and more offshore waters, these relatively long-lived species remain in the estuary for a protracted period before moving out into marine spawning areas. Furthermore, while larger *S. punctata* were rarely caught in gill nets during the present study, this species forms an important component of the commercial and recreational fishery in Leschenault Estuary, where large numbers of fish >250 mm are often caught (Australian Bureau of Statistics unpubl. data). The low numbers of these larger and older fish, *i.e.* 1+ fish, caught during this study suggests that the recruitment strength of this cohort in Leschenault Estuary was weak. However, relatively large numbers of 0+ *S. punctata* were caught in the seine nets, possibly reflecting a stronger recruitment of this younger age class into Leschenault Estuary. The large numbers of marine estuarine-opportunists in Leschenault Estuary parallels the situation in the Swan and Peel-Harvey estuaries on the lower west coast of Australia, and further emphasises the importance of estuaries as nursery grounds for many marine species.

Classification and ordination showed that the fish fauna in the shallows of Leschenault Estuary differed markedly from that of the nearshore waters in the adjacent Koombana Bay. This difference can in part be attributed to the presence of marine species that were restricted to marine waters and estuarine species which were found only in the estuary. In addition, many marine species were far more abundant in the estuary than in the neighbouring marine embayment. This conclusion is supported by the fact that species such as *Sillaginodes punctata* and *Sillago burrus* were present in relatively high numbers in Leschenault Estuary, but absent in adjacent marine waters. This presumably reflects the fact that, although the regions sampled in Koombana Bay were the most protected in that area, they were not as protected as those extreme cases where nearshore waters are well protected from prevailing wind and wave activity due to the presence of islands and prominent headlands. Indeed, *S. punctata* and *S. burrus* occupy only highly protected waters, whereas *Sillago bassensis*, which was regularly caught in Koombana Bay, typically occupies more exposed waters (Hyndes *et al.* 1996a). Thus, while the juveniles of marine estuarine-opportunist species, such as *Aldrichetta forsteri* and *Contusus brevicaudatus*, occur in both environments, estuaries act as important nursery habitats for certain marine species, particularly when suitable habitats are not present in nearby marine embayments.

Composition of the fish communities of Blackwood River Estuary

Salinity and temperature

Since the mean salinities and water temperatures at the three sites in each region were almost invariably similar between day and night, the data for these two variables in the day and night in each region have been pooled. Mean monthly salinities in the Blackwood River Estuary varied markedly between regions and months (Fig. 42). Salinities in the basin and channel remained above *ca* 25‰ until May, but then started to decline precipitously in June, eventually reaching a minimum of *ca* 2 and 4‰, respectively, in July. Salinities remained low in these two regions until September, after which they rose sharply, reaching *ca* 29‰ in the basin and 32‰ in the channel in December (Fig. 42). Although salinities in Deadwater Lagoon remained above 28‰ for most of the year, they did decline to *ca* 23‰ in July. Salinities in Flinders Bay remained above 31‰ in all months except March, when they declined to *ca* 29‰ (Fig. 42).

The trends shown by the mean monthly temperatures in the basin and channel were very similar, with values reaching relatively high levels of *ca* 24°C in March, before declining progressively to a minimum of *ca* 14°C in July (Fig. 42). Temperatures in both regions then increased to *ca* 24°C in November. In Deadwater Lagoon, temperatures reached a peak of *ca* 27°C during March, and then decreased markedly to *ca* 17°C in May and remained at about this level over the ensuing months, before rising sharply to *ca* 27°C in November. Although temperatures followed the same seasonal trends in Flinders Bay as in each region of the estuary, they ranged only from *ca* 18 to 23°C (Fig. 42).

Faunal composition of shallow waters

A total of 63587 fish, representing 49 species, was collected by seine net from the shallows of the estuary basin, entrance channel and Deadwater Lagoon of the Blackwood River Estuary, and from Flinders Bay between February and December 1994 (Table 15). This corresponded to a total of 54816 fish, after the numbers of fish in each sample in each region had been adjusted to an area of 100 m^2 (Table 15). The numbers of species recorded in the estuary basin and entrance channel, *i.e.* 31 and 34, respectively, were greater than the 23 collected in Deadwater Lagoon and the 26 caught in Flinders Bay. However, the total number of fish caught in Deadwater Lagoon, *i.e.* 25021, was far greater than in both the estuary basin and entrance channel, *i.e.* 10031 and 16654, respectively, and more than eight times the 3110 obtained in Flinders Bay (Table 15).

The suites of the relatively most abundant species, *i.e.* those that typically contributed more than 1% to the total number of fish, were similar in the estuary basin, entrance channel and Deadwater Lagoon of the Blackwood River Estuary, but these differed markedly from that in Flinders Bay (Table 15). Thus, in terms of relative abundance, the same nine species were the most numerous species in both the estuary basin and entrance channel, and seven of these were amongst the eight most numerous species in Deadwater Lagoon, whereas only two of these species ranked amongst the eight most abundant species in Flinders Bay. In terms of ranking by abundance, the species sequence was more similar between the estuary basin and entrance channel than between either of these regions and Deadwater Lagoon. The most abundant species in the estuary basin and entrance channel included the estuarine species *Leptatherina wallacei*, *Afurcagobius suppositus*, *Atherinosoma elongata*, and *Pseudogobius olorum*, the estuarine/marine species *Favonigobius lateralis* and *Leptatherina presbyteroides*, and the marine estuarine-opportunists *Pelates sexlineatus*, *Rhabdosargus sarba* and *Aldrichetta forsteri* (Table 15). With the exception of *P. sexlineatus*, and more particularly *A. suppositus*, the above species were also relatively abundant in Deadwater Lagoon. However, the marine estuarine-opportunist *Sillaginodes punctata* was more abundant in Deadwater Lagoon than in either the estuary basin or entrance channel. The only two species which, in terms of relative abundance, ranked in the top nine in the estuary basin and entrance channel and had a similar high ranking in Flinders Bay, were *L. presbyteroides* and *A. forsteri* (Table 15).

The fauna in Flinders Bay was so dominated by *Leptatherina presbyteroides* that this species contributed over three quarters of the total number of fish collected in the shallows of that marine embayment (Table 15). However, the total catch of this species was still very much lower in Flinders Bay than in both the entrance channel and Deadwater Lagoon. The catches of *L. presbyteroides* in the entrance channel and Deadwater Lagoon, as well as in Flinders Bay, were far greater than in the estuary basin (Table 15). Other species that made a substantial contribution to the total catch in Flinders Bay included the marine species *Sillago bassensis*, *Pelsartia humeralis*, *Leseurina platycephala* and *Spratelloides robustus*, which are rarely found in the main body of estuaries, *Sillago schomburgkii* and *Aldrichetta forsteri*, which use both estuaries and protected marine waters as nursery areas, and *Cnidoglanis macrocephalus*, which can spawn in both estuaries and marine environments. With the exception of *A. forsteri*, the above species were either not caught, or were caught only in very small numbers inside the estuary (Table 15).

Life-cycle categories

The fish collected from throughout the Blackwood River Estuary, including Deadwater Lagoon, comprised 29 marine species, of which 17 were marine stragglers and 12 were marine estuarine-opportunists, together with nine estuarine/marine species and four estuarine species (Table 16). In terms of number of individuals, the estuarine/marine and estuarine categories, *i.e.* species which are able to spawn in estuaries, contributed 43.1 and 39.4%, respectively. The marine estuarine-opportunists contributed 17.2% and the marine stragglers 0.3% to the total number of individuals (Table 16).

Within each region of the estuary, the marine stragglers were represented by more species in the entrance channel (13) than in either the estuary basin (10) or Deadwater Lagoon (3) (Table 16). Marine estuarine-opportunists were represented by between nine and 11 species in each estuarine region. While each of the four estuarine species was found in the three estuarine regions, more estuarine/marine species were recorded in the estuary basin (8) and entrance channel (7) than in Deadwater Lagoon (5) (Table 16).

In terms of number of individuals, the estuarine category made the greatest contribution in both the estuary basin and Deadwater Lagoon, *i.e.* 46.2 and 53.7%, respectively, but represented only 13.8% of the fish caught in the entrance channel (Table 16). Conversely, the contribution of the estuarine/marine category in the entrance channel, *i.e.* 57.3%, was far greater than in any other region. However, this latter category still made a substantial contribution to the fish faunas of the estuary basin and Deadwater Lagoon, in which regions it represented 35.4 and 36.8% of the total number of fish, respectively. The contribution made by marine estuarine-opportunists in the entrance channel, *i.e.* 28.3%, was also relatively greater than in the estuary basin and even more particularly Deadwater Lagoon, where they represented only 9.5% of the total fish collected. The overall contribution of individuals to the marine straggler category was minimal, comprising less than 1% of the total number of fish in the estuary basin, entrance channel and Deadwater Lagoon (Table 16).

Twenty one of the 26 species collected from Flinders Bay were marine species which do not spawn in estuaries (Table 16). Five of these marine species have never been recorded in estuaries and six are only found irregularly and in low numbers in estuaries, whereas the other ten species also use estuaries as nursery areas, and thus belong to the marine estuarine-opportunist category. Five of the species found in Flinders Bay can spawn in both estuaries and marine waters. In terms of the number of fish collected in Flinders Bay, the estuarine/marine category was by far the most abundant group, representing 80.8% of the overall catch, with the marine estuarine-opportunists representing only 3.8% (Table 16).

Number of species and densities in different regions

ANOVA showed that the number of fish species differed significantly amongst the three estuarine regions and Flinders Bay and also between day and night (Table 17, Fig. 43). However, the mean squares were far greater for region than for time of day. Scheffé's *a posteriori* test showed that the number of species was significantly greater in each of the three estuarine regions than in Flinders Bay. This point is illustrated by the fact that the mean number of species recorded monthly during both the day and night was usually greater than five in each of the three estuarine regions, but less than five in Flinders Bay

(Fig. 43). The number of species recorded in each region was generally greater at night than during the day (Fig. 43), reflecting the fact that some of the less abundant species tend to move near the shore at night, a feature that was also recorded for certain species in the Moore River Estuary further north in Western Australia (Young *et al.* 1997).

The densities of fish also differed significantly among regions and months, but not between time of day (Table 17, Fig. 43). The significance level and mean squares were both far higher for region than for month. Scheffé's *a posteriori* test showed that densities were significantly greater in each of the three estuarine regions than in Flinders Bay, and were also significantly greater in Deadwater Lagoon than in either the estuary basin or entrance channel. These differences are emphasised by the fact that the mean monthly densities of fish during both day and night were generally greater than 240 fish per 100 m^2 in Deadwater Lagoon, 120 fish per 100 m^2 in the entrance channel and 68 fish per 100 m^2 in the estuary basin, whereas they were always less than 65 fish per 100 m^2 in Flinders Bay, except at night in November (Fig. 43).

In the case of the ANOVAs for the densities of the five most abundant species, it should be noted that *Leptatherina presbyteroides* was the only one of these species to be caught regularly and in sufficient numbers in Flinders Bay for its densities to merit inclusion in the respective ANOVAs. The densities of *L. presbyteroides, Atherinosoma elongata, Leptatherina wallacei* and *Rhabdosargus sarba* differed significantly among regions and, together with *Favonigobius lateralis,* also among months (Table 17). A significant diel effect was also detected in the case of *L. presbyteroides* and *L. wallacei.* There was a highly significant region x month interaction for each of the above five species, except *L. presbyteroides* (Table 17).

The mean squares for the densities of *Leptatherina presbyteroides* and *Atherinosoma elongata* were far greater for region than for month or time of day, which in turn, were higher than those for the interaction between region and month (Table 17). The results of the Scheffé's *a posteriori* tests for the densities of fish in different regions were clearly reflected by the trends shown by the total numbers of individuals (Table 15). The densities of *L. presbyteroides* were significantly greater in the entrance channel and Deadwater Lagoon than in the estuary basin and Flinders Bay, and those of *A. elongata* were significantly greater in Deadwater Lagoon than in the entrance channel and estuary basin. The densities of *A. elongata* were significantly higher in September and December than in February and March. The mean squares for the densities of *Leptatherina wallacei* were similar in the case of region and time of day, both of these being slightly higher than those for month and the interaction between region and month. The densities of *L. wallacei* were significantly higher in the estuary basin than in the entrance channel, and were generally greater during the day than night. With *Rhabdosargus sarba*, the mean square for region was greater than for both month and the region x month interaction, which were likewise significant but at a lower level (Table 17). The densities of *R. sarba* in Deadwater Lagoon were significantly greater than those in the estuary basin or entrance channel.

The significant interaction between region and month for each species often partly reflects the fact that the increase in freshwater discharge and/or decline in salinity that occurs in the estuary basin and entrance channel in winter had an influence on the densities of these species in these regions, whereas this was not the case in Deadwater Lagoon, where these environmental parameters exhibited far less variability.

Classification and ordination

Classification of the mean densities of each species during the day and night in each region and in each month separated the samples collected from the three regions inside the estuary (group A) from those obtained in Flinders Bay (group B) (Fig. 44). Samples from the estuarine regions then separated into two major groups, one containing mainly samples from the estuary basin and entrance channel and during late summer and autumn (group C), and the other comprising those taken from the same two regions during winter, spring and early summer, together with the majority of those from Deadwater Lagoon throughout the year (group D). The latter group then separated into one group (E) that comprised samples from the estuary basin and entrance channel and another group (F) that consisted mostly of samples from Deadwater Lagoon (Fig. 44).

The results of the MDS ordination paralleled those produced by classification (*cf* Figs 44, 45a). Thus, samples from the three estuarine regions formed a group that was totally distinct from those collected in Flinders Bay (Fig. 45a). The samples for both day and night within the latter group were far more widely dispersed than those collected during the day and night in any of the three estuarine regions (Table 18, Fig. 45a). Ordination of samples from the three estuarine regions, independently of those from Flinders Bay, resulted in samples from the estuary basin and entrance channel during late summer and early autumn forming a group to the left of those taken from these regions during winter, spring and early summer (Fig. 45b). Furthermore, these two groups were separate from those constituting samples taken in Deadwater Lagoon throughout the year (Fig. 45b).

SIMPER showed that the species composition of Flinders Bay was characterised by *Leseurina platycephala*, whereas that of the estuary was characterised by *Favonigobius lateralis, Leptatherina wallacei* and *Rhabdosargus sarba.* ANOSIM demonstrated that, within the estuary, the compositions of the fish fauna in Deadwater Lagoon during both the day and night differed significantly from those during both the day and night in the estuary basin and entrance channel. *Atherinosoma elongata* typified Deadwater Lagoon, while *Afurcagobius suppositus* typified the estuary basin and entrance channel.

Comparisons between marine estuarine-opportunists in Ruppia megacarpa *and bare sand*

A total of 7156 fish and 17 species and 7390 fish and 10 species were caught in *Ruppia megacarpa* and over bare sand, respectively, on the four separate occasions when these extreme habitat types were sampled between May 1994 and January 1995. The mean number of species in these four months ranged from 7.0 to 8.0 in *Ruppia* and from 5.2 and 6.0 over bare sand. Three marine species, namely *Rhabdosargus sarba*, *Pelates sexlineatus* and *Aldrichetta forsteri*, were represented in the samples obtained collectively from dense *Ruppia* and over bare sand by 866, 221 and 103 individuals, respectively. The mean densities of *R. sarba* were greater in *Ruppia* than over bare sand in each month and *P. sexlineatus* was only ever caught in *Ruppia.* In contrast, 66% of the *A. forsteri* were caught over bare sand. None of the above three species were recorded during the sampling period in 1996 when beds of *Ruppia* were no longer present in Deadwater Lagoon.

Faunal composition in deeper waters

A total of 447 fish representing 17 species was collected by gill nets in the deeper waters of the Blackwood River Estuary between November 1993 and July 1994 (Table 19). Of these species, 11 were marine estuarine-opportunists, three were species which complete their life cycles in estuaries (E and E/M), two were marine stragglers and one was a freshwater species. The marine estuarine-opportunists *Rhabdosargus sarba*, *Mugil cephalus, Sillago schomburgkii* and *Pelates sexlineatus* were the most abundant species caught in gill nets, contributing 21.0, 18.6, 17.6 and 16.1% to the total catch, respectively (Table 19). *Rhabdosargus sarba* and *P. sexlineatus* were also among the most numerous species recorded in the seine net samples from the shallow regions of the estuary, while *M. cephalus* and *S. schomburgkii* were relatively less abundant in the shallows (Table 15).

While only one *Acanthopagrus butcheri* representing <0.1% of the total catch, was caught during the present study, this species was the most abundant species captured by gill net during a study of the Blackwood River Estuary in 1974/5, contributing 26.5% to the total catch (Lenanton 1977). The much lower contribution of this commercially and recreationally important species 20 years after the first study most likely reflects increased fishing from commercial and recreational fishers since the mid 1970's (Caputi 1976, Lenanton and Potter 1987), which has led to a depletion of stocks of this species in the Blackwood River Estuary.

Faunal composition of the basin and entrance channel of the Blackwood River Estuary

The fish faunas in both the estuary basin and entrance channel of the Blackwood River Estuary were dominated by the small teleosts *Leptatherina wallacei, Favonigobius lateralis* and *Leptatherina presbyteroides*, which are each able to complete their life cycles in estuarine waters and, in the case of the last two species, also protected marine waters (Prince and Potter 1983, Potter *et al.* 1990, Neira *et al.* 1992). These species, and other estuarine-spawning atherinids and gobiids, are also amongst the most abundant teleosts in estuaries elsewhere from the lower west coast to the lower east coast of Australia (Loneragan *et al.* 1986, Potter *et al.* 1993, Connolly 1994, Molsher *et al.* 1994, Pollard 1994, Potter and Hyndes 1994) and also in southern Africa (Bennett 1989, Potter *et al.* 1990).

Large numbers of the juveniles of marine estuarine-opportunists, such as *Pelates sexlineatus, Rhabdosargus sarba, Aldrichetta forsteri* and *Sillaginodes punctata*, entered the Blackwood River Estuary in 1994, as they did 20 years earlier (Lenanton 1977), which parallels the situation in other large estuaries northwards on the lower west coast of Australia, such as the Swan and Peel Harvey estuaries (Loneragan *et al.* 1986, Loneragan and Potter 1990). However, the juveniles of these species are far less abundant in Wilson Inlet and the Nornalup-Walpole Estuary further east along the south coast (Potter *et al.* 1993, Potter and Hyndes 1994), implying that the sizes of the spawning populations of these species are greater along the west coast than along the far less protected south coast. The utilisation of the Blackwood River Estuary by juveniles of marine species means that this estuary provides a good model system both for examining the effects of certain seasonal changes on the distribution and abundance of these fish and for elucidating the relative roles of estuaries and nearby, protected marine waters as nursery areas for this category of fish.

Influence of freshwater discharge and/or salinity declines

Classification and ordination emphasised that the ichthyofaunas of the estuary basin and entrance channel both underwent pronounced changes in winter. This change occurred when the heavy and highly seasonal rainfall, that characterises south-western Australia, resulted in a massive increase in freshwater discharge and a consequent marked decline in salinities to *ca* 2‰ in the estuary basin and 4‰ in the entrance channel. The change in the ichthyofaunas of these regions was attributable, in part, to a pronounced decline in both the number of marine straggler species and the densities of marine estuarine-opportunist species, and particularly those of *Pelates sexlineatus* and *Rhabdosargus sarba.* The faunal change in the estuary basin in winter also reflects the immigration from riverine areas of *Leptatherina wallacei*, a species which, in estuaries, is often most abundant in regions of low salinity, but is subject to the effects of freshwater flushing (Prince and Potter 1983, Loneragan and Potter 1990). The faunal change was also enhanced by the immigration from the sea of the new 0+ recruits of *Aldrichetta forsteri*, a species which, in south-western Australia, enters estuaries between late autumn and late spring, when freshwater discharge ensures that estuary mouths are open (Chubb *et al.* 1981).

The conclusion that the pronounced changes that occur in the ichthyofaunal compositions of the estuary basin and entrance channel in winter, are related either to marked increases in freshwater discharge and/or marked declines in salinity is supported by the fact that no such changes occurred in Deadwater Lagoon, which has no tributary rivers and remained at salinities greater than 28‰ in all but one month and, even in that month, only declined to 23‰. It was particularly noteworthy that, in contrast to the situation in the estuary basin and entrance channel, large numbers of *Rhabdosargus sarba* remained in Deadwater Lagoon throughout the winter and spring. Although *Leptatherina wallacei* is often found in reduced salinities (Prince and Potter 1983), it does occur in areas of high salinity in Deadwater Lagoon where dense beds of *Ruppia* are present, as is also the case in Wilson Inlet (Humphries and Potter 1993).

Colonisation of Deadwater Lagoon and the influence of Ruppia megacarpa

The far greater overall density of fish in Deadwater Lagoon than in either the entrance channel or even the estuary basin is presumably related, at least in part, to the higher productivity and greater protection from predators that must result from the presence of the extensive patches of *Ruppia megacarpa* that are found throughout this lagoonal water body. Despite the increase in structural heterogeneity that is produced by the patches of *Ruppia* in Deadwater Lagoon, the total number of species in that water body was lower than in the estuary basin. This largely reflects the immigration of a far lower number of marine straggler species into Deadwater Lagoon than into the estuary basin, presumably because the tidal flow through its narrow and shallow side channel from the entrance channel is far weaker than that of the more direct flow which occurs through the entrance channel into the estuary basin. However, the fact that the marine estuarine-opportunists *Rhabdosargus sarba, Aldrichetta forsteri, Sillaginodes punctata* and *Mugil cephalus* each attained far higher densities in Deadwater Lagoon than in the estuary basin, emphasises that, although the chances of colonisation of the former region by marine species is less likely, once the members of a species have migrated into that water body, they remain there and capitalise on its productive and protected environment. Since *R. sarba* was far more abundant in dense patches of *Ruppia* than over bare sand during the main study period, but was not caught in 1996 following the disappearance of this angiosperm in the intervening period, the very high densities of this species in Deadwater Lagoon is probably related, in part, to the presence of numerous patches of *Ruppia* in that water body. This view is consistent with the fact that the estuarine species *Atherinosoma elongata* and, to a lesser extent, *Leptatherina wallacei*, which also reached much higher densities in Deadwater Lagoon than in the estuary basin and entrance channel and were far more abundant in *Ruppia* than over sand in Wilson Inlet (Humphries and Potter 1993), were caught only in small numbers in Deadwater Lagoon in 1996 when *Ruppia* was no longer present. In contrast, *L. presbyteroides*, which occurs in greater densities in sand than nearby *Ruppia* (Humphries and Potter 1993), was still abundant in 1996. The importance of *Ruppia* in increasing habitat complexity is emphasised by the fact that the number of fish species was greater in this habitat than over nearby bare sand. Although Humphries *et al.* (1992) recorded more species over bare sand than in *Ruppia* in Wilson Inlet, the numbers of marine species were lower in that other south-western Australian estuary and most of those species tended to occur more in *Ruppia* than over bare sand in the Blackwood River Estuary.

Role of embayments as fish habitats

Classification and ordination emphasised that the ichthyofaunal composition of the shallows of Flinders Bay, immediately outside the estuary mouth, differs markedly from that of the shallows within the estuary, including that of Deadwater Lagoon. This difference can largely be attributed to the fact that the samples collected from that embayment yielded five marine species that were not recorded in the Blackwood River Estuary (or in other south-western Australian estuaries), and did not yield any of the four estuarine species which were caught in that estuary. The differences are further emphasised by the fact that only two of the nine most abundant species in the estuary basin and entrance channel ranked amongst the eight most abundant species in that embayment. While one of these species, *Leptatherina presbyteroides*, constituted over 75% of the total number of fish caught in Flinders Bay, the densities of this species in this embayment was less than in the entrance channel and Deadwater Lagoon. The large numbers of this atherinid found throughout the estuary basin, entrance channel, and in Deadwater Lagoon and Flinders Bay, suggests that this species has a continuous distribution within and immediately outside the Blackwood River Estuary.

Although *Leptatherina presbyteroides* was very abundant at times in Flinders Bay, all of the other species that spawn in both marine and estuarine waters, and were caught in the Blackwood River Estuary, were either absent or present in very low densities in Flinders Bay except for *Cnidoglanis macrocephalus*. However, this last species, which was represented only by juveniles in Flinders Bay, was predominantly caught on those occasions when detached macrophytes were present. Detached macrophytes have been shown to provide an important nursery habitat for this and other species elsewhere in marine waters in south-western Australia (Lenanton *et al.* 1982, Lenanton and Caputi 1989). Although the sites we studied in Flinders Bay were moderately protected and typical of many such marine areas in south-western Australia, they were not as protected as those extreme cases where the shore line is well sheltered by headlands and/or offshore reefs (Hyndes *et al.* 1996a). This would account for the presence in Flinders Bay of species such as *Sillago bassensis*, as the juveniles of this species do not require highly protected waters as a nursery area (Hyndes *et al.* 1996a), and for the absence of *Favonigobius lateralis*, as this species tends only to occur in very sheltered regions (Gill and Potter 1993). While marine embayments can provide alternative fish nursery areas to those found in estuaries (Lenanton 1982, Lenanton and Potter 1987), the absence of the juveniles of a number of marine species from Flinders Bay, which are abundant in the Blackwood River Estuary, emphasises that for certain marine species, estuaries are particularly important nursery areas. The high densities of many species of fish in the Blackwood River Estuary and their low numbers in Flinders Bay suggest that estuaries provide a greater source of food and/or protection than is offered by moderately protected waters within marine embayments, such as those found in Flinders Bay. The far higher dispersion values for the ichthyofauna of Flinders Bay than in any of the three estuarine regions, presumably reflects the greater fluctuations that occur in this environment, through variations in the degree of wave activity and the relative volume of detached macrophytes.

(VII) Benefits

The main overall objective of this study was to provide the Western Australian Fisheries Department with data on the biology of King George whiting and Black bream which the members of that department could then use to determine the status of the stocks, and also to ensure that the resources of those two species were equitably shared between commercial and recreational fishers. We were thus requested by the Fisheries Department to determine the age and growth, size and age and maturity, spawning season and locality and mesh selectivity for both species. These data were communicated to Dr R.C.J. Lenanton at the W.A. Fisheries Department, as soon as we had finished analysing the data for each of those areas of study. Dr Lenanton has already used the data we obtained on changes in habitat types during the growth of King George whiting, and their relationship to attainment of maturity, to resolve amicably a dispute between commercial and recreational fishers about sharing the resource for this species in Leschenault Estuary. Our finding that, while the King George whiting use estuaries as nursery areas, its juveniles tend to congregate in high densities in nearshore waters, but only when the habitats in those waters are very protected, is also being used by Dr Lenanton for in developing management policies for maintaining the crucial habitats of important finfish species in Western Australia. Since we have also shown that King George whiting spawns in and around reefs in winter, Dr Lenanton is also aware of the need to protect these waters at that time. Our study has also clearly demonstrated that scales are inadequate for ageing purposes and whole otoliths can only be used for ageing young King George whiting, *i.e.* <2+. The discovery that scales cannot be used to age King George whiting and that the otoliths of all but the young King George whiting have to be sectioned in order to age this species accurately is relevant to ageing studies on this important commercial and recreational species elsewhere in Australia. Although whole otoliths could be used to age Black bream up to six years in age, the otoliths of the older members of this species also have to be sectioned to determine ages.

Our study clearly demonstrated that, in systems such as the Swan Estuary, the Black bream shows a strong tendency to occupy predominantly the low saline reaches of the upper estuary, except in autumn and winter, when this species is flushed downstream and is then caught by commercial fishers. The closure of the upper estuary to commercial fishing, at least in the Swan Estuary, almost certainly accounts for the maintenance of good catches, including large fish, by recreational fishers throughout the year and by commercial fishers in winter. This view is supported by the fact that, in the Blackwood River Estuary, which used to house a substantial fishery for Black bream, but has no waters closed to commercial fishing, only one small representative of this species was captured during the whole of our study. We have shown that the Black bream is not fished in estuaries until after it has reached both the length and age at which sexual maturity is attained and that, in estuaries where growth is slow, it can take four years to reach the legal minimum size for capture. These data are of obvious management relevance.

Our discovery that Black bream populations in different estuaries are genetically distinct has obvious implications for attempts to translocate this species. This is especially the case in view of the marked variability in the growth rates of this species in different estuaries, a feature which may be genetically determined. This information is vital importance to the W.A. Fisheries Department as they attempt to control the translocation of this species within temperate Western Australia.

Although our study was mainly aimed at providing information for the W.A. Fisheries Department, we have given numerous talks to angling clubs. We have also kept Mr M. Roennfeldt, the fishing editor for the Western Australian newspaper and also chief writer for the Western Angler magazine, informed of the results of our study and he has communicated these results to the anglers in the public through his articles. We have also published a detailed article on the biology of the King George whiting for Prowest, the magazine of the Western Australian Professional Fishing Industry Council and will shortly offer to do the same for Black bream. The provision of these data on the biology of these species to both commercial and recreational fishers will make those fishers more aware of the scientific data that are being used by the W.A. Fisheries Department to resolve management issues associated with those species.

The data produced from the present study on the biology of King George whiting and Black bream will allow the W.A. Fisheries Department to undertake stock assessment analyses. Although we were unable to estimate fecundity values for King George whiting and Black bream (because these species are multiple spawners), Mr. N.G. Hall is confident he can undertake yield per recruit and egg per recruit analyses for use by fisheries managers. Yield per recruit analyses will use estimates of growth rates, length/weight relationships and assumptions of natural mortality and age-dependent fishing mortality rates. Estimates of relative egg per recruit may be calculated using the above information and relative spawning indices, calculated from the relationship between gonadal weight and fish length.

Our studies on the fish faunas of estuaries were carried out concomitantly with studies on the fish faunas of nearby marine waters. The results emphasise that estuaries are a very important habitat for the juveniles of certain commercial and recreational fish species, especially when the nearby marine waters were not highly protected. The results also showed that, when eutrophication in estuaries involved an increased production of macrophytes, the abundance of fish increased, whereas the reverse occurs when eutrophication is reflected by massive growths of blue-green algae or toxic dinoflagellates. The results will be used by the W.A. Fisheries Department in developing management schemes for fisheries dependent on estuarine and nearshore waters.

The training of several students in sophisticated approaches and techniques used in fisheries studies has produced capable fisheries biologists, which will facilitate the collection of appropriate data in future studies, and thus for the management fisheries in Australia.

The benefits and beneficiaries are exactly as stated in the original application.

(VIII) Intellectual Property

Not applicable.

(IX) Further Development

Although we have fulfilled all of the objectives of this study, we intend to continue, by using resources from Murdoch University and RFAC (Recreational Fishing Advisory Committee), to explore the growth rates of Black bream in different estuaries, and to use mitochondrial DNA to elucidate further the relationships between Black bream in different estuaries.

We will also provide biological advice to Dr R.C.J. Lenanton and Mr N.G. Hall as they use our data for various purposes during the refinement of management plans for King George whiting, Black bream and both estuarine and marine habitats. We will also continue to give talks and write articles to disseminate the main finding of our studies to both commercial and recreational fishers.

(X) Staff and Students

Principal Investigator:	Professor Ian Potter
Professional Officer:	Dr Glenn Hyndes (Salary from W.A. Fisheries grant)
Research Assistant:	Ms Margaret Platell (Salary from FRDC grant)
PhD student:	Mr Gavin Sarre (Murdoch University Post-Graduate Scholarship)
Honours student:	Mr Glen Young
Honours student:	Mr David Tiivel
Honours student:	Ms Fiona Valesini
Honours student:	Mr Richard McCulloch
Honours student:	Mr Graeme Baudains

(XI) Final Cost

FRDC Contribution:	$115 674
W. A. Fisheries Department Contribution:	$150 000
Murdoch University Contribution:	$224 000

(XII) Publications, Conferences And Workshops

Hyndes, G.A., Potter, I.C. and Lenanton, R.C.J., 1996. Habitat partitioning by whiting species (Sillaginidae) in coastal waters. *Environmental Biology of Fishes*, **45**, 21-40.

Hyndes, G.A., Platell, M.E. and Potter, I.C., 1997. Relationships between the diet and body size, mouth morphology, habitat and movements of six sillaginid species in coastal waters: implications for resource partitioning. *Marine Biology*, in press.

Young, G.C., Potter, I.C., Hyndes, G.A. and de Lestang, S., 1997. The ichthyofauna of an intermittently open estuary. Implications of bar breaching and low salinities on faunal composition. *Estuarine, Coastal and Shelf Science*, in press.

Valesini, F.J., Potter, I.C., Platell, M.E. and Hyndes, G.A., submitted. Comparisons between the shallow water ichthyofaunas of a temperate Australian estuary and an interconnected lagoon and adjacent marine embayment. *Marine Biology*

Potter *et al.* (in preparation) Fish faunas of Leschenault Estuary anu Koombana Bay

Hyndes *et al.* (in preparation) Age, growth and reproductive biology of King George whiting in south-western Australia.

The last two manuscripts are to be completed by the end of the year.

Sarre, G.A. "Age, growth and reproduction of the sparid *Acanthopagrus butcheri*, with comparison between the growth of two populations." Conference: 76th Annual Meeting of the American Society of Ichthyologist and Herpetologists, New Orleans, USA.

Hyndes, G.A. "Age, growth, reproductive biology of King George whiting in south-western Australia." Workshop: Development of a strategic plan for research on the King George whiting fishery of South Australia, SARDI.

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(XIV) Tables

Table 1 von Bertalanffy growth parameters derived from length at age data for King George whiting caught on the lower west coast of Australia. L_∞ is the asymptotic length, K is the growth coefficient, t_0 is the hypothetical age at which fish would have zero length, R^2 is the regression coefficient, N is the sample size.

Sex	von Bertalanffy parameters				
	L_∞	K	t_0	R^2	N
Females	535.0	0.46	0.13	0.97	699
Males	501.6	0.52	0.15	0.96	594

Table 2 Frequency of occurrence (%F) and volume (%V) of the different dietary categories to the diet of the King George whiting caught on the lower west coast of Australia.

Dietary Category	%F	%V
Sipuncula	**1.6**	**1.7**
Polychaeta	**60.7**	**39.5**
Errant	47.5	32.9
Sedentary	17.2	6.6
Mollusca	**7.4**	**4.8**
Bivalves	2.5	0.6
Opisthobranch gastropods	5.7	3.6
Cephalopods	0.8	0.6
Crustacea	**69.7**	**47.6**
Copepods	18.0	10.4
Leptostracans	4.1	2.0
Stomatopods	4.9	1.8
Amphipods	50.0	21.4
Cumaceans	3.3	0.8
Tanaids	15.7	1.5
Isopods	3.3	0.5
Carid decapods	27.9	7.5
Crabs	2.5	1.7
Echinodermata	**0.8**	**<0.1**
Echinoids	0.8	<0.1
Chordata	**0.8**	**0.8**
Teleosts	0.8	0.8
Algae and seagrass	**18.9**	**4.4**
Detrital material	**2.8**	**4.1**

Table 3 von Bertalanffy growth parameters derived from length at age data for Black bream caught in the upper Swan Estuary. L_∞ is the asymptotic length, K is the growth coefficient, t_0 is the hypothetical age at which fish would have zero length, R^2 is the regression coefficient, N is the sample size.

Sex	von Bertalanffy parameters				
	L_∞	K	t_0	R^2	N
Swan Estuary					
Females	443	0.29	-0.16	0.93	756
Males	423	0.30	-0.17	0.93	926
Moore River Estuary					
Females	463	0.10	-0.52	0.91	307
Males	342	0.15	-0.44	0.89	275

Table 4 Frequency of occurrence (%F) and volume (%V) of the different dietary categories to the diet of Black bream caught in the upper Swan Estuary.

Dietary Category	%F	%V
Polychaeta	**21.9**	**8.4**
Ceratonereis aequisetis	16.0	4.1
Marphysa sanguinea	4.7	3.6
Mollusca	**36.7**	**23.2**
Xenostrobus spp.	33.6	21.2
Arthritica semen	3.1	0.9
Hydrobia ulvae	1.2	0.3
Crustacea	**34.4**	**10.5**
Ostracods	0.4	0.4
Amphipods	29.3	6.5
Isopods	0.8	<0.1
Carid decapods	3.1	1.6
Crabs	2.7	1.1
Insecta	**0.8**	**<0.1**
Larvae and adults	0.8	<0.1
Chordata	**6.6**	**2.8**
Teleosts	6.6	2.8
Algae	**36.3**	**22.7**
Detrital material	**52.3**	**33.1**

Table 5 Numerical ranking, numbers and biomass, percentage contributions to the total catch in terms of numbers and biomass, mean total lengths, length range and life-cycle categories (S = marine straggler, O = marine estuarine-opportunist, E = estuarine, A = semi-anadromous, F = freshwater) of teleost species caught in the mouth and lower, middle and upper regions of the Moore River Estuary between February 1994 and February 1995. The numbers and biomass were calculated after the catches for each sample from each site had been adjusted to numbers and biomass caught per 100 m^2.

Rank	Species	Number of fish		Biomass of fish		Mean length (mm)	Length range (mm)	Life cycle category
		(N)	(%)	(kg)	(%)			
1	*Leptatherina wallacei*	78890	74.8	29.41	21.8	38	15-75	E
2	*Pseudogobius olorum*	9346	8.8	1.57	1.2	27	11-52	E
3	*Acanthopagrus butcheri*	5705	5.4	20.07	14.9	50	15-335	E
4	*Aldrichetta forsteri*	2440	2.3	46.17	34.2	105	20-332	O
5	*Amniataba caudavittata*	2408	2.3	8.02	5.9	57	15-197	E
6	*Favonigobius lateralis*	2184	2.1	0.81	0.6	36	16-79	E
7	*Mugil cephalus*	1444	1.4	21.43	15.9	82	20-315	O
8	*Afurcagobius suppositus*	1439	1.4	1.25	0.9	43	14-104	E
9	*Sillago schomburgkii*	810	0.8	1.61	1.2	59	12-246	O
10	*Sillago burrus*	375	0.3	1.44	1.1	59	17-131	O
11	*Sillago vittata*	297	0.3	2.16	1.6	91	43-120	S
12	*Pelates sexlineatus*	33	<0.1	0.11	<0.1	64	33-108	O
13	*Spratelloides robustus*	30	<0.1	0.03	<0.1	55	43-61	O
14	*Gambusia affinis*	19	<0.1	<0.01	<0.1	30	25-42	F
15	*Gerres subfasciatus*	14	<0.1	0.19	0.1	83	35-136	O
15	*Hyperlophus vittatus*	14	<0.1	0.03	<0.1	68	53-85	O
17	*Nematalosa vlaminghi*	11	<0.1	0.03	0.1	65	48-92	A
18	*Carassius auratus*	8	<0.1	0.05	<0.1	69	43-101	F
19	*Rhabdosargus sarba*	6	<0.1	0.11	<0.1	73	30-179	O
20	*Amoya bifrenatus*	5	<0.1	<0.01	<0.1	34	18-45	E
21	*Pomatomus saltatrix*	3	<0.1	0.08	<0.1	122	32-185	O
21	*Atherinomorus ogilbyi*	3	<0.1	<0.01	<0.1	75	70-79	O
23	*Sillaginodes punctata*	2	<0.1	<0.01	<0.1	72	70-74	O
23	*Pseudorhombus jenynsii*	2	<0.1	<0.01	<0.1	29	26-33	O
25	*Leptatherina presbyteroides*	1	<0.1	<0.01	<0.1	75	75	E
25	*Engraulis australis*	1	<0.1	<0.01	<0.1	80	80	E
25	*Contusus brevicaudatus*	1	<0.1	0.04	<0.1	107	107	S
Totals	27 species	105491		134.9				

Table 6 Mean squares and significance levels for ANOVAs of the number of species and the densities of all fish and of the eight most abundant species caught in the mouth and lower, middle and upper regions of the Moore River Estuary in each month between February 1994 and February 1995 and during the day and night (diel). * p<0.05, ** p<0.01, *** p<0.001.

	Main effects			**Two-way interactions**			**Three-way interaction**	**Residual**
	Region (R)	Month (M)	Diel (D)	R x M	R x D	M x D	R x M x D	
Degrees of freedom	3	12	1	32	3	12	32	190
Number of species	30.45***	11.01***	245.53***	4.94***	2.86	4.64**	1.64	1.66
Density of fish	5.58***	1.53***	2.44***	0.37**	0.79**	0.45**	0.25	0.18
Leptatherina wallacei	12.76***	1.86***	2.91**	1.01***	3.48***	0.76*	0.72**	0.40
Pseudogobius olorum	29.47***	1.47***	3.01***	0.65***	0.22	0.55***	0.39***	0.17
Acanthopagrus butcheri	6.02***	1.74***	18.79***	0.78***	1.03***	1.46***	0.17	0.17
Aldrichetta forsteri	7.25***	0.54**	10.83***	0.35**	0.72*	0.15	0.30*	0.20
Amniataba caudavittata	0.31	1.93***	3.35***	0.28***	1.40***	0.43***	0.30***	0.12
Favonigobius lateralis	10.46***	0.60***	0.07	0.39***	0.11	0.14	0.12	0.16
Mugil cephalus	0.79**	0.87***	8.70***	0.17	0.82**	0.42**	0.17	0.16
Afurcagobius suppositus	4.04***	0.50***	10.74***	0.19***	1.92***	0.50***	0.19***	0.08

Table 7 Pearson correlation coefficients between the number of species, the densities of all fish and of the eight most abundant species caught in the Moore River Estuary and the salinity and distance from estuary mouth in that estuary between February 1994 and February 1995. Significance of the regression coefficient for each variable in each multiple regression equation is shown in parentheses. * p<0.05, ** p<0.01, *** p<0.001.

Variable	Salinity	Distance from estuary mouth
Number of species	0.08	-0.21*** (***)
Density of fish	-0.27** (***)	0.39*** (***)
Leptatherina wallacei	-0.23***	0.37*** (***)
Pseudogobius olorum	-0.39**	0.68*** (***)
Acanthopagrus butcheri	-0.22**	0.35*** (***)
Aldrichetta forsteri	0.28**	-0.44*** (***)
Amniataba caudavittata	0.08	-0.06
Favonigobius lateralis	0.15*(***)	-0.58*** (***)
Mugil cephalus	-0.07	-0.15**(***)
Afurcagobius suppositus	-0.05(***)	0.37***(***)

Table 8 Numbers of the 11 most abundant species caught in the mouth and lower, middle and upper regions of the Moore River Estuary between February 1994 and February 1995, and the percentage contribution of the number of each species in each region to the total number of that species in the whole estuary. The numbers were calculated after the catches for each sample from each site had been adjusted to numbers caught per $100m^2$.

Species	Mouth		Lower		Middle		Upper		Total
	N	%	N	%	N	%	N	%	N
Leptatherina wallacei	5692	7.2	22292	28.3	24877	31.5	26029	33.0	78890
Pseudogobius olorum	74	0.8	1102	11.8	2728	29.2	5440	58.2	9346
Acanthopagrus butcheri	629	11.0	686	12.0	1785	31.3	2607	45.7	5705
Aldrichetta forsteri	1346	55.2	477	19.5	100	4.1	517	21.2	2440
Amniataba caudavittata	1085	45.1	269	11.2	827	34.3	227	9.4	2408
Favonigobius lateralis	1633	74.8	450	20.6	4	0.2	97	4.4	2184
Mugil cephalus	233	16.1	190	13.2	393	27.2	628	43.5	1444
Afurcagobius suppositus	317	22.0	61	4.2	617	42.9	444	30.8	1439
Sillago schomburgkii	75	9.2	729	90.0	6	0.7	0	0	810
Sillago burrus	330	88.0	36	9.6	9	2.4	0	0	375
Sillago vittata	284	95.6	13	4.4	0	0	0	0	297

Table 9 Numbers (N) and percentage contributions (%) of species and individuals to each life-cycle category in different regions in the Moore River Estuary between February 1994 and February 1995. Numbers of individuals in each life-cycle category represent total numbers after the catch in each sample from each site had been adjusted to a constant area of $100m^2$.

Life-cycle category	Whole estuary		Region of estuary							
			Mouth		Lower		Middle		Upper	
	N	%	N	%	N	%	N	%	N	%
Species										
Marine straggler	2	7.4	2	8.7	1	5.3	0	0	0	0
Estuarine-opportunist	13	48.2	12	52.2	9	47.4	6	40.0	2	22.2
Estuarine	9	33.3	8	34.8	7	36.8	6	40.0	6	66.7
Semi-anadromous	1	3.7	1	4.3	1	5.3	1	6.7	0	0
Freshwater	2	7.4	0	0	1	5.3	2	13.3	1	11.1
Total	27		23		19		15		9	
Individuals										
Marine straggler	298	0.3	285	2.4	13	<0.1	0	0	0	0
Estuarine-opportunist	5099	4.8	1981	16.8	1461	5.5	512	1.6	1145	3.2
Estuarine	100055	94.8	9515	80.7	24860	94.4	30838	98.3	34842	96.7
Semi-anadromous	12	<0.1	8	<0.1	2	<0.1	2	<0.1	0	0
Freshwater	27	<0.1	0	0	1	<0.1	9	<0.1	17	<0.1
Total	105491		11789		26337		31361		36004	

Table 10 Dispersion values for ordination plots for samples collected during the day and night in the mouth and lower, middle and upper estuary of the Moore River Estuary between February 1994 and February 1995.

	Region of Estuary			
	Mouth	**Lower**	**Middle**	**Upper**
Day	1.48	1.38	0.92	1.33
Night	1.04	0.58	0.58	0.71

Table 11 Life-cycle categories (SM = solely marine, S = marine straggler, O = marine estuarine-opportunist, E/M = estuarine/marine, E = estuarine), minimum and maximum lengths, numbers (N), percentage contributions (%) and rankings by abundance (R) of species of elasmobranchs and teleosts caught in the shallows of the Leschenault Estuary and Koombana Bay between February and December 1994. The number of individuals of each species represents the total catch of that species, after the numbers in each sample had been corrected to a constant area of 100m^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	11
Leptatherina presbyteroides	E/M	11-67	3025	16.6	3	4	0.3	15
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	18-137	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	17
Gymnapistes marmoratus	O	15-93	107	0.6	12	7	0.5	13
Torquigener pleurogramma	O	81-154	93	0.5	13	6	0.4	14
Contusus brevicaudatus	O	22-130	85	0.5	14	228	14.9	4
Sillago burrus	O	18-99	83	0.5	15	11	0.7	12
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	10
Arripis georgianus	O	41-209	26	0.1	19	48	3.1	7
Urocampus carinirostris	E/M	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	E/M	66-231	17	0.1	23	6	0.4	14
Scobinichthys granulatus	S	32-73	16	0.1	24	1	<0.1	18
Rhabdosargus sarba	O	16-220	15	0.1	25	2	0.1	17
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	17
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	17
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	16
Callogobius mucosus	O	57-96	5	<0.1	33			
Pseudorhombus jenynsii	O	55-263	5	<0.1	33	1	<0.1	18
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	16
Cnidoglanis macrocephalus	E/M	37-445	3	<0.1	37	6	0.4	14
Pomatomus saltatrix	O	32-291	3	<0.1	37	6	0.4	14
Amniataba caudavittata	E	41-163	3	<0.1	37			
Platycephalus speculator	E/M	79-299	1	<0.1	40	6	0.4	14
Pseudolabrus parilus	S	22-22	1	<0.1	40			
Cristiceps australis	S	129-129	1	<0.1	40			
Trygonorhina fasciata	SM	227-227				1	<0.1	18
Aptychotrema vincentiana	SM	400-400				1	<0.1	18
Pelsartia humeralis	SM	78-161				29	1.9	9
Arripis truttaceus	O	36-210				3	0.2	16
Leseurina platycephala	SM	19-101				379	24.8	1
Cynoglossus maculipinnis	SM	82-157				3	0.2	16
Paraplagusia unicolor	SM	32-125				12	0.8	11
Scorpis aequipinnis	S	35-54				2	0.1	17
Total number of species				42			34	
Total number of fish				18269			1526	

Table 12 Numbers (N) and percentage contributions (%) of species and individuals to each life-cycle category caught in the middle and lower regions of Leschenault Estuary and Koombana Bay between February and December 1994. The number of fish represents the sum of the numbers in each sample, after the number had been corrected to an area of 100 m^2 seined.

Life-cycle category	Whole Estuary		Middle region		Lower region		Whole Bay		Koombana east		Koombana west	
	N	%	N	%	N	%	N	%	N	%	N	%
Species												
Solely marine	0	0	0	0	0	0	6	17.6	3	13.6	5	15.6
Marine straggler	9	21.5	4	11.1	9	23.1	5	14.8	4	18.2	4	12.5
Estuarine-opportunist	18	42.9	18	50.0	17	43.6	17	50.0	11	50.0	17	53.1
Estuarine/Marine	10	23.8	9	25.0	8	20.5	6	17.6	4	18.2	6	18.8
Estuarine	5	11.9	5	13.9	5	12.8	0	0	0	0	0	0
Total	42		36		39		34		22		32	
Individuals												
Solely marine	0	0	0	0	0	0	425	27.9	227	46.7	198	19.0
Marine straggler	187	1.0	149	1.2	38	0.7	272	17.8	63	12.9	209	20.1
Estuarine-opportunist	5666	31.0	4885	39.6	781	13.1	679	44.5	187	38.5	492	47.3
Estuarine/Marine	9693	53.1	4919	40.0	4774	80.1	150	9.8	9	1.9	141	13.6
Estuarine	2723	14.9	2359	19.2	364	6.1	0	0	0	0	0	0
Total	18269		12312		5957		1526		486		1040	

Table 13 Mean squares and significance levels for ANOVAs of the number of species and the densities of all fish recorded in the middle and lower regions of the Leschenault Estuary and the eastern and western regions of Koombana Bay between February and December 1994 and during the day and night (diel). * $p<0.05$, *** $p<0.001$.

	Main effects			Two-way interactions			Three-way interaction	Residual
	Region (R)	Month (M)	Diel (D)	R x M	R x D	M x D	R x M x D	
Degrees of freedom	3	7	1	20	3	7	19	120
Number of species	53.49***	31.18***	1.29	11.85***	22.85***	4.46	5.11	3.90
Density of fish	6.51***	1.62***	0.80*	0.41***	0.39*	0.59***	0.21	0.13

Table 14 Life-cycle categories (S = marine straggler, O = marine estuarine-opportunist, E/M = estuarine/marine, E = estuarine, A = anadromous), minimum and maximum lengths, numbers (N), percentage contributions (%) and rankings by abundance (R) of species of elasmobranchs and teleosts caught in deeper waters using composite gill nets in Leschenault Estuary between September 1993 and July 1994.

Species	Life cycle category	Length range (mm)	N	%	R
Nematalosa vlaminghi	A	104-300	466	35.7	1
Mugil cephalus	O	158-474	385	29.5	2
Aldrichetta forsteri	O	133-324	105	8.1	3
Pomatomus saltatrix	O	94-359	94	7.2	4
Arripis georgianus	O	167-274	50	3.5	5
Pelates sexlineatus	O	135-197	46	3.2	6
Sillago schomburgkii	O	174-282	26	2.0	7
Pseudocaranx dentex	O	68-298	26	2.0	7
Arripis truttaceus	O	145-250	25	1.9	9
Myliobatis australis	O	497-1600	19	1.5	10
Acanthopagrus butcheri	E	110-354	17	1.3	11
Engraulis australis	E/M	91-129	14	1.1	12
Gerres subfasciatus	O	116-184	10	0.8	13
Sillaginodes punctata	O	186-283	4	0.3	14
Torquigener pleurogramma	O	111-131	4	0.3	14
Amniataba caudavittata	E	124-128	3	0.2	16
Rhabdosargus sarba	O	144-223	3	0.2	16
Aptychotrema vincentiana	S	700-801	2	0.2	18
Dasyatis thetidis	S	1600-2500	2	0.2	18
Carcharhinus leucas	S	1020	1	0.1	20
Atherinomorus ogilbyi	O	125	1	0.1	20
Contusus brevicaudatus	O	182	1	0.1	20
Total number of species				22	
Total number of fish				1304	

Table 15 Life cycle categories (SM = solely marine, S = marine straggler, O = marine estuarine-opportunist, E/M = estuarine/marine, E = estuarine), minimum and maximum lengths, numbers (N), percentage contributions (%) and rankings by abundance (R) of species of elasmobranchs and teleosts caught in the shallows of the estuary basin, entrance channel and Deadwater Lagoon of the Blackwood River Estuary and Flinders Bay between February and December 1994. The number of individuals of each species represents the total catch of that species, after the numbers in each sample had been corrected to a constant area of 100m^2.

Species	Life cycle category	Length range (mm)	Estuary Basin			Entrance Channel			Deadwater Lagoon			Flinders Bay		
			N	%	R	N	%	R	N	%	R	N	%	R
Leptatherina wallacei	E	18-82	3537	35.3	1	1348	8.1	4	6051	24.2	3			
Favonigobius lateralis	E/M	12-74	2127	21.2	2	2894	17.4	3	2910	11.6	4			
Leptatherina presbyteroides	E/M	17-89	1359	13.6	3	6625	39.8	1	6287	25.1	2	2363	76.0	1
Pelates sexlineatus	O	9-213	1158	11.5	4	3546	21.3	2	137	0.5	9			
Afurcagobius suppositus	E	16-90	563	5.6	5	162	1.0	9	45	0.2	11			
Rhabdosargus sarba	O	10-264	378	3.8	6	814	4.9	5	1259	5.0	5	3	0.1	17
Atherinosoma elongata	E	22-101	291	2.9	7	570	3.4	6	7022	28.1	1			
Pseudogobius olorum	E	15-65	240	2.4	8	218	1.3	8	309	1.2	7			
Aldrichetta forsteri	O	21-368	202	2.0	9	279	1.7	7	447	1.8	6	31	1.0	8
Engraulis australis	E/M	42-105	36	0.4	10	2	<0.1	26						
Sillago schomburgkii	O	34-357	22	0.2	11	7	<0.1	19	43	0.2	12	48	1.5	7
Pseudorhombus jenynsii	O	19-245	15	0.2	12	19	0.1	12	7	<0.1	15	6	0.2	14
Amoya bifrenatus	E/M	22-128	15	0.2	12	3	<0.1	24	9	<0.1	14			
Haletta semifasciata	S	49-154	13	0.1	14	9	0.1	15						
Enoplosus armatus	S	28-87	12	0.1	15	8	<0.1	18						
Sillaginodes punctata	O	40-253	9	0.1	16	18	0.1	13	293	1.2	8			
Spratelloides robustus	S	28-110	8	0.1	17	25	0.2	11	6	<0.1	16	70	2.3	6
Mugil cephalus	O	18-164	7	0.1	18	5	<0.1	20	136	0.5	10	2	0.1	18
Torquigener pleurogramma	O	40-141	7	0.1	18	9	0.1	15	40	0.2	13	12	0.4	10
Scobinichthys granulatus	S	26-52	6	0.1	20	1	<0.1	29				1	<0.1	24
Pseudolabrus parilus	S	41-117	5	0.1	21	4	<0.1	22	1	<0.1	20			
Cnidoglanis macrocephalus	E/M	40-462	4	<0.1	22	10	0.1	14	6	<0.1	16	131	4.2	3
Penicipelta vittiger	S	54-62	4	<0.1	22									
Urocampus carinirostris	E/M	57-193	3	<0.1	24				6	<0.1	16	2	0.1	18
Hyporhamphus melanochir	E/M	67-152	3	<0.1	24							5	0.2	15
Platycephalus speculator	E/M	34-305	2	<0.1	26	3	<0.1	24				10	0.3	11
Cristiceps australis	S	46-105	1	<0.1	27	5	<0.1	20				2	0.1	18

Sillago bassensis	S	22-197	1	<0.1	27	48	0.3	10				144	4.6	2
Sillago burrus	O	24	1	<0.1	27									
Halichoeres brownfieldii	S	21	1	<0.1	27									
Platycephalus laevigatus	S	96	1	<0.1	27									
Arripis georgianus	O	42-284				4	<0.1	22	4	<0.1	19	9	0.3	12
Arripis truttaceus	O	172							1	<0.1	20			
Contusus brevicaudatus	O	81-147				9	0.1	15	1	<0.1	20	2	0.1	18
Stigmatophora argus	S	101-146							1	<0.1	20	2	0.1	18
Upeneichthys sp.	S	32-36				2	<0.1	26						
Pseudocaranx dentex	S	38-80				2	<0.1	26						
Ammotretis elongata	S	62-146				1	<0.1	29				9	0.3	12
Apogon rueppellii	E/M	19				1	<0.1	29						
Pagrus auratus	S	147				1	<0.1	29						
Kyphosus sydneyanus	S	309				1	<0.1	29						
Trachurus mccullochi	S	210				1	<0.1	29						
Pelsartia humeralis	SM	38-167										130	4.2	4
Leseurina platycephala	SM	17-82										101	3.2	5
Paraplagusia unicolor	SM	25-110										19	0.6	9
Atherinomorus ogilbyi	O	73-162										4	0.1	16
Trygonorhina fasciata	SM	450-500										2	0.1	18
Gonorynchus greyi	O	92										1	<0.1	24
Scorpis georgianus	SM	328										1	<0.1	24
Total number of species				31			34			23			26	
Total number of fish				10029			16652			25021			3108	

Table 16 Numbers (N) and percentage contributions (%) of species and individuals to each life-cycle category caught in the estuary basin, entrance channel and Deadwater Lagoon regions of the Blackwood River Estuary and in Flinders Bay between February and December 1994. The number of individuals of each life-cycle category represents the total catch of that group, after the numbers in each sample had been corrected to a constant area of $100m^2$.

Life-cycle category	Whole Estuary		Estuary Basin		Entrance Channel		Deadwater Lagoon		Flinders Bay	
	N	%	N	%	N	%	N	%	N	%
Species										
Solely marine	0	0	0	0	0	0	0	0	5	19.2
Marine straggler	17	40.5	10	32.3	13	38.2	3	13.0	6	23.1
Estuarine-opportunist	12	28.6	9	29.2	10	29.4	11	47.8	10	38.5
Estuarine/Marine	9	21.4	8	25.8	7	20.6	5	21.7	5	19.2
Estuarine	4	9.5	4	12.9	4	11.8	4	17.4	0	0
Total	42		31		34		23		26	
Individuals										
Solely marine	0	0	0	0	0	0	0	0	253	8.1
Marine straggler	167	0.3	52	0.5	108	0.6	8	0.03	227	7.3
Estuarine-opportunist	8875	17.2	1797	17.9	4709	28.9	2368	9.5	117	3.8
Estuarine/Marine	22304	43.1	3549	35.4	9536	57.3	9218	36.8	2511	80.8
Estuarine	20356	39.4	4631	46.2	2298	13.8	13427	53.7	0	0
Total	51702		10029		16652		25021		3108	

Table 17 Mean squares and significance levels for ANOVAs of the number of species and the densities of all fish and of the five most abundant species caught in the Blackwood River Estuary and Flinders Bay between February and December 1994 and during the day and night (diel). * p<0.05, ** p<0.01, *** p<0.001. Since the latter four species, designated as ′, were not caught, or were caught only in very low numbers in Flinders Bay, the data for these species in this region were not included in the ANOVA. The degrees of freedom for this ANOVA are in parentheses.

	Main effects			Two-way interactions			Three-way interaction	Residual
	Region (R)	Month (M)	Diel (D)	R x M	R x D	M x D	R x M x D	
Degrees of freedom	3 (2)	7 (7)	1 (1)	21 (14)	3 (2)	7 (7)	21 (14)	120 (93)
Number of species	128.06***	16.49	47.35**	4.43	2.85	14.69	4.63	6.29
Density of fish	13.36***	0.52*	0.07	0.27	0.33	0.24	0.31	0.22
Leptatherina presbyteroides	5.90***	1.40*	2.60*	1.22*	0.52	0.51	1.09*	0.64
'*Favonigobius lateralis*	0.34	0.67*	0.59	0.86***	0.04	0.26	0.36	0.29
'*Atherinosoma elongata*	19.70***	4.21***	0.81	1.46***	0.59	0.27	0.40	0.28
'*Leptatherina wallacei*	3.75***	2.16***	4.04**	2.07***	0.17	0.99	0.56	0.49
'*Rhabdosargus sarba*	2.08***	1.05**	0.74	0.73**	0.28	0.59	0.31	0.30

Table 18 Relative dispersion values for ordination plots for samples collected during the day and night in the estuary basin, entrance channel and Deadwater Lagoon regions of the Blackwood River Estuary and in Flinders Bay between February and December 1994.

	Estuary Basin	Entrance Channel	Deadwater Lagoon	Flinders Bay
Day	0.79	1.02	0.91	1.45
Night	0.79	0.75	0.62	1.67

Table 19 Life-cycle categories (S = marine straggler, O = marine estuarine-opportunist, E/M = estuarine/marine E = estuarine, F = freshwater), minimum and maximum lengths, numbers (N), percentage contributions (%) and rankings by abundance (R) of species of teleosts caught in deeper waters using composite gill nets in Blackwood River Estuary between November 1993 and July 1994.

Species	Life cycle category	Length range (mm)	N	%	R
Rhabdosargus sarba	O	97-300	94	21.0	1
Mugil cephalus	O	116-350	83	18.6	2
Sillago schomburgkii	O	224-349	79	17.6	3
Pelates sexlineatus	O	144-279	72	16.1	4
Aldrichetta forsteri	O	150-354	32	7.1	5
Cnidoglanis macrocephalus	E/M	280-620	25	5.6	6
Pseudocaranx dentex	O	159-225	16	3.6	7
Arripis georgianus	O	206-277	16	3.6	7
Arripis truttaceus	O	209-295	10	2.1	9
Engraulis australis	E	75-97	7	1.6	10
Trachurus mccullochi	S	183-223	7	1.6	10
Chrysophrys auratus	O	182	3	0.6	12
Pomatomus saltatrix	O	306	2	0.3	13
Enoplosus armatus	S	92	2	0.3	13
Sillaginodes punctata	O	271	1	0.2	15
Tandanus bostocki	F	251	0.5	0.1	16
Acanthopagrus butcheri	E	122	0.2	<0.1	17
Total number of species				17	
Total number of fish				447	

(XV) FIGURES

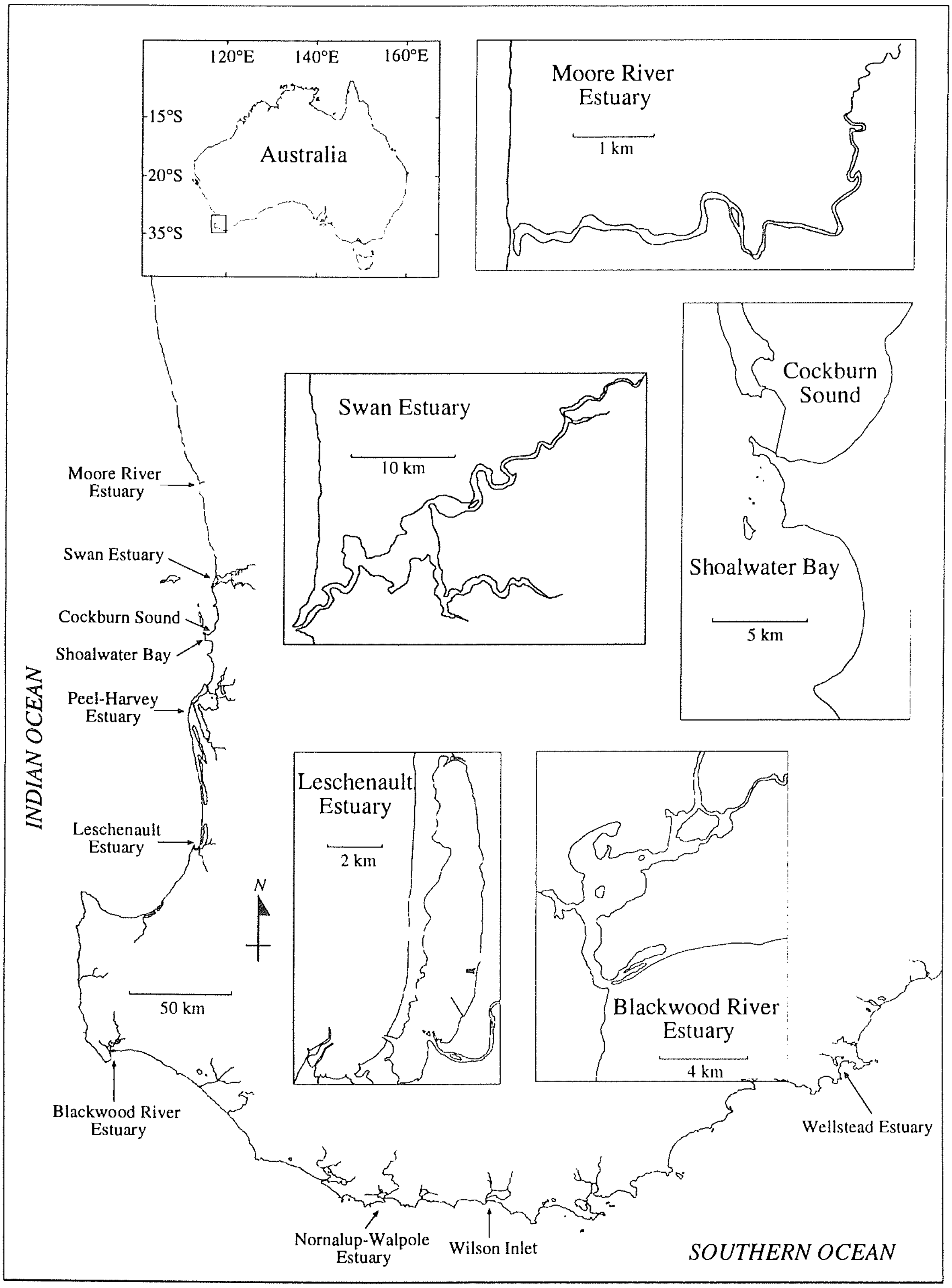


Figure 1 Map showing the positions of the different sampling locations in the estuarine and marine waters of south-western Australia.

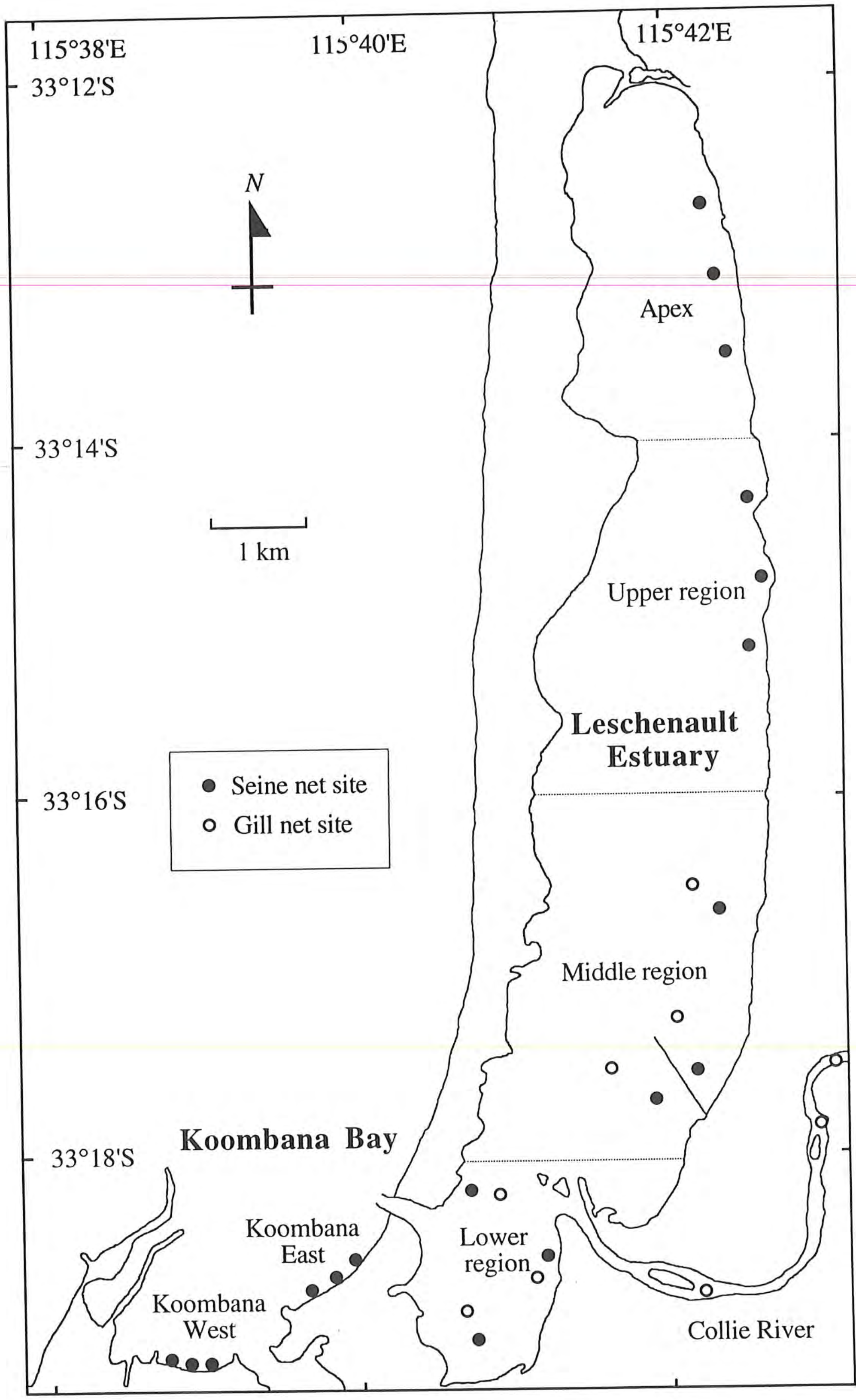


Figure 2 Map showing the positions of the seine and gill net sampling sites in the lower, middle, upper, apex and riverine regions of the Leschenault Estuary and the eastern and western regions of Koombana Bay.

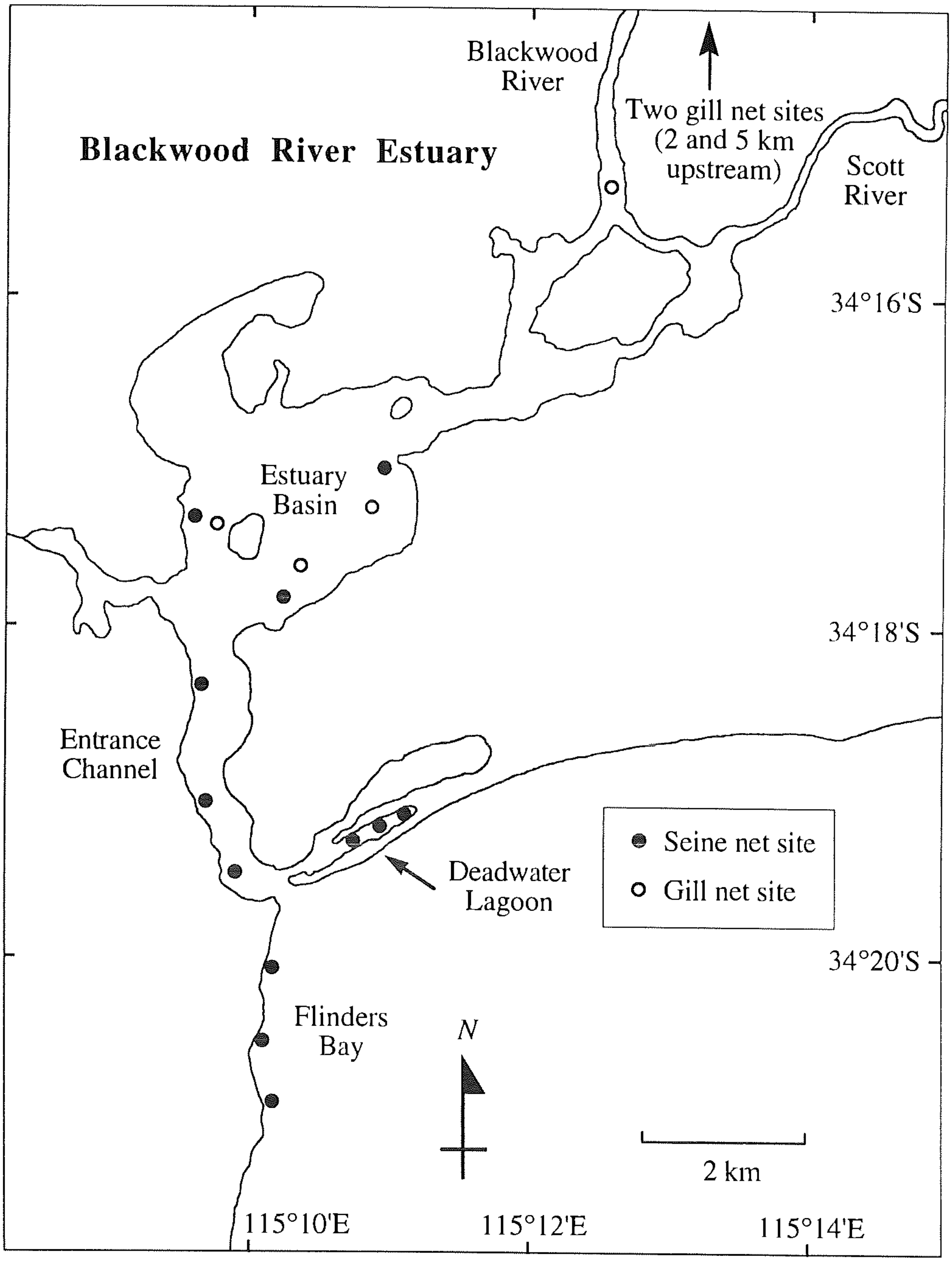


Figure 3 Map showing the positions of the three sampling sites in the estuary basin, entrance channel, Deadwater Lagoon and riverine regions of the Blackwood River Estuary and in Flinders Bay.

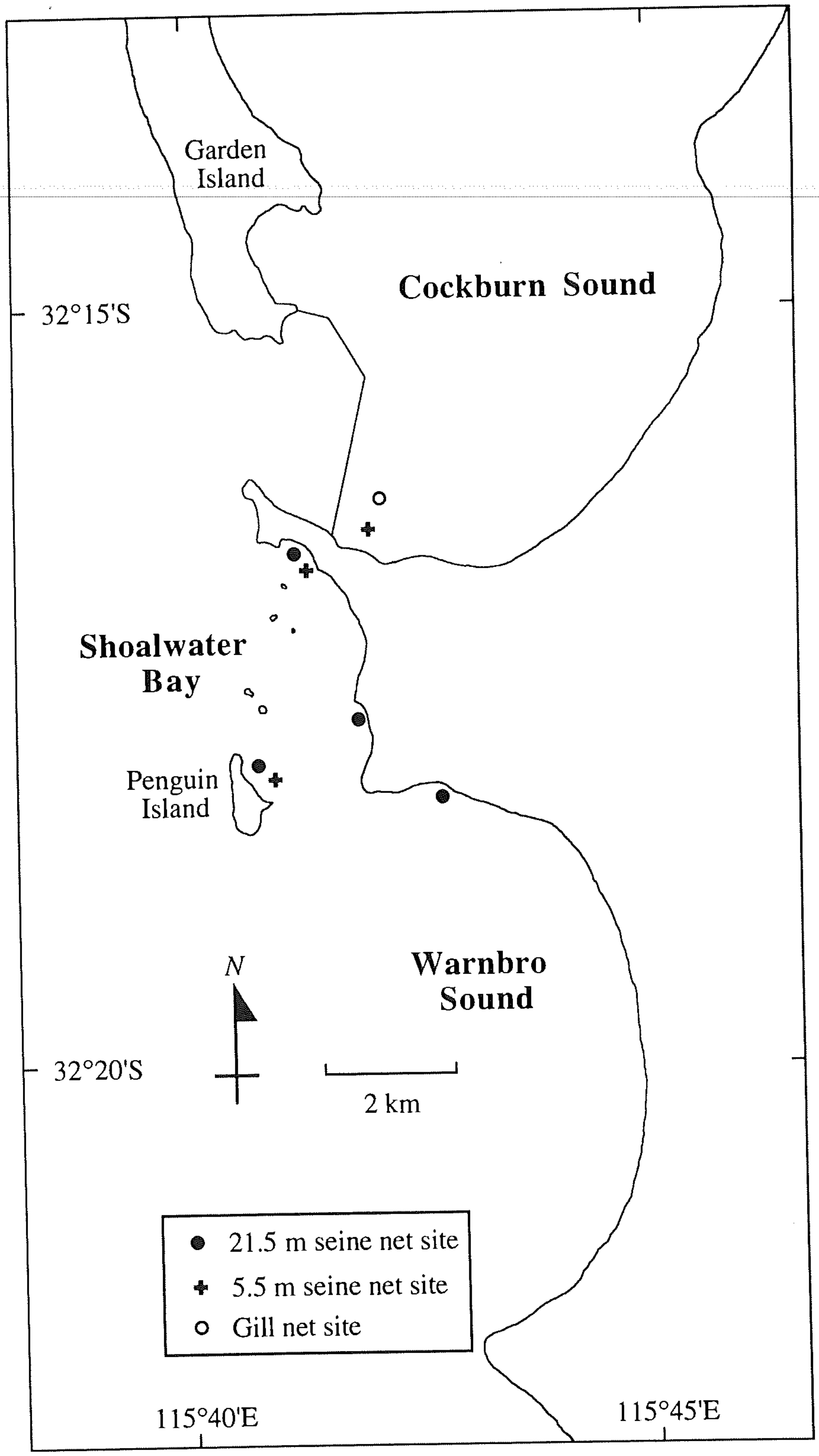


Figure 4 Map showing the positions of the different sampling sites within Shoalwater Bay, Warnbro Sound and Cockburn Sound.

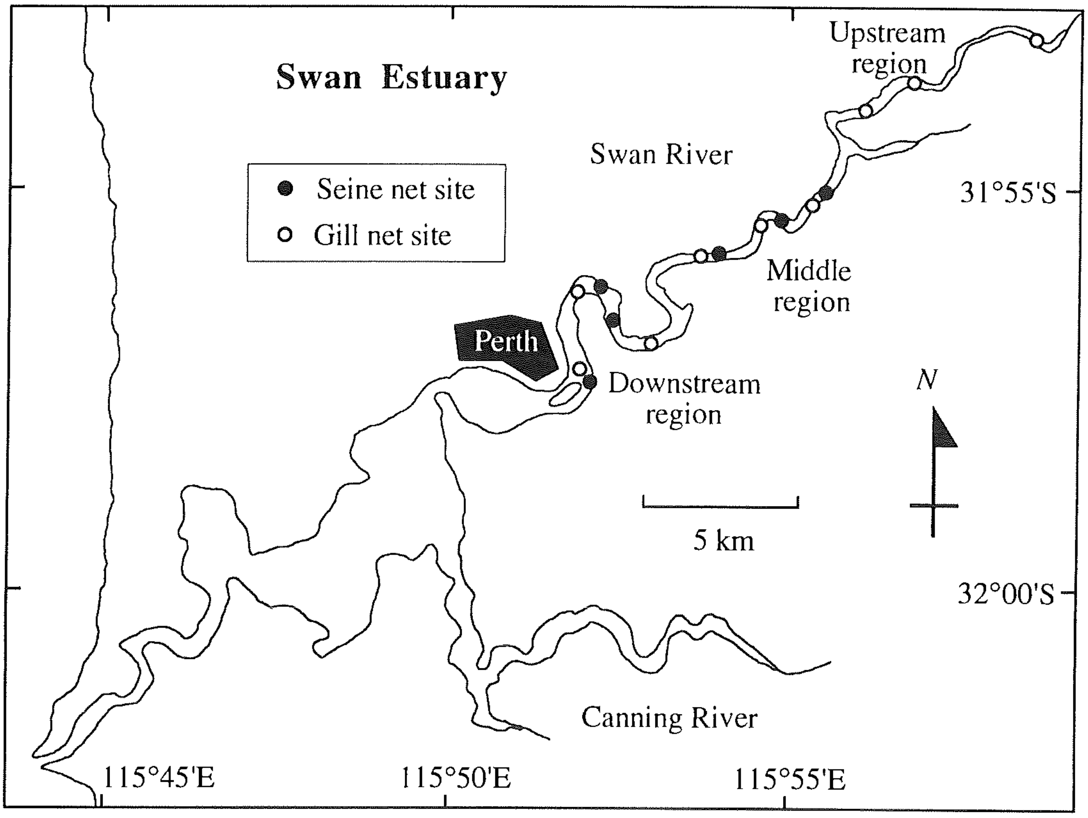


Figure 5 Map showing the positions of the three sampling sites in the downstream, middle and upstream regions of the upper Swan Estuary.

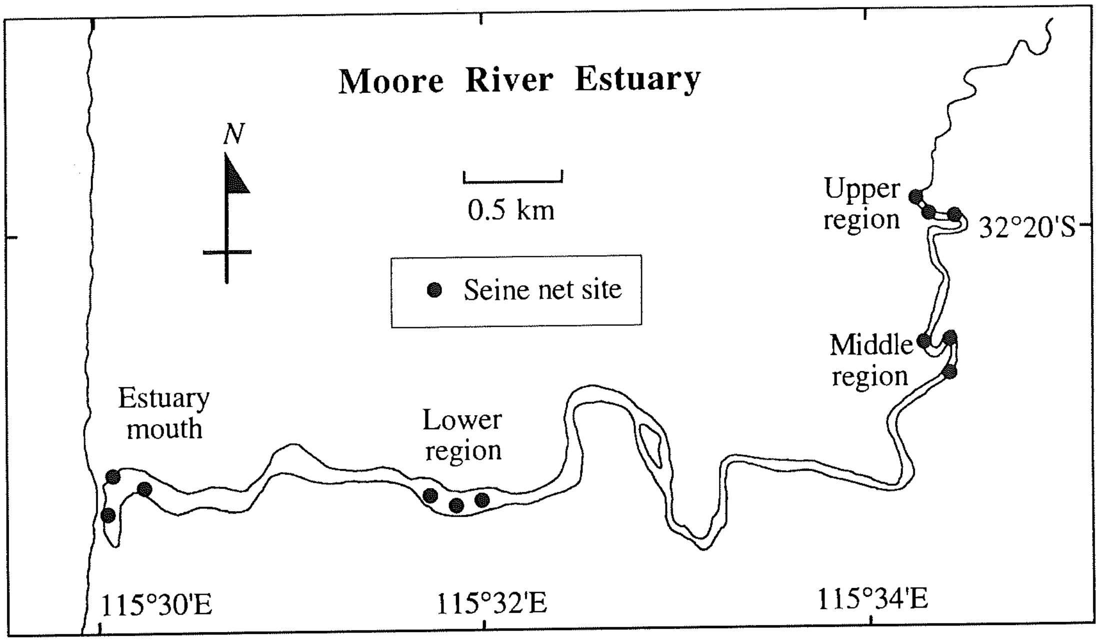
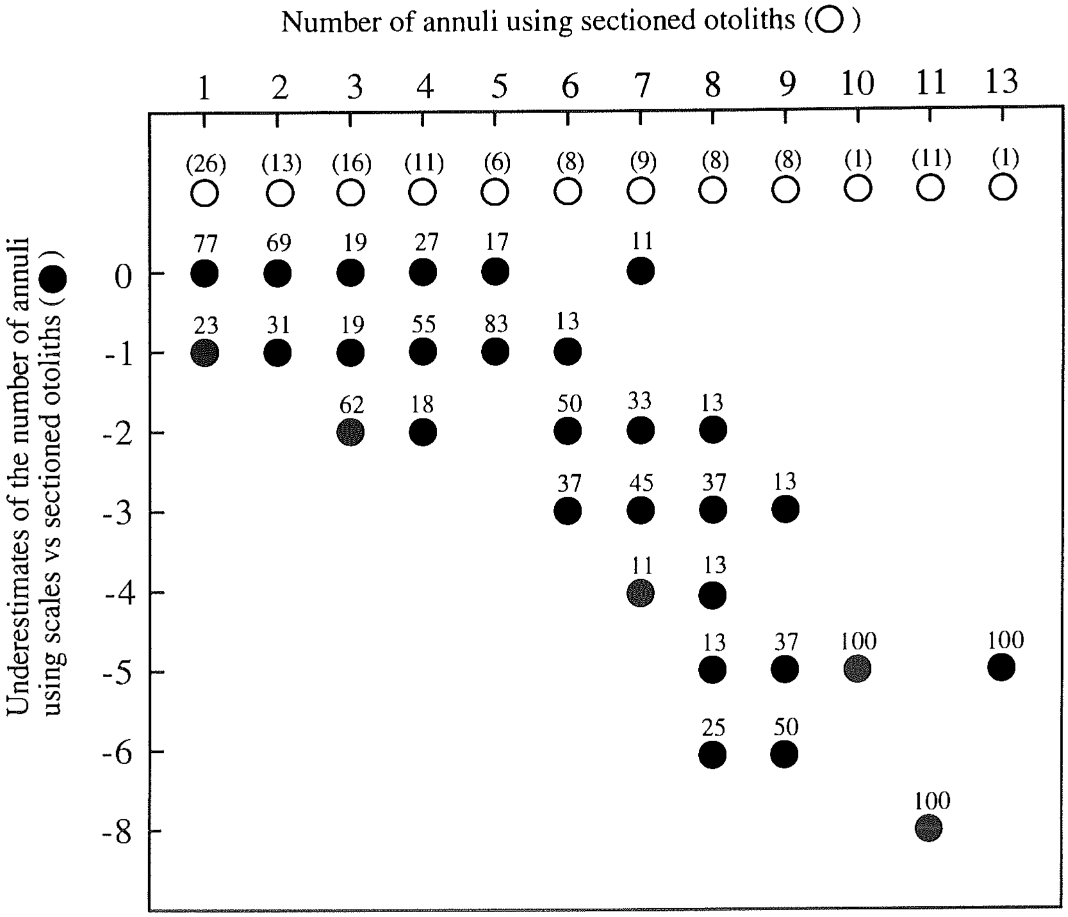


Figure 6 Map showing the positions of the three sampling sites in the mouth and the lower, middle and upper regions of the Moore River Estuary.

(a) Scales *vs* sectioned otoliths



(b) Whole *vs* sectioned otoliths

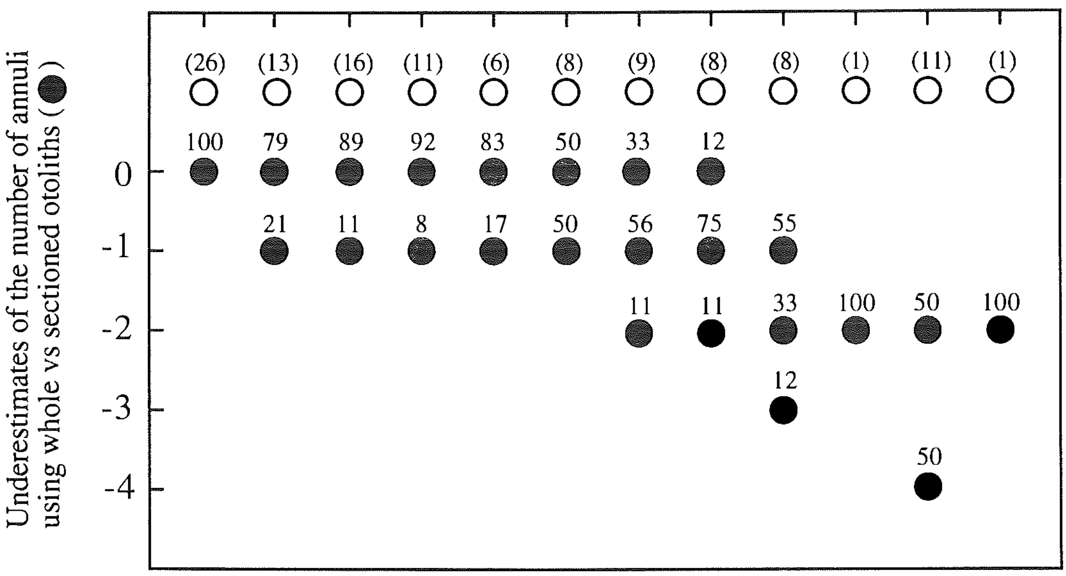


Figure 7 Number of otoliths with 1-13 annuli based on sectioned otoliths of King George whiting caught on the lower west coast of Australia, and underestimates of the number of zones observed on (a) the corresponding scales and, (b) those sagittal otoliths prior to sectioning. Numbers in parentheses indicate the number of fish of different ages based on sectioned otoliths, while numbers above the closed circles indicate the percentage of underestimates using scales or whole otoliths.

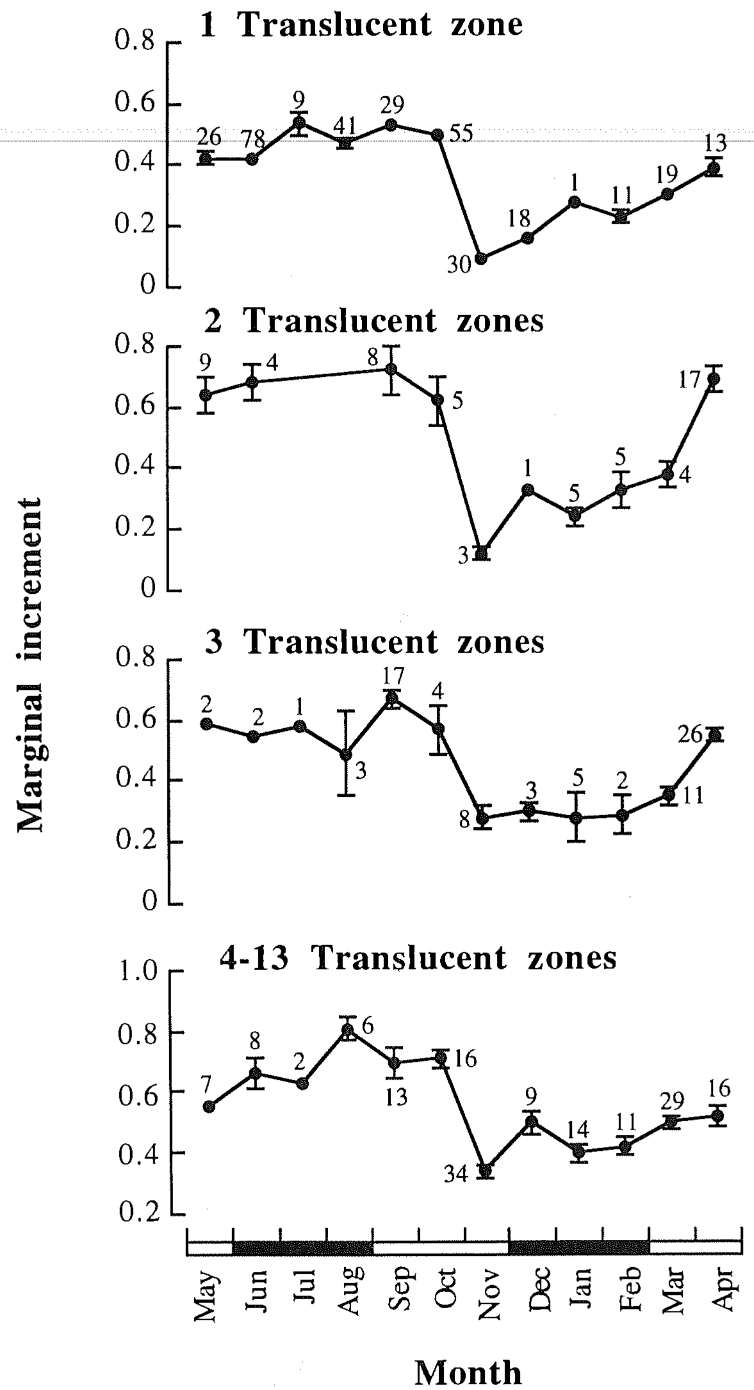


Figure 8 Mean monthly marginal increments ±1SE for sagittal otoliths of King George whiting caught on the lower west coast of Australia. The mean marginal increment is expressed as a proportion of the distance between the focus and the outer translucent zone, when only one zone was present, and as a proportion of the distance between the outer edges of the two outermost translucent zones, when two or more such zones were present. Sample sizes are given for each month. In this and Fig. 13, black rectangles and open rectangles on the x-axis denote summer and winter months, and spring and autumn months, respectively.

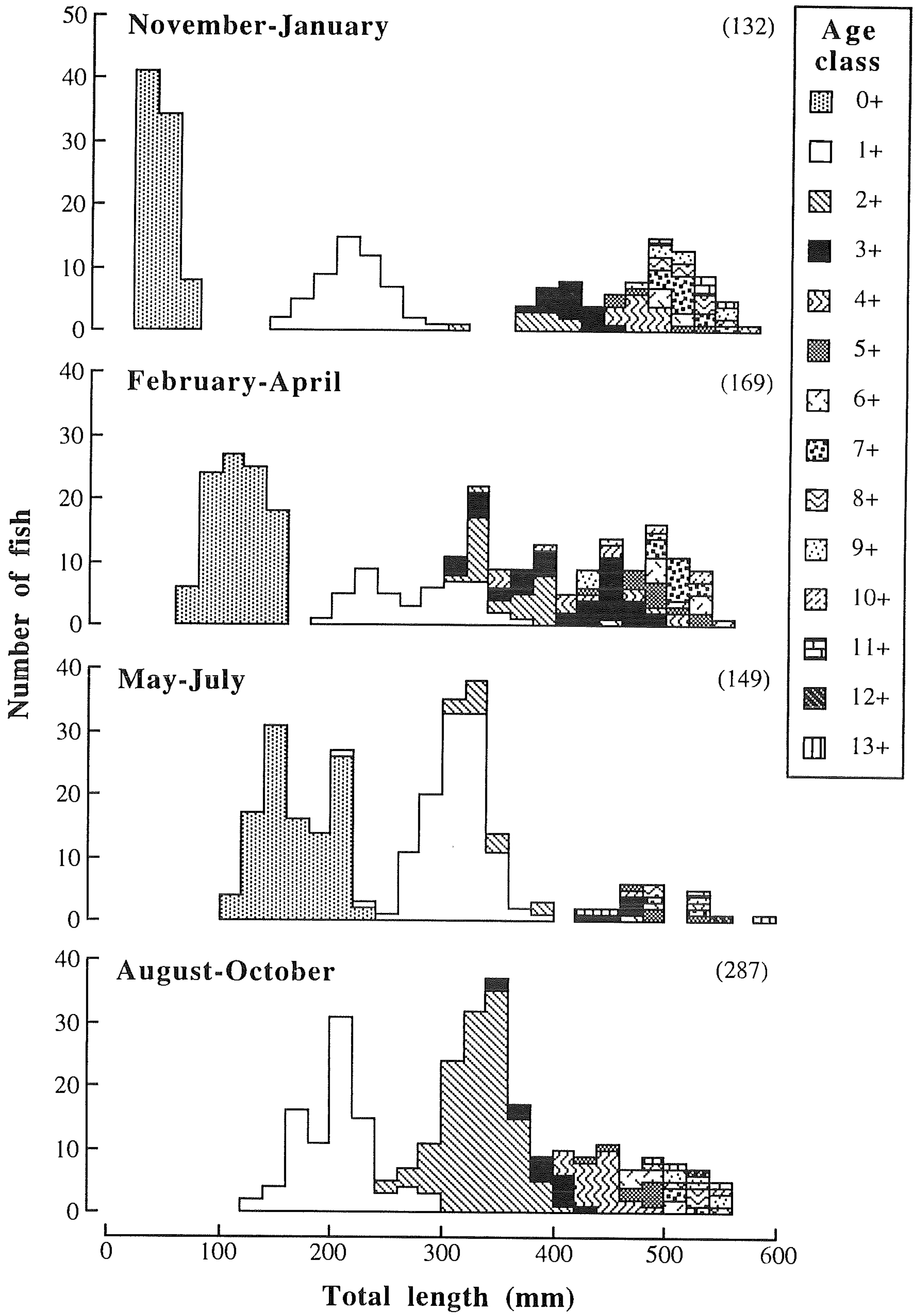


Figure 9 Length-frequency histograms for the different age classes of King George whiting based on samples collected by the 21.5 m seine net (3 mm in the pocket) in nearshore waters and by anglers in deeper water in around reefs on the lower west coast of Australia. Sample sizes are given in parentheses.

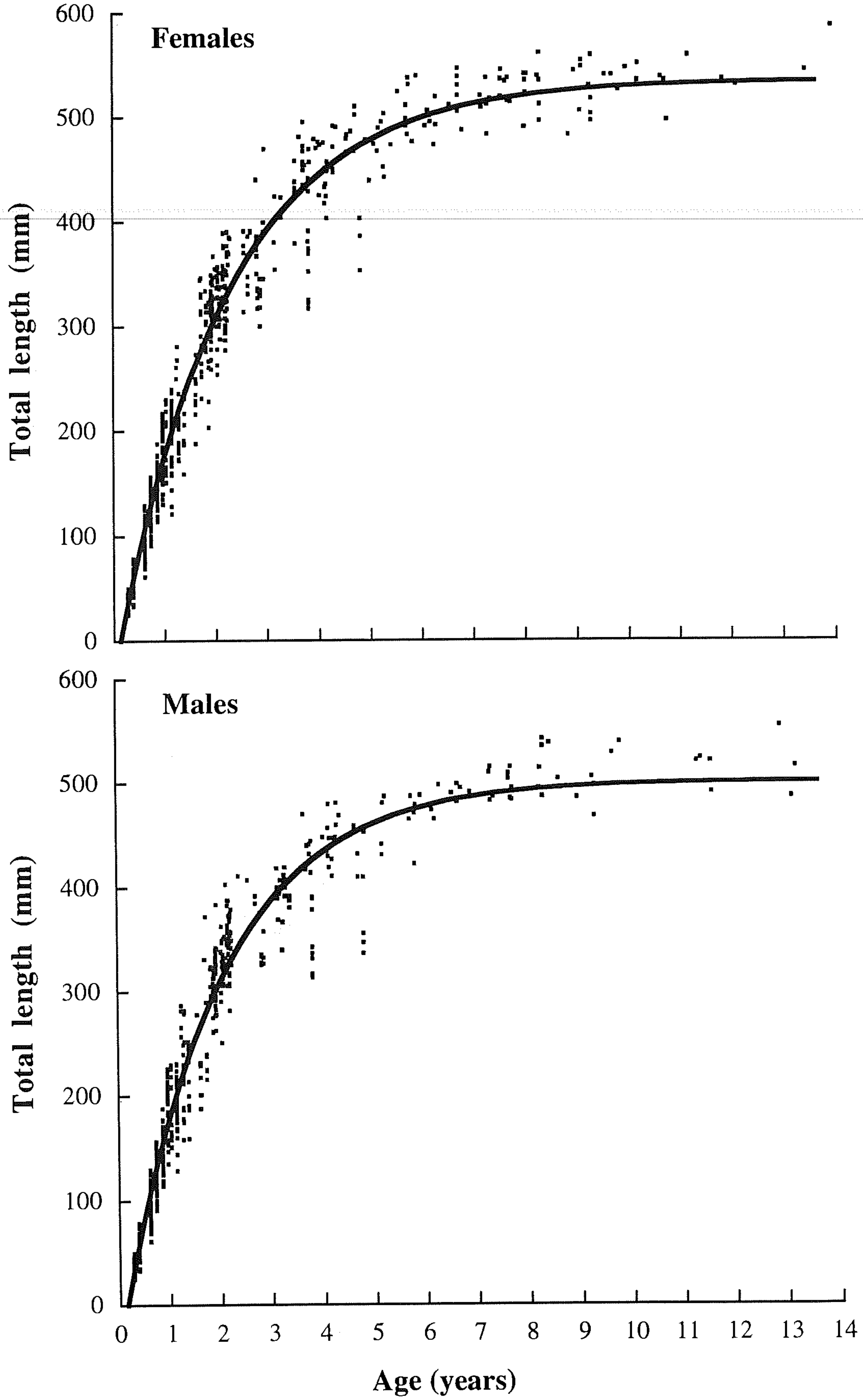


Figure 10 von Bertalanffy growth curves fitted to length at age data derived from sagittal otoliths of female and male King George whiting caught on the lower west coast of Australia.

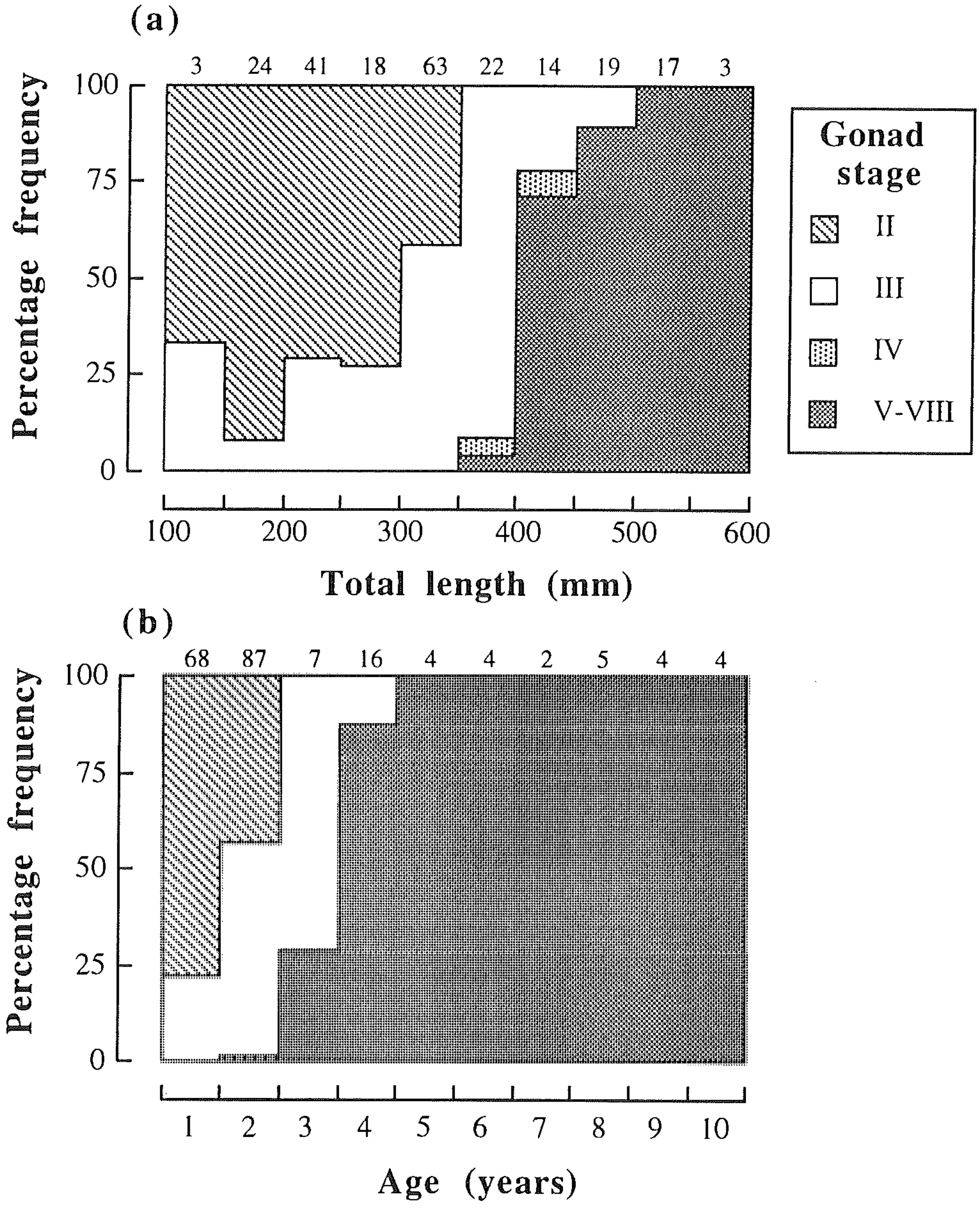


Figure 11 Percentage frequency of occurence of sequential stages in gonadal development in **(a)** each sequential 50 mm length category and **(b)** age class of female King George whiting caught between June and September on the lower west coast of Australia. Sample sizes are given above each length and age category.

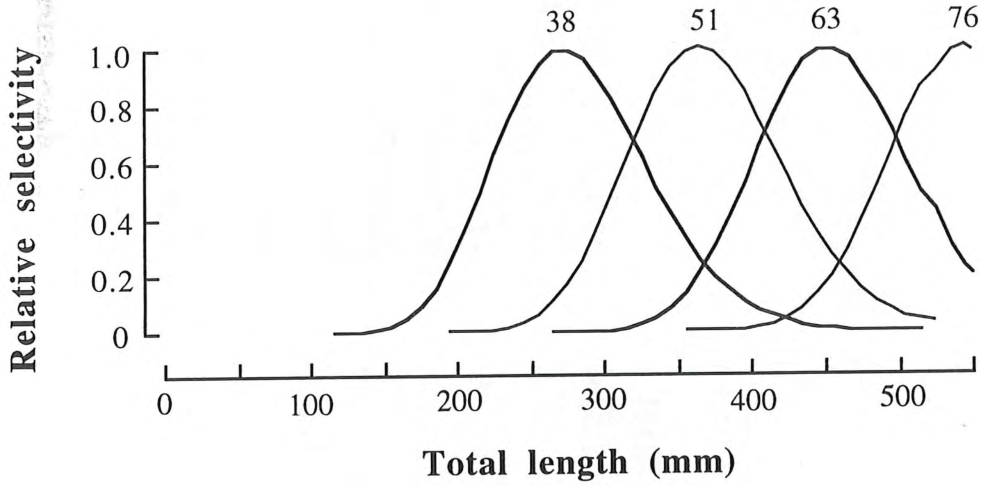


Figure 12 Mesh selectivity curves for different lengths of King George whiting in four mesh sizes in gill nets.

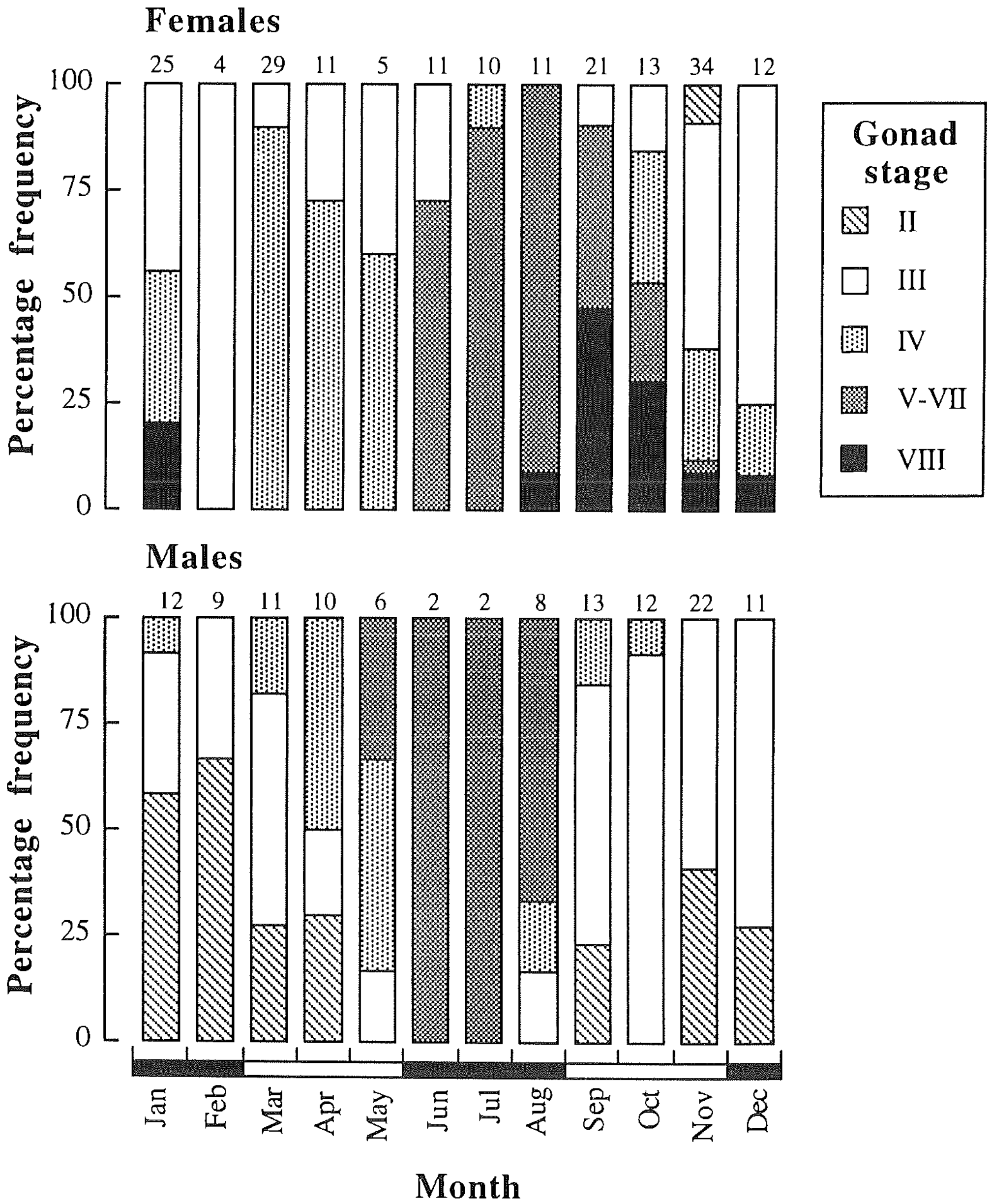


Figure 13 Monthly percentage frequencies of occurrence of sequential gonadal development stages in female and male King George whiting caught on the lower west coast of Australia. Sample sizes are given above each month. x-axis as in Fig. 8.

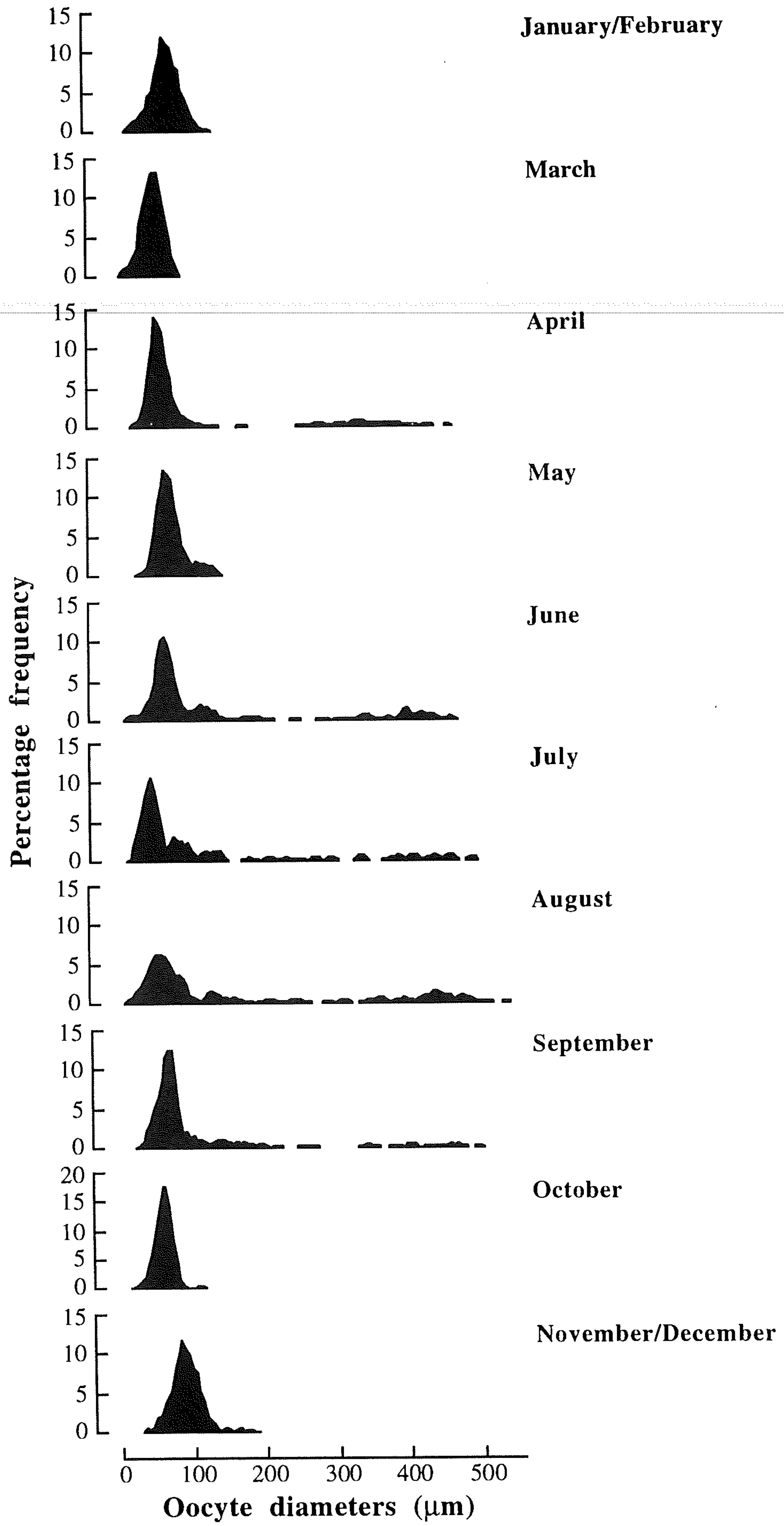


Figure 14 Monthly percentage frequencies for oocyte diameters in ovaries of King George whiting caught on the lower west coast of Australia.

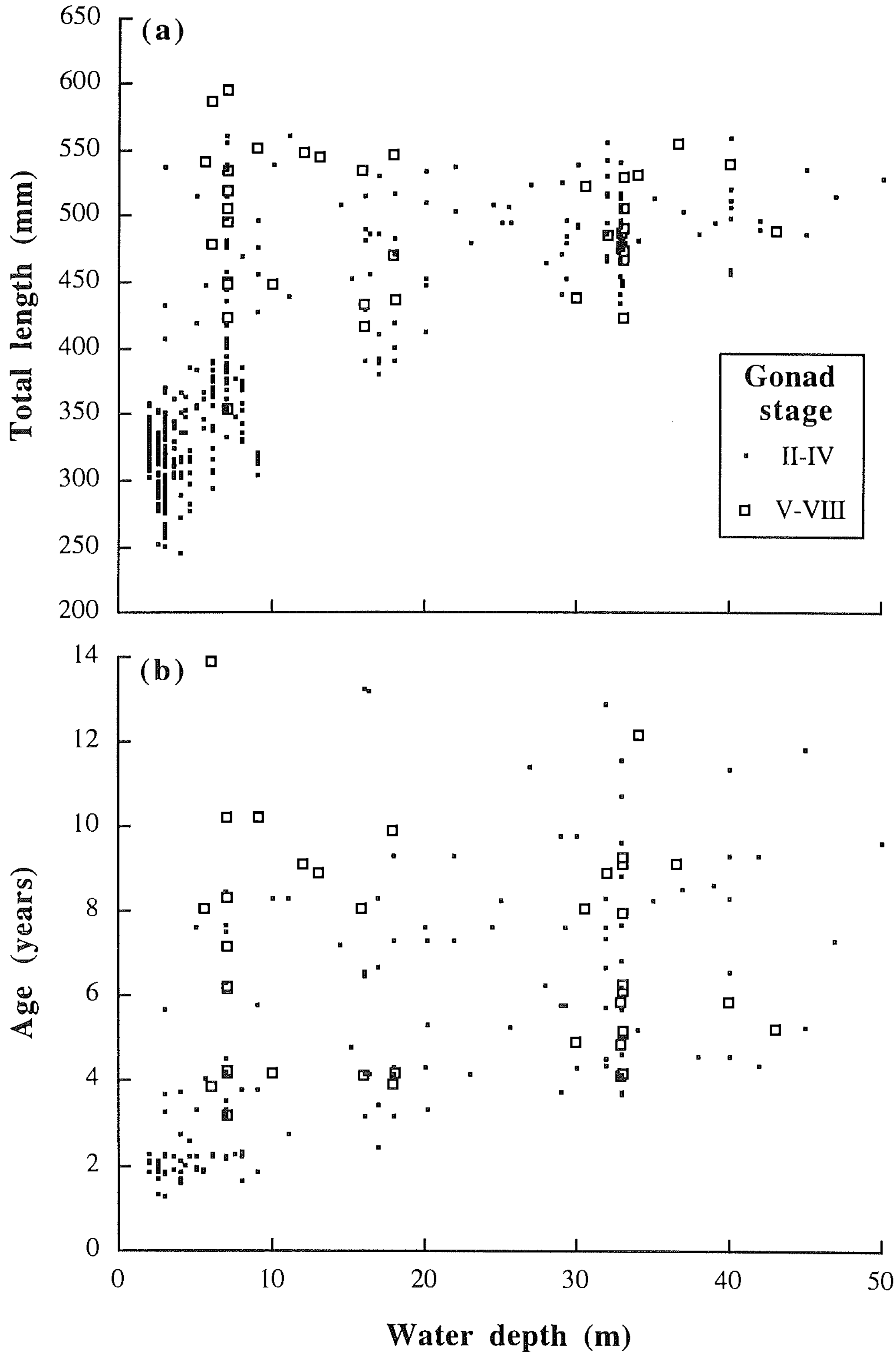


Figure 15 (a) Lengths and (b) ages at capture of immature (stages II-IV) and mature (stages V-VIII) representatives of King George whiting collected at different depths by recreational fishers in the inner shelf of the lower west coast of Australia.

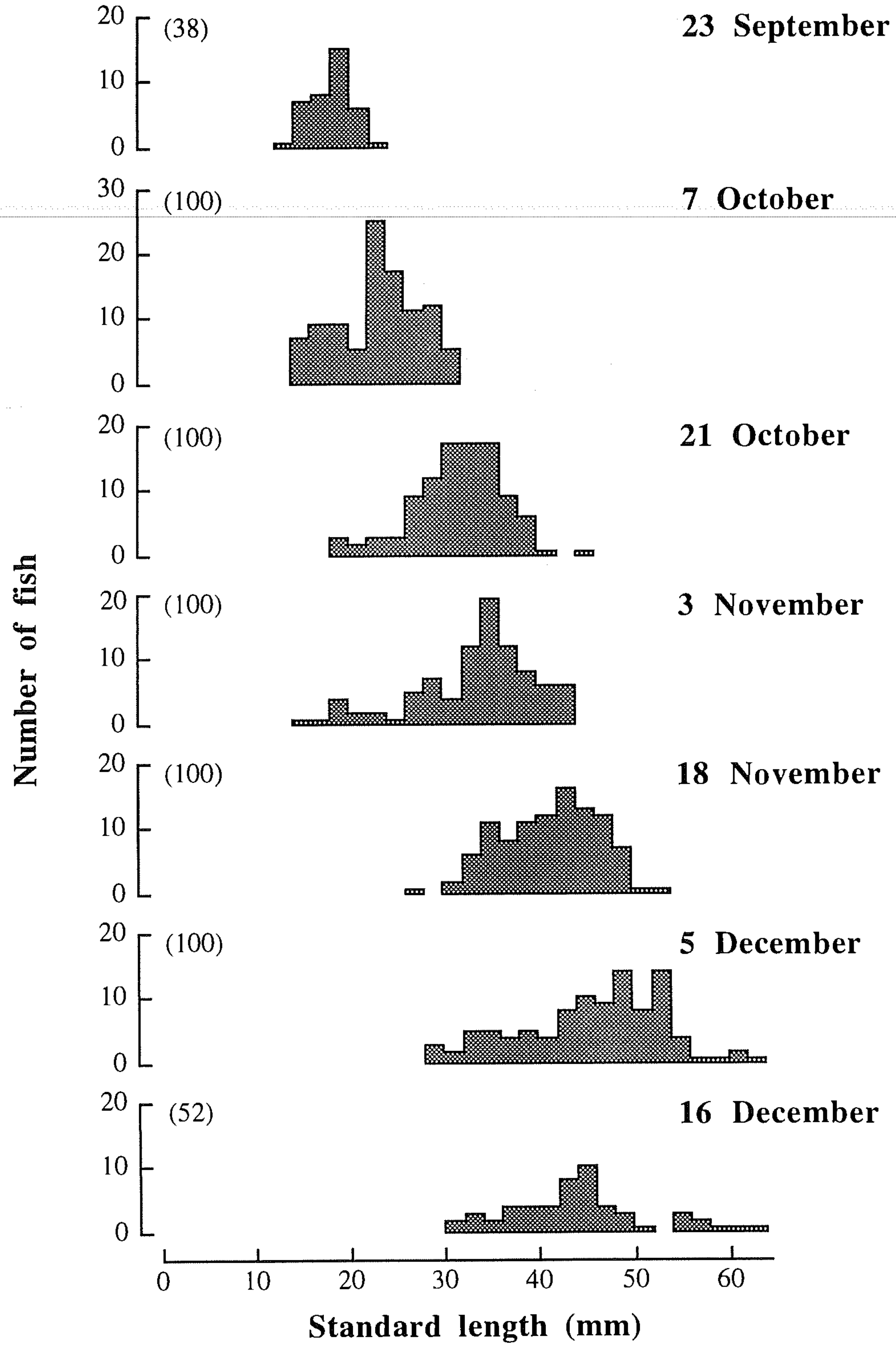


Figure 16 Length-frequency histograms for King George whiting caught at two weekly intervals by the 5.5 m seine net (1 mm mesh) in nearshore waters between September and December 1994 on the lower west coast of Australia. The numbers in parentheses represent the number of fish measured.

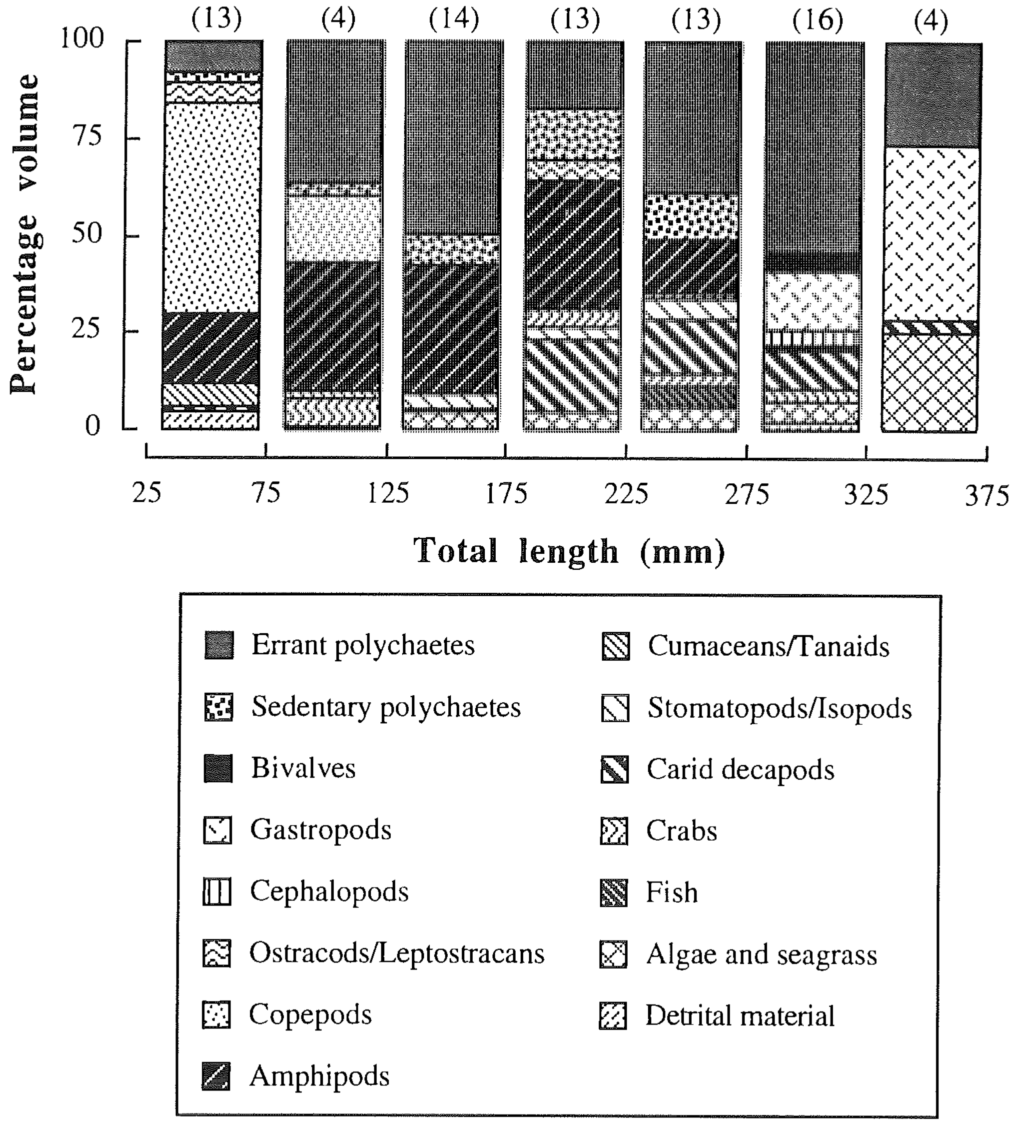


Figure 17 Percentage composition by volume of different dietary categories in sequential 50 mm length classes of King George whiting caught in the marine waters of the lower west coast of Australia. Numbers in parentheses refer to the number of guts in that length class.

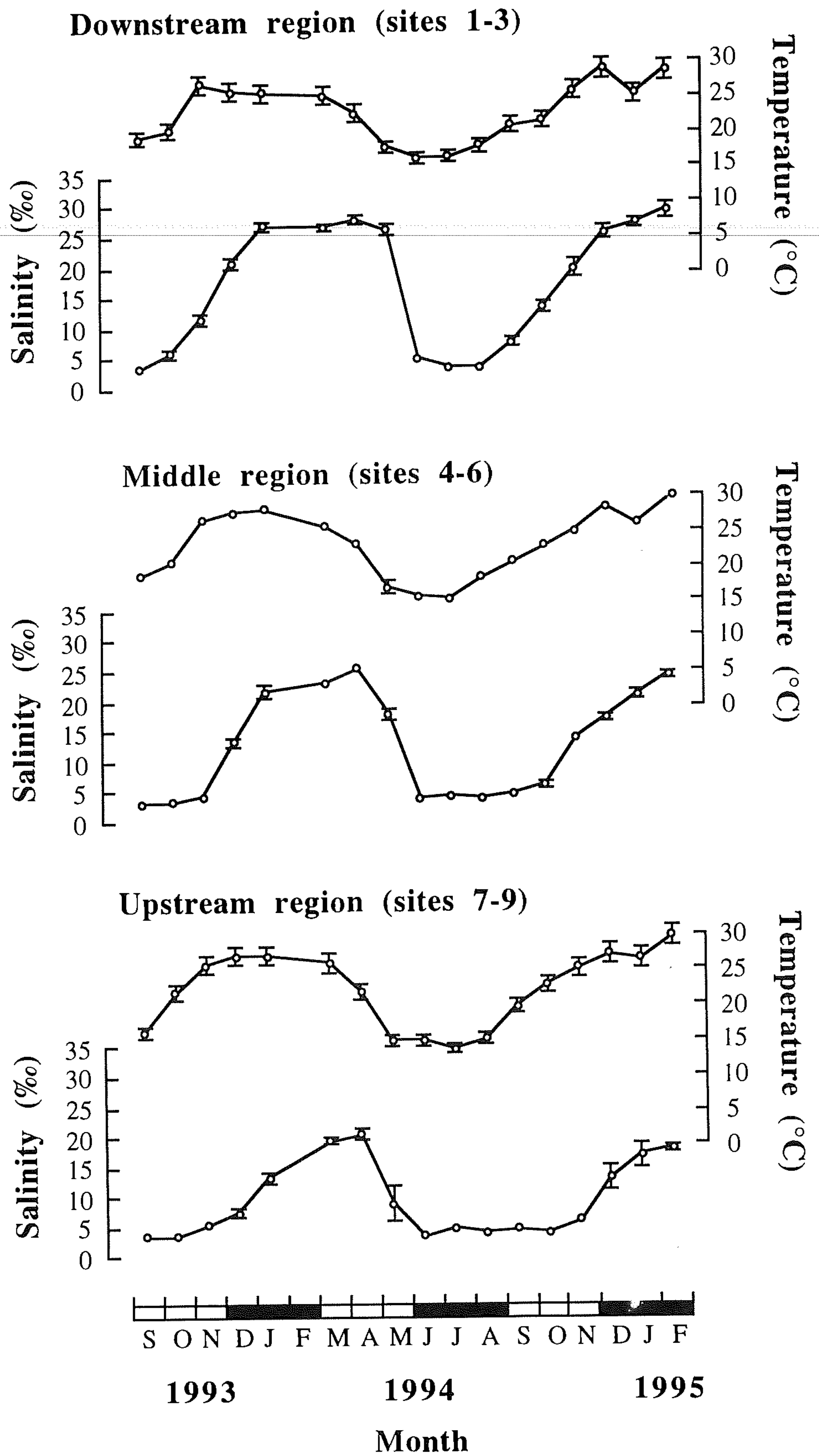


Figure 18 Mean surface salinities and temperatures ±1SE taken at sampling sites in the downstream, middle and upstream regions of the upper Swan Estuary between September 1993 and February 1995. In this and Figs 22, 28 and 29, black rectangles and open rectangles on the x-axis denote summer and winter months, and spring and autumn months, respectively.

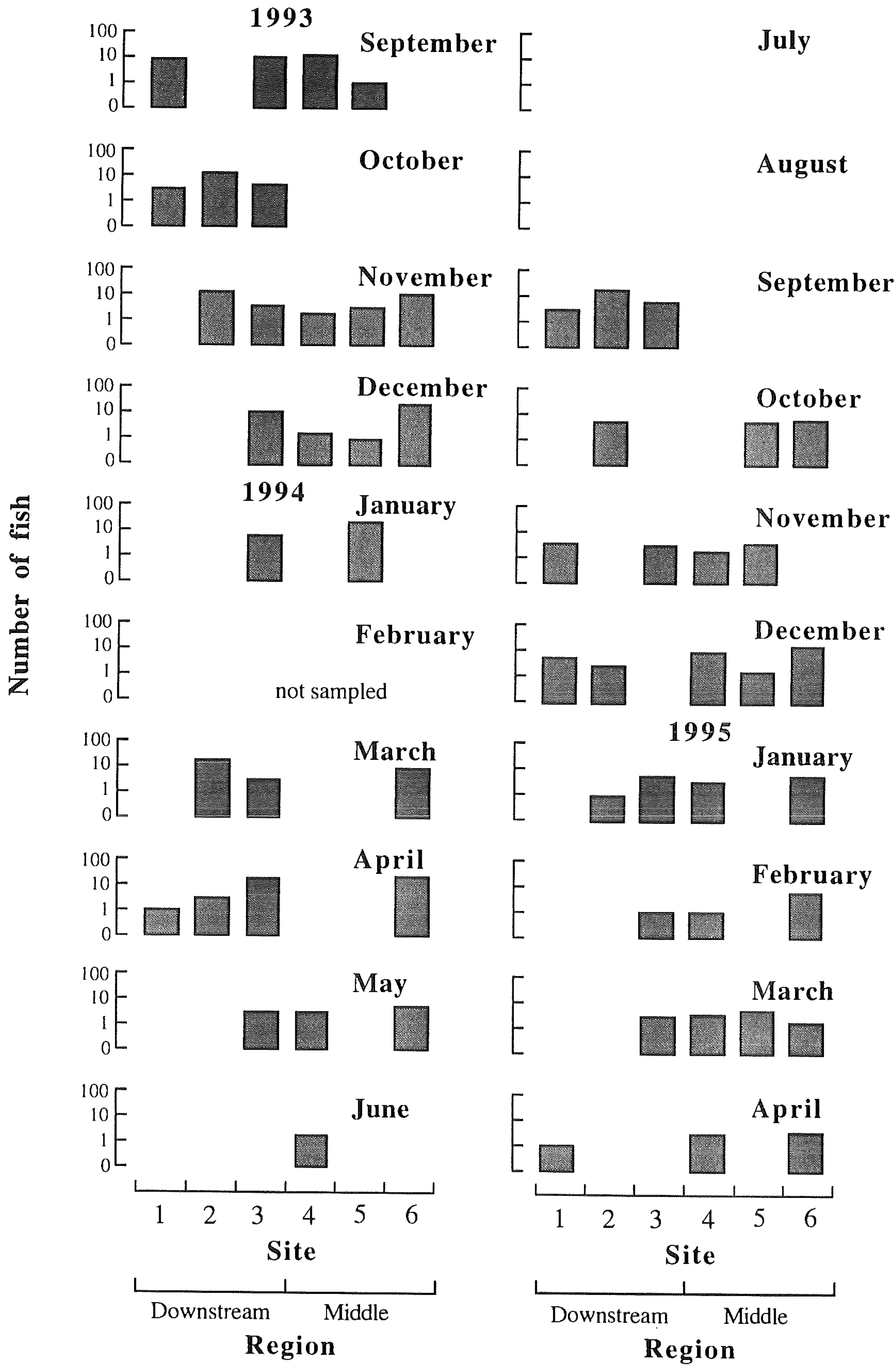


Figure 19 Total numbers of Black bream captured using the 41.5 m seine net in the downstream and middle regions of the upper Swan Estuary between September 1993 and April 1995.

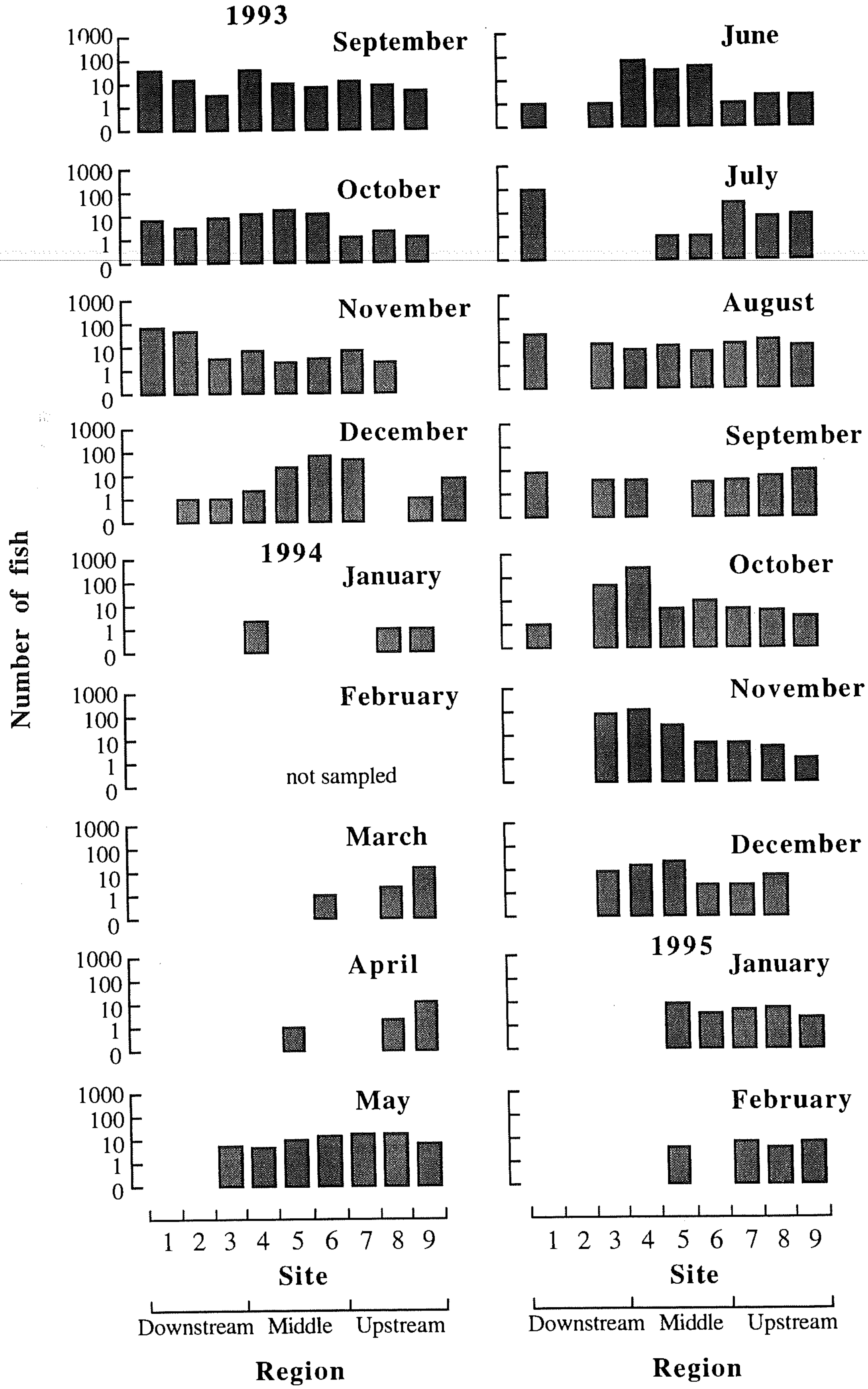


Figure 20 Total numbers of Black bream captured using composite gill nets in the downstream, middle and upstream regions of the upper Swan Estuary between September 1993 and February 1995.

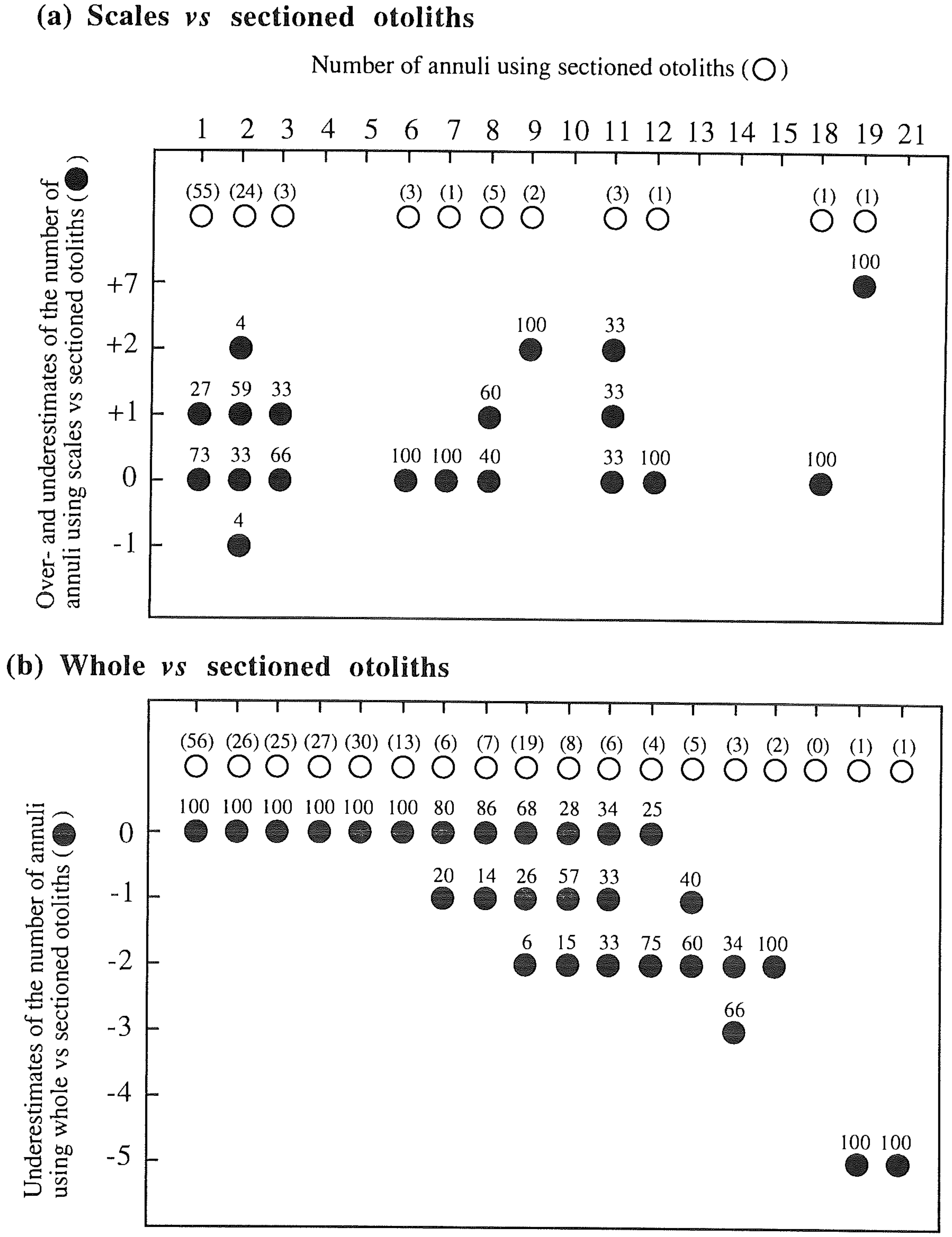


Figure 21 Number of otoliths with 1-21 annuli based on sectioned otoliths of Black bream caught in the upper Swan Estuary, and differences in estimates of the number of zones observed on (a) corresponding scales and, (b) those sagittal otoliths prior to sectioning. Numbers in parentheses indicate the number of fish of different ages based on sectioned otoliths, while numbers above the closed circles indicate the percentage of over- or underestimates using whole otoliths.

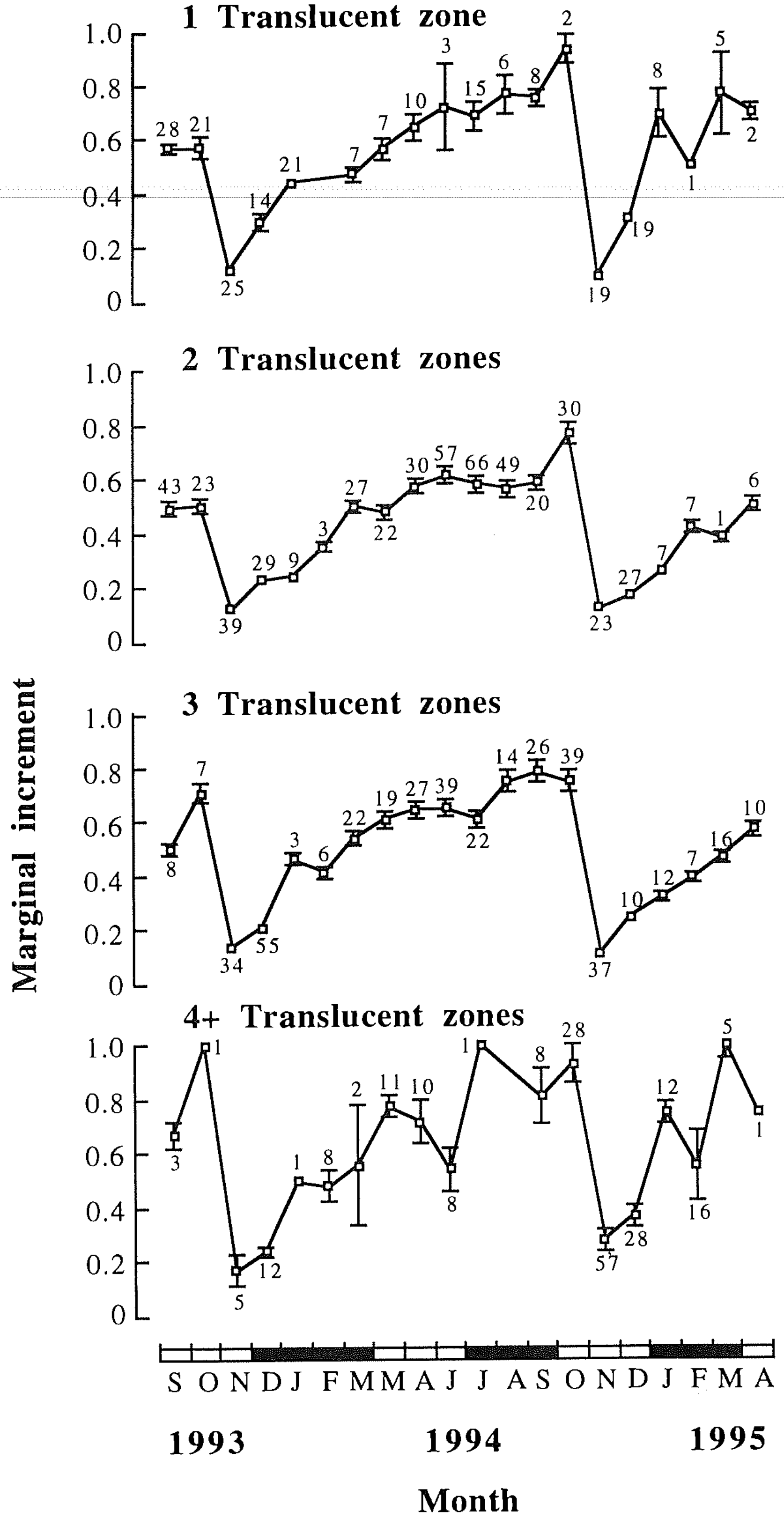


Figure 22 Mean monthly marginal increments ±1SE for sagittal otoliths of Black bream caught in the upper Swan Estuary. The mean marginal increment is expressed as a proportion of the distance between the focus and the outer translucent zone, when only one zone was present, and as a proportion of the distance between the outer edges of the two outermost translucent zones, when two or more such zones were present. Sample sizes are given for each month. x-axis as in Fig. 18.

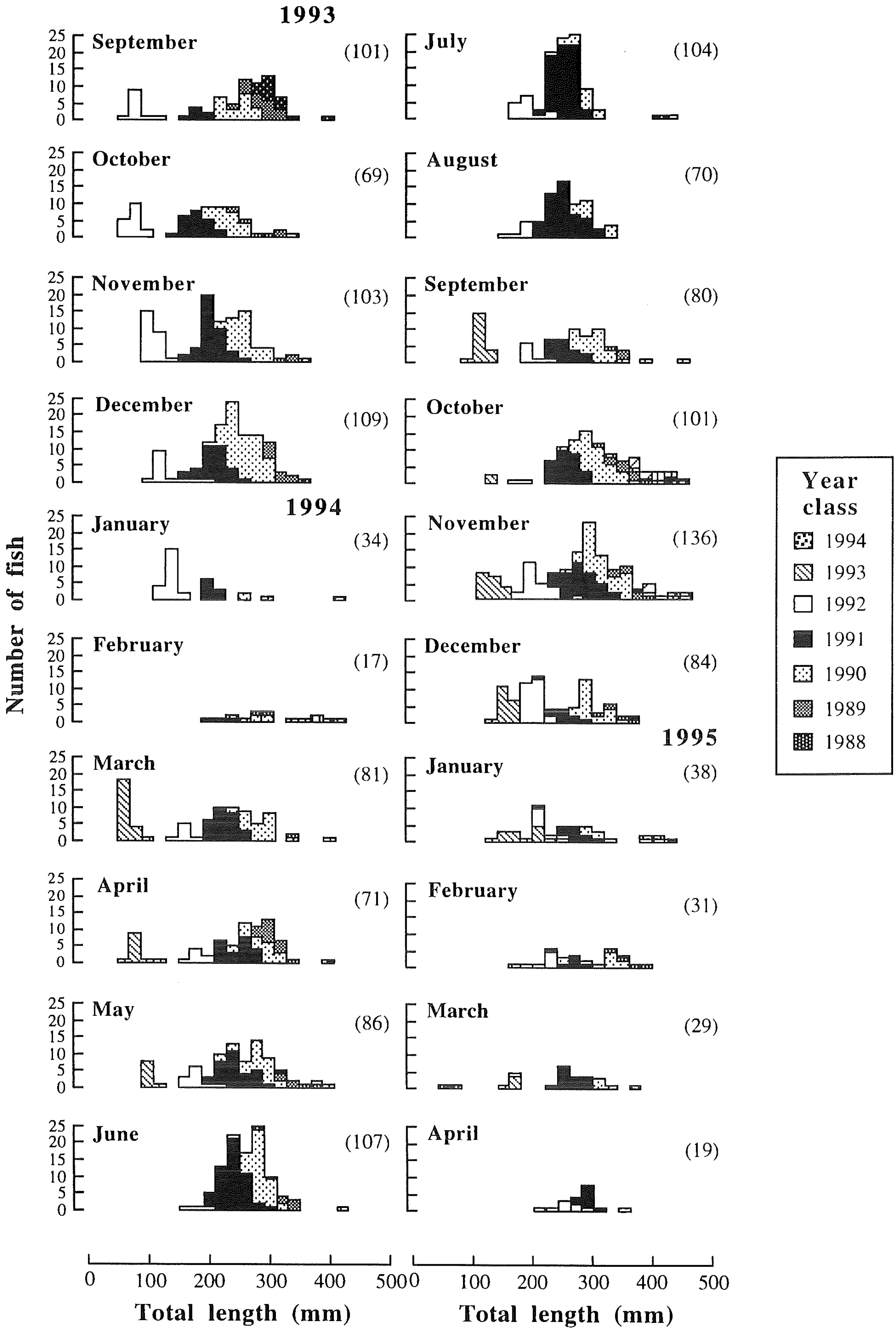


Figure 23 Length-frequency histograms for the different year classes of Black bream based on samples collected using seine and gill nets in the upper Swan Estuary. Sample sizes are given in parentheses.

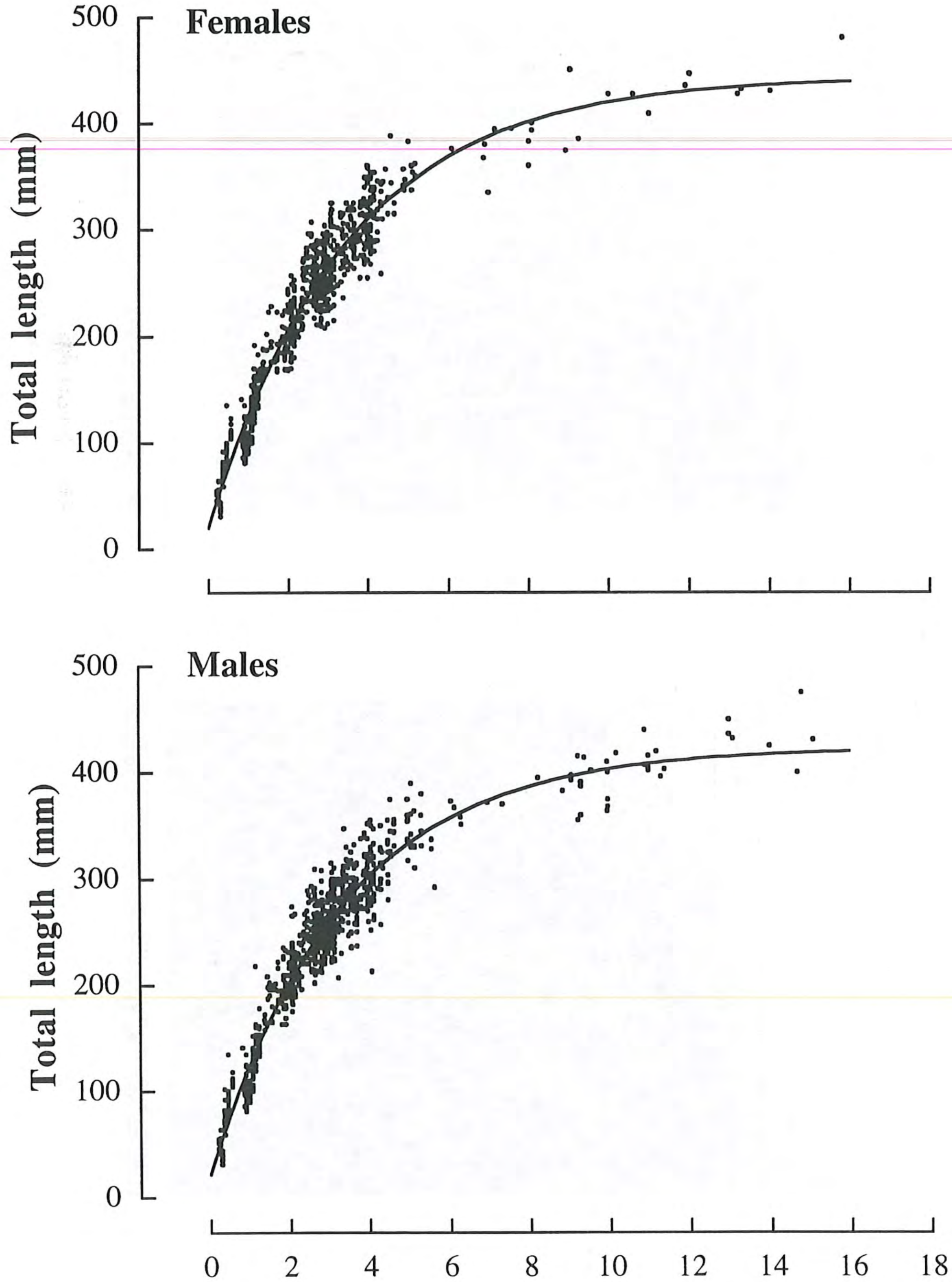


Figure 24 von Bertalanffy growth curves fitted to length at age data derived from sagittal otoliths of female and male Black bream caught in the upper Swan Estuary.

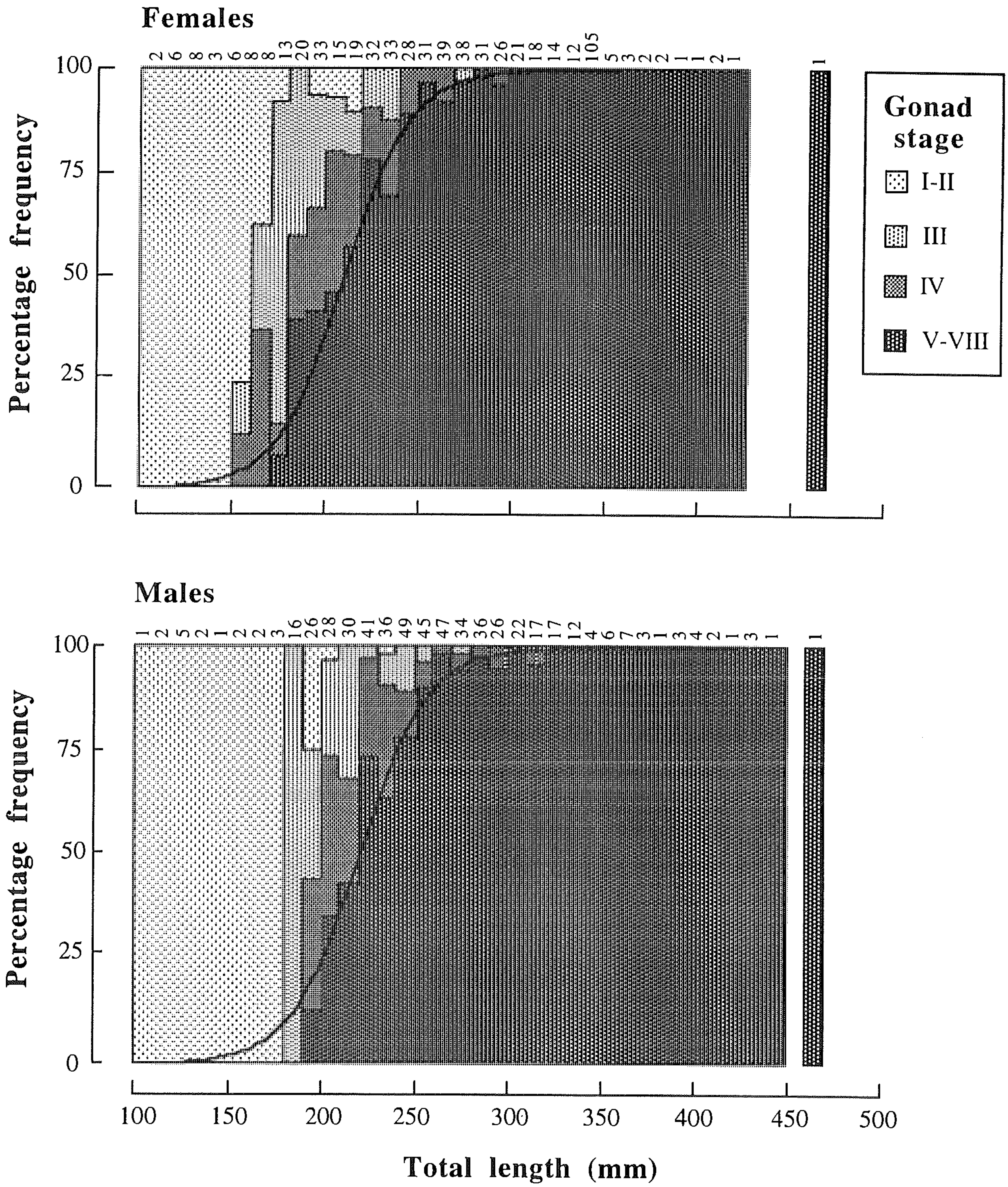


Figure 25 Percentage frequency of occurrence of sequential stages in gonadal development in each sequential 10 mm length category of female and male Black bream caught between September and December in the upper Swan Estuary. Sample sizes are given above each length category. The logistic curve derived from the percentage of mature gonads for each 10 mm length class is shown for each sex.

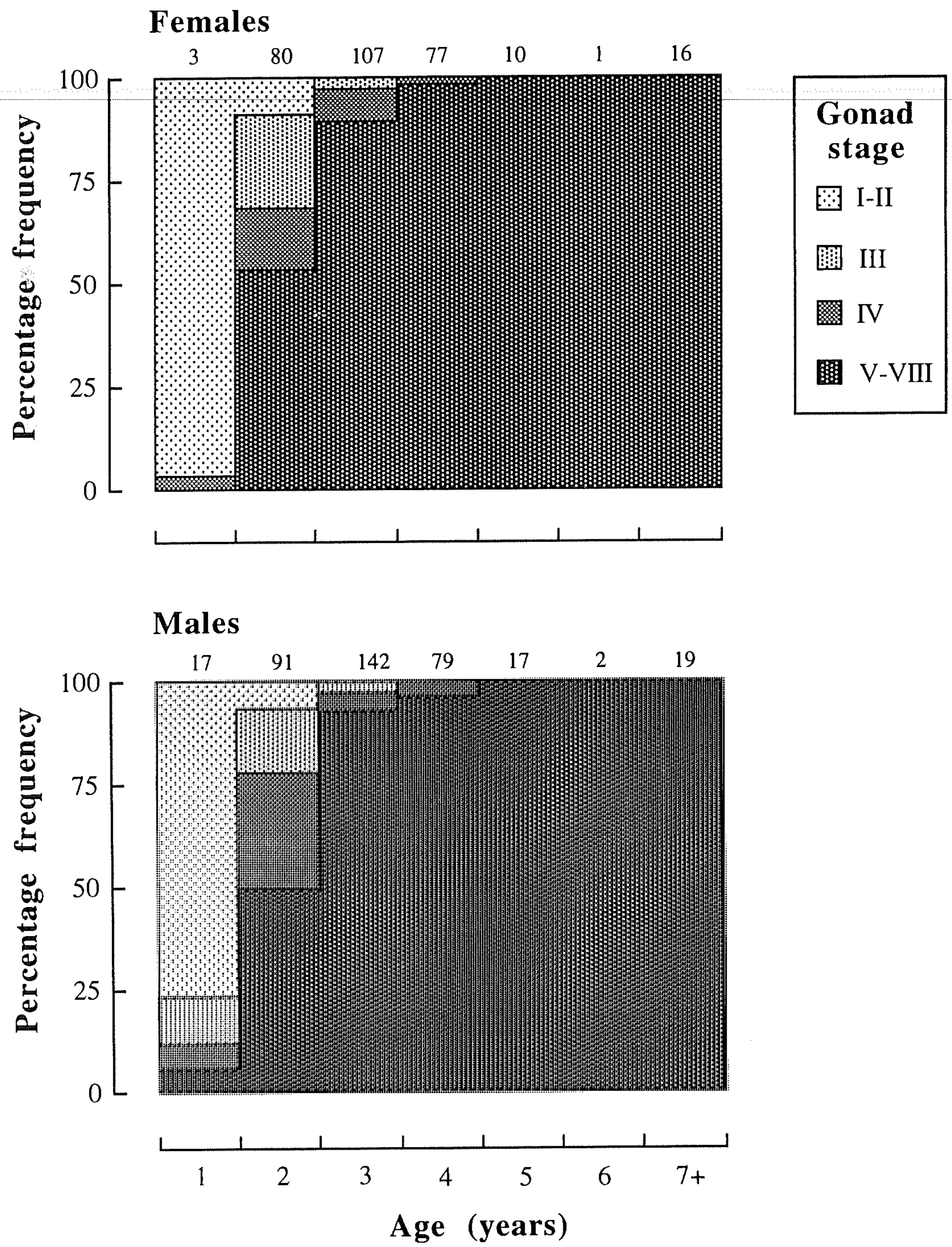


Figure 26 Percentage frequency of occurrence of sequential stages in gonadal development in each age class of female and male Black bream caught between September and December in the upper Swan Estuary. Sample sizes are given above each age class.

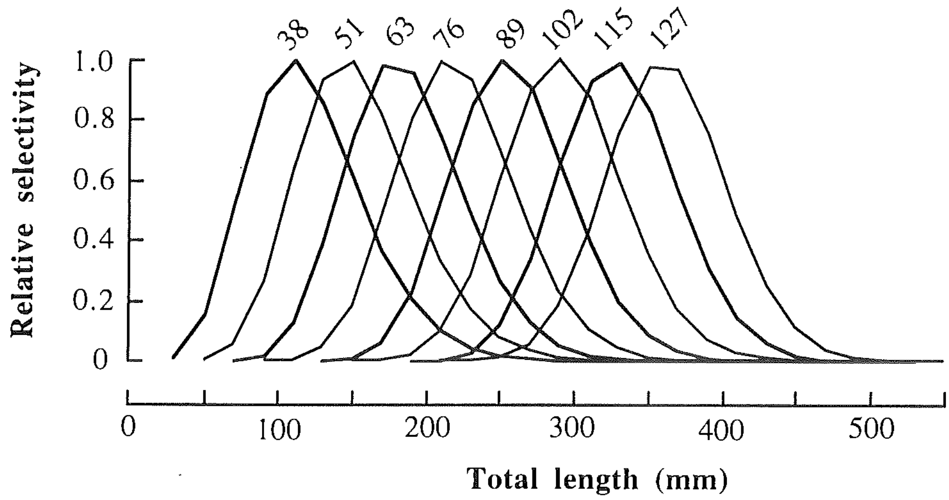


Figure 27 Mesh selectivity curves for different lengths of Black bream in eight mesh sizes in gill nets.

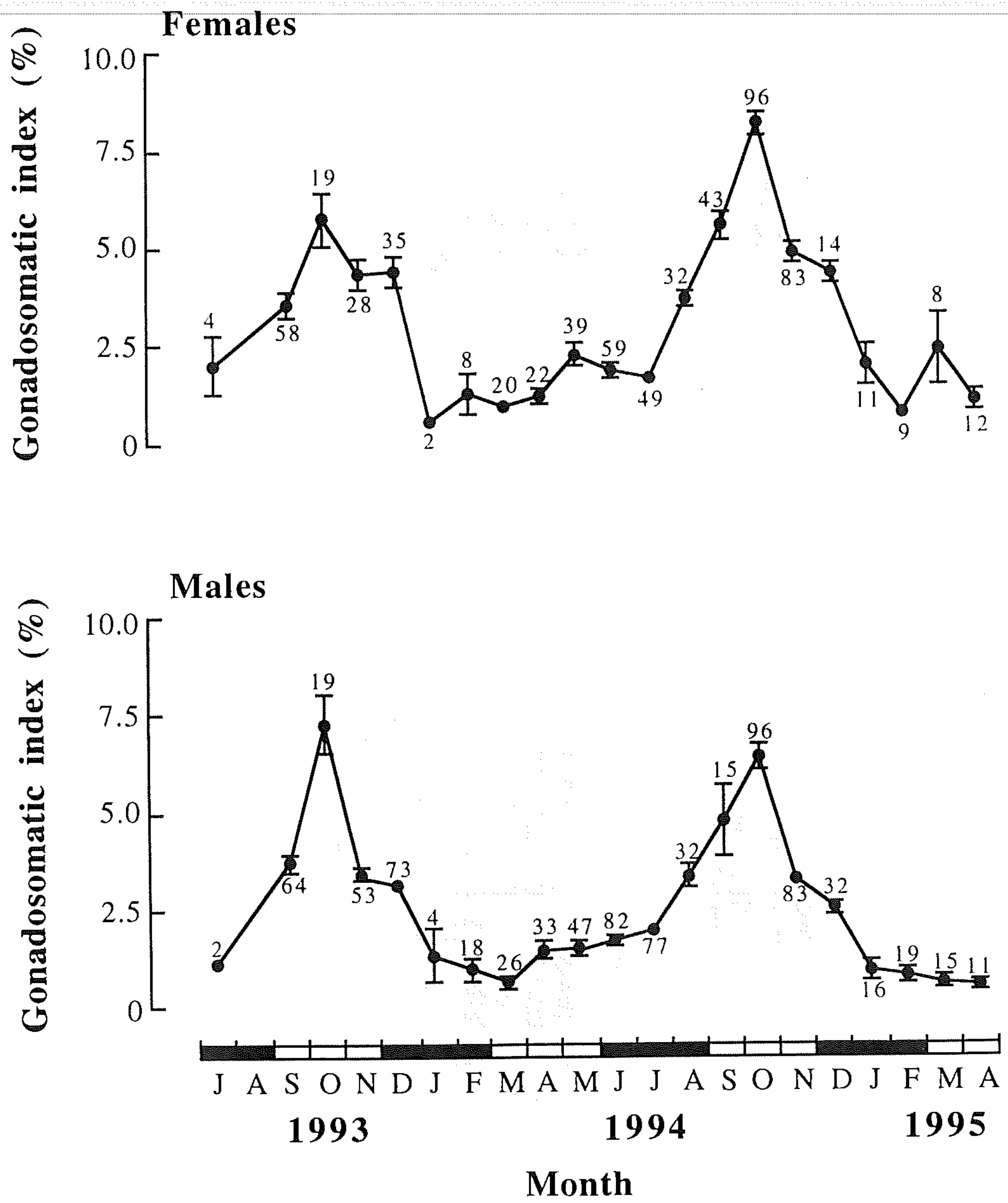


Figure 28 Mean monthly gonadosomatic indices ±1SE for mature female and male Black bream caught in the upper Swan Estuary. Sample sizes are given for each month. x-axis as in Fig. 18.

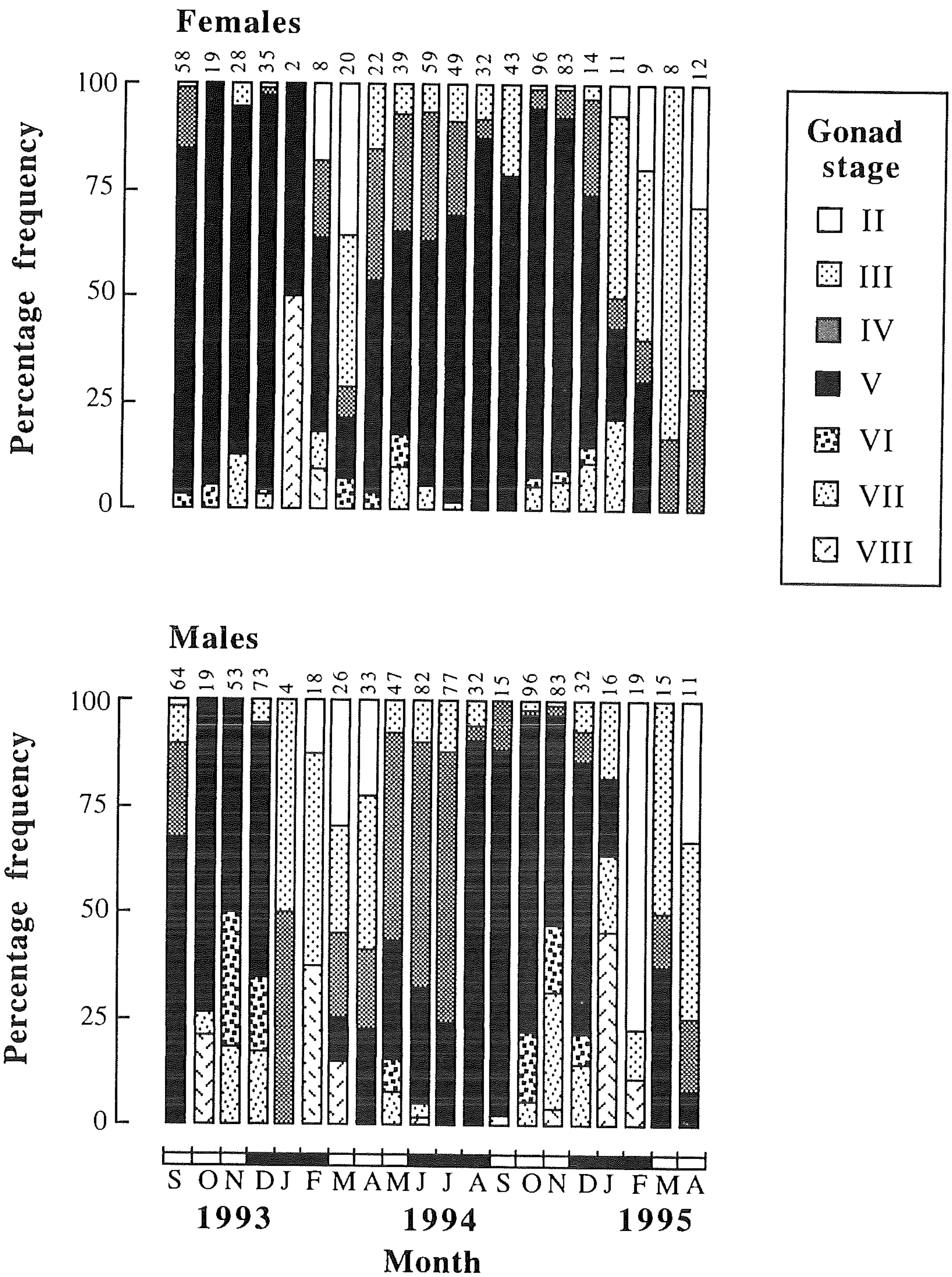


Figure 29 Monthly percentage frequencies of occurrence of sequential gonadal development stages in female and male Black bream caught in the upper Swan Estuary. Sample sizes are given above each month. x-axis as in Fig. 18.

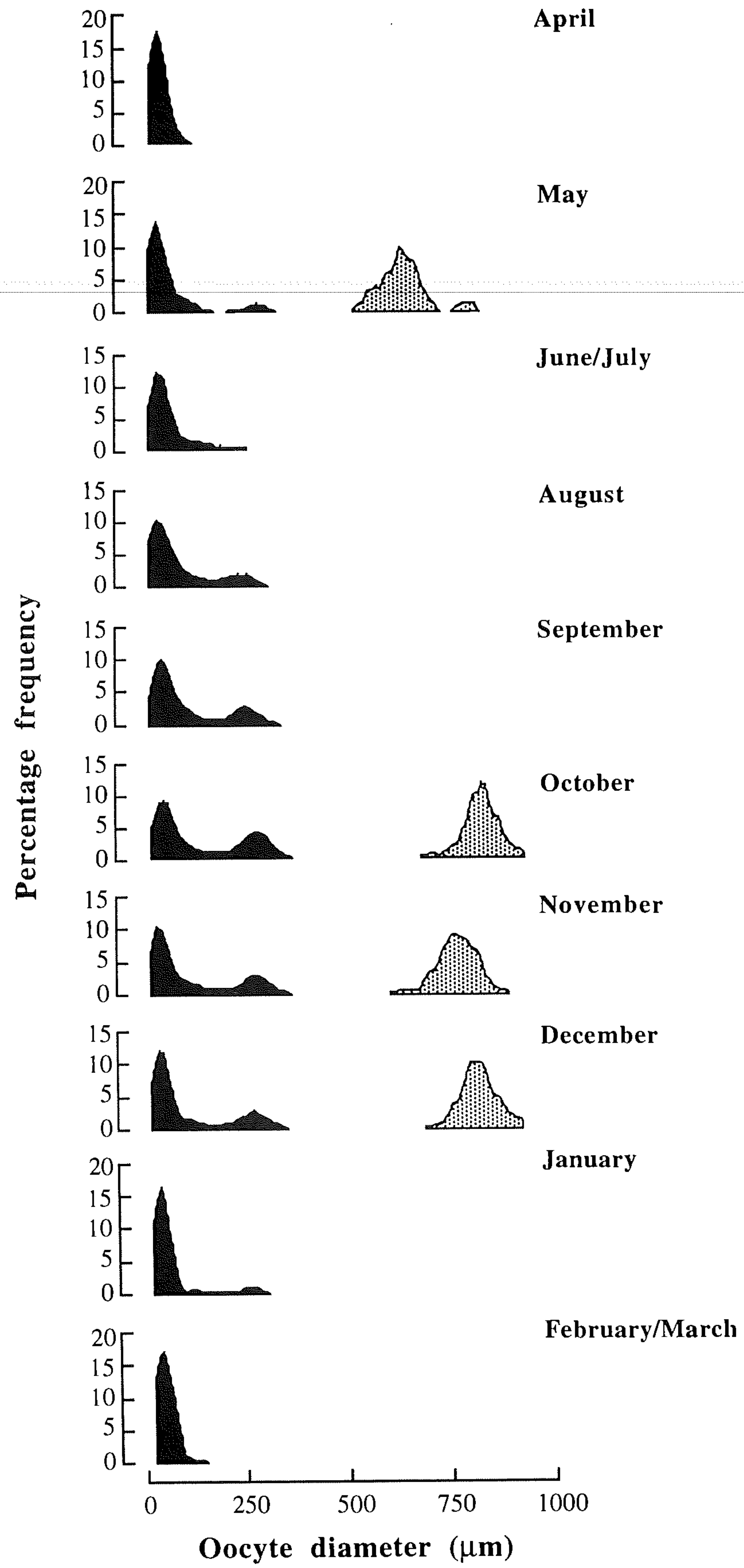


Figure 30 Monthly percentage frequencies for oocyte diameters in ovaries of Black bream caught in the upper Swan Estuary. Shaded areas represent hydrated oocytes.

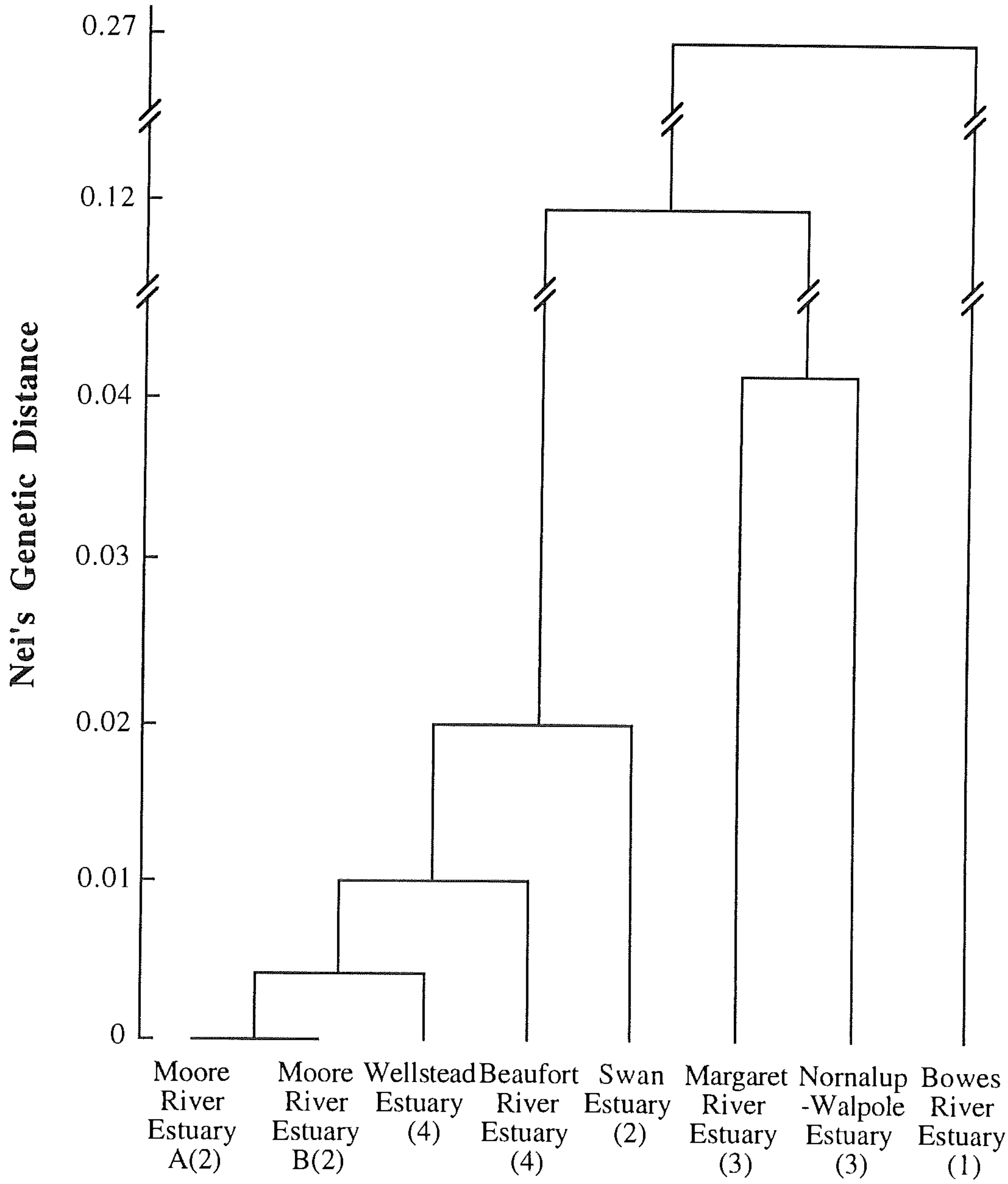


Figure 31 Dendogram summarising the genetic relatedness among samples from seven estuarine populations of Black bream. Populations are categorised according to whether they occur in the (1) northern, (2) central, (3) south-western or (4) southern part of the range of Black bream in Western Australia. Two samples from Moore River Estuary were analysed; one collected in 1994 (A), the other in 1996 (B).

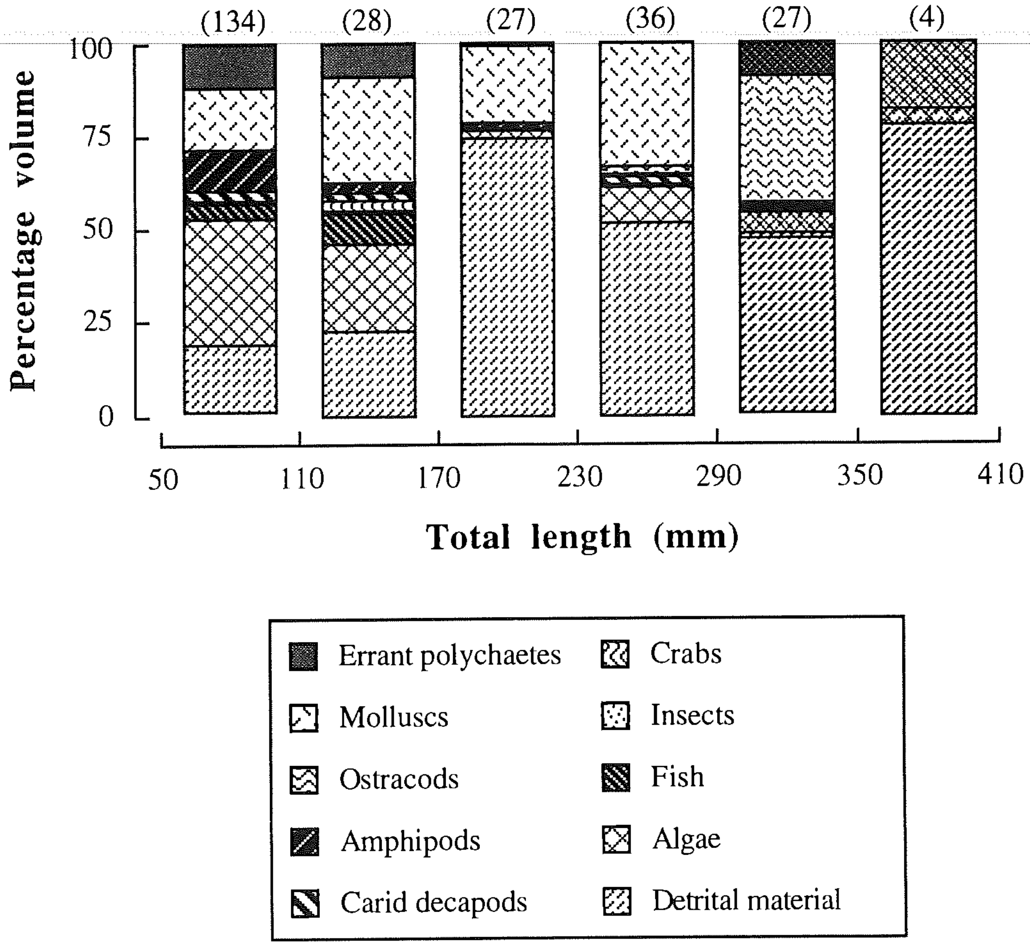


Figure 32 Percentage composition by volume of different dietary categories in sequential 60 mm length classes of Black bream caught in the upper Swan Estuary. Numbers in parentheses refer to the number of guts in that length class.

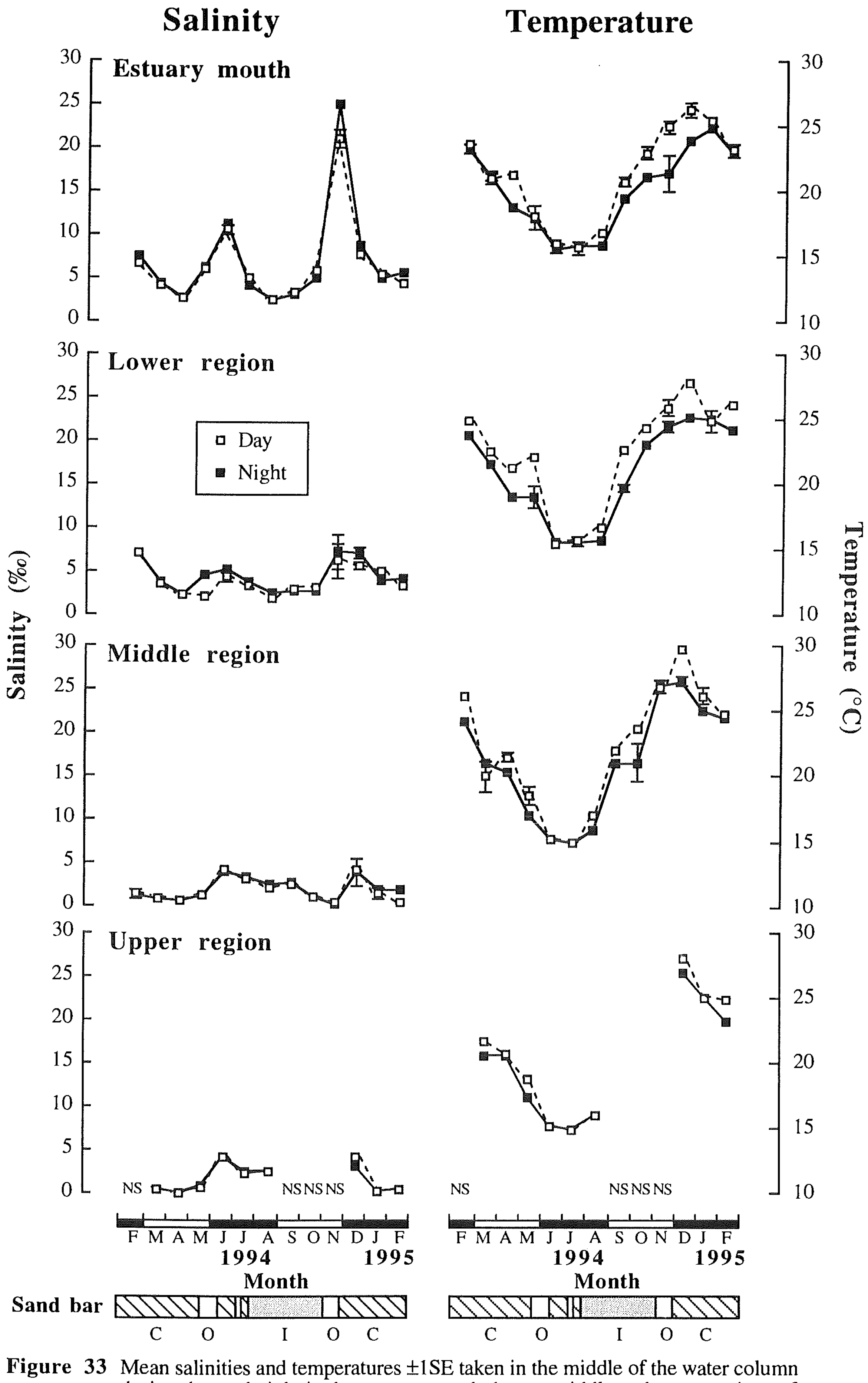


Figure 33 Mean salinities and temperatures ±1SE taken in the middle of the water column during day and night in the estuary mouth, lower, middle and upper regions of the Moore River Estuary between February 1994 and February 1995. The stage of closure of the estuary mouth is shown as either closed (C), open (O) or intermittently open (I). NS means not sampled. In this and Figs 34 and 35, black rectangles and open rectangles on the x-axis denote summer and winter months, and spring and autumn months, respectively.

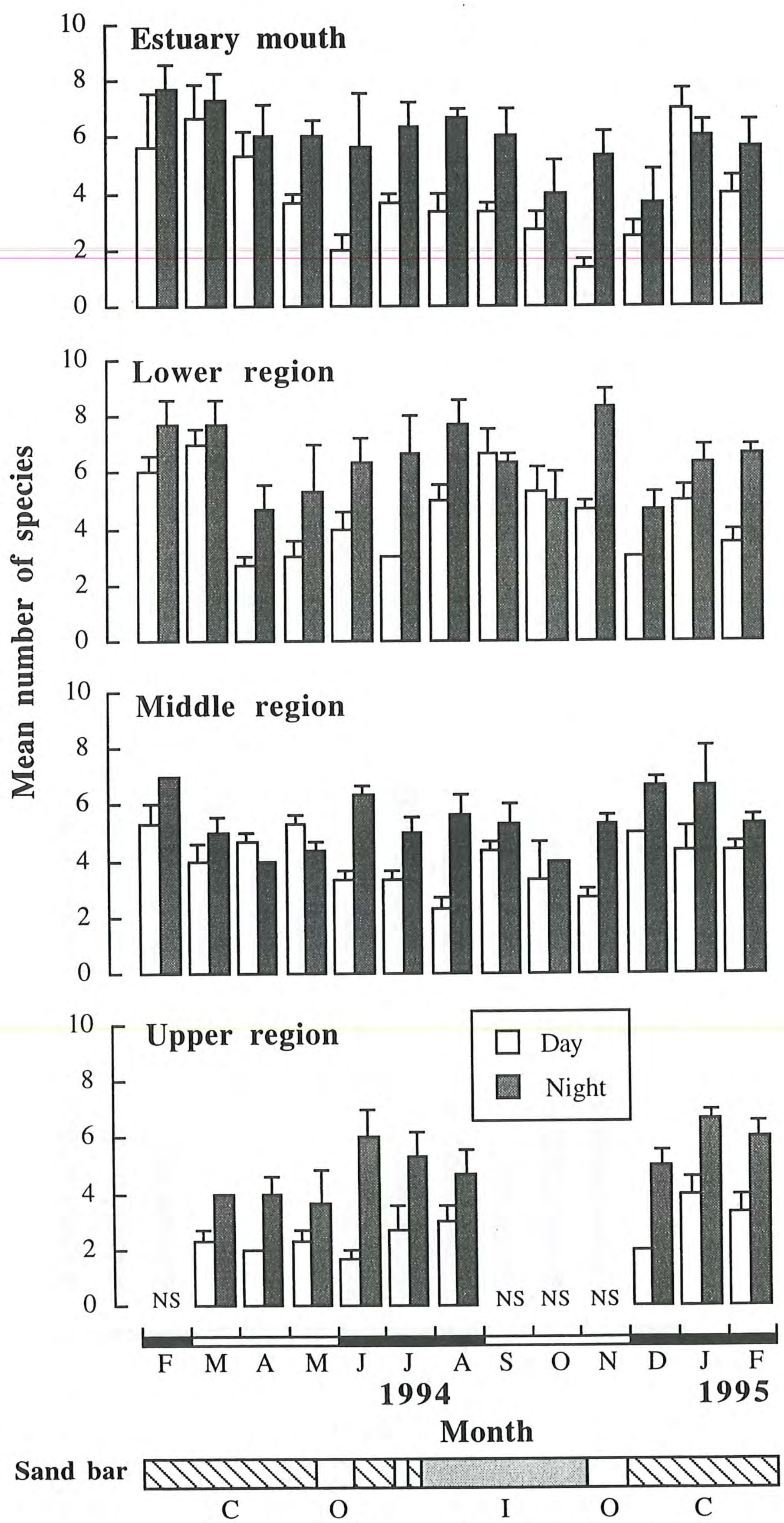


Figure 34 Mean number of fish species ±1SE during day and night in the estuary mouth, lower, middle and upper regions of the Moore River Estuary between February 1994 and February 1995. NS means no sample taken. x-axis as in Fig. 33.

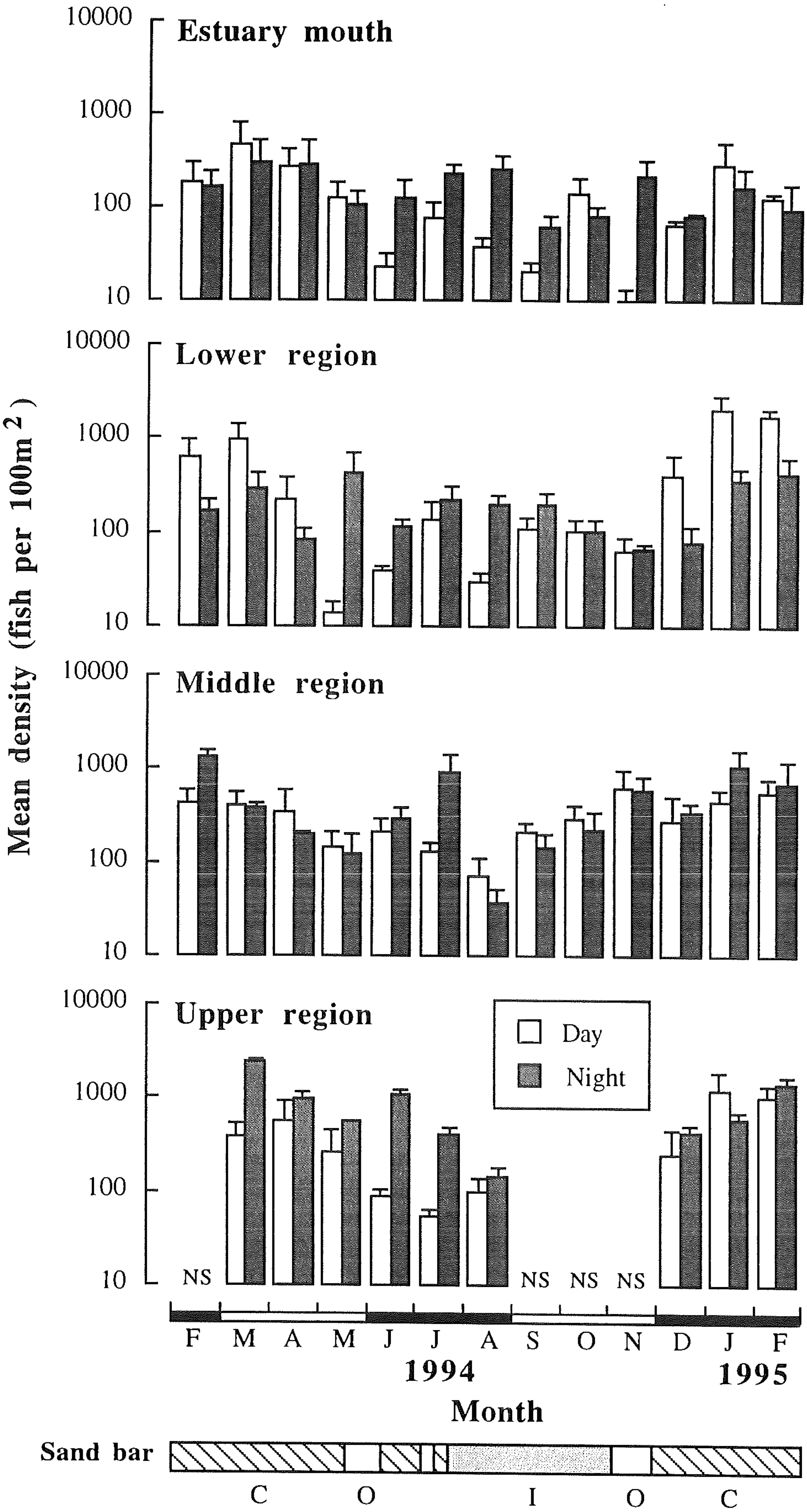


Figure 35 Mean density of fish ±1SE during day and night in the estuary mouth, lower, middle and upper regions of the Moore River Estuary between February 1994 and February 1995. NS means no sample taken. x-axis as in Fig. 33.

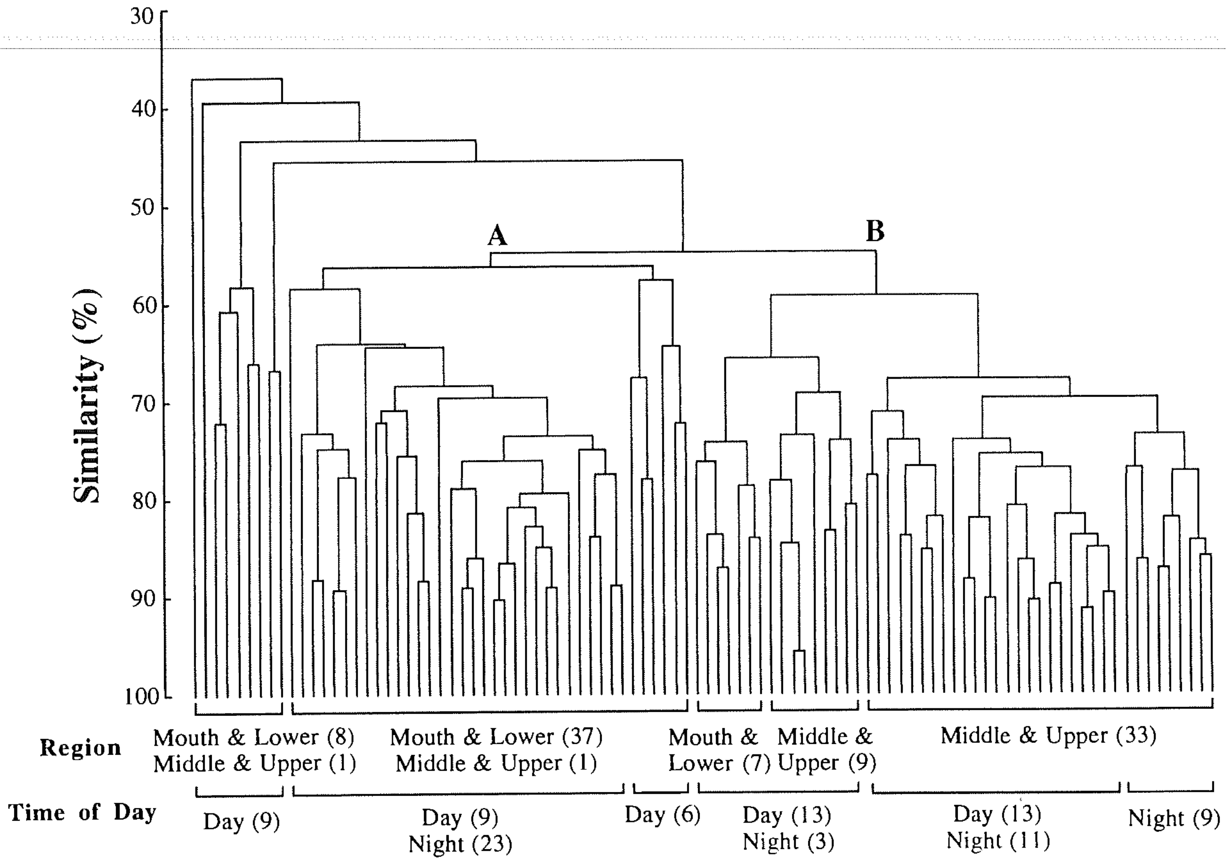


Figure 36 Classification of mean densities recorded for each species during the day and night in the estuary mouth, lower, middle and upper regions of the Moore River Estuary between February 1994 and February 1995.

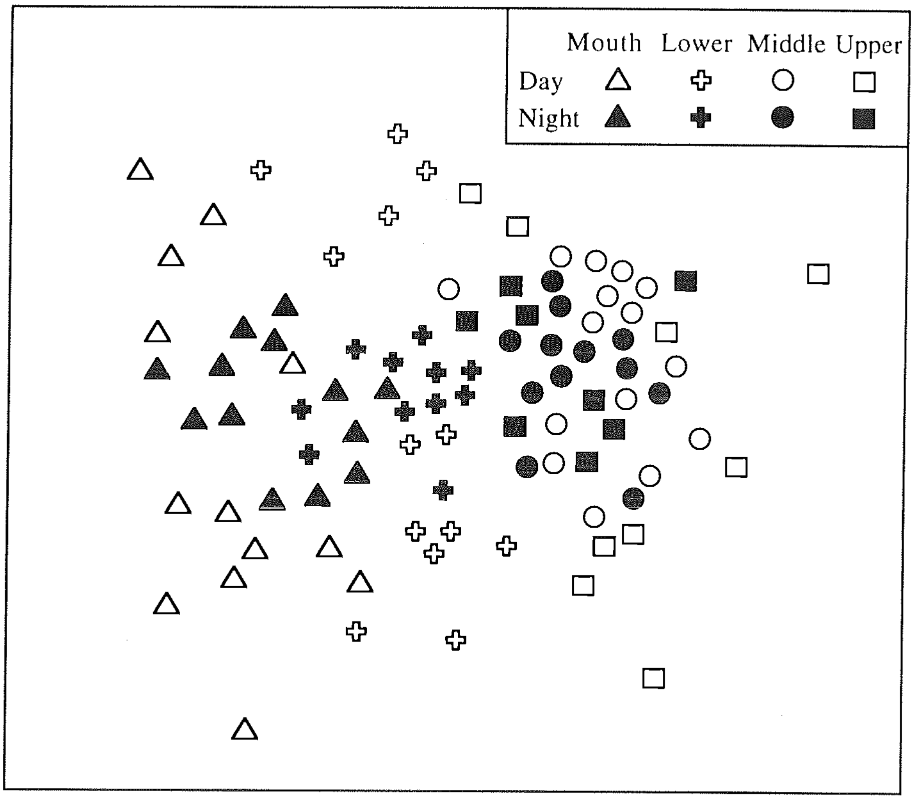


Figure 37 Ordination of mean densities recorded for each fish species during day and night in the estuary mouth, lower, middle and upper regions of the Moore River Estuary between February 1994 and February 1995.

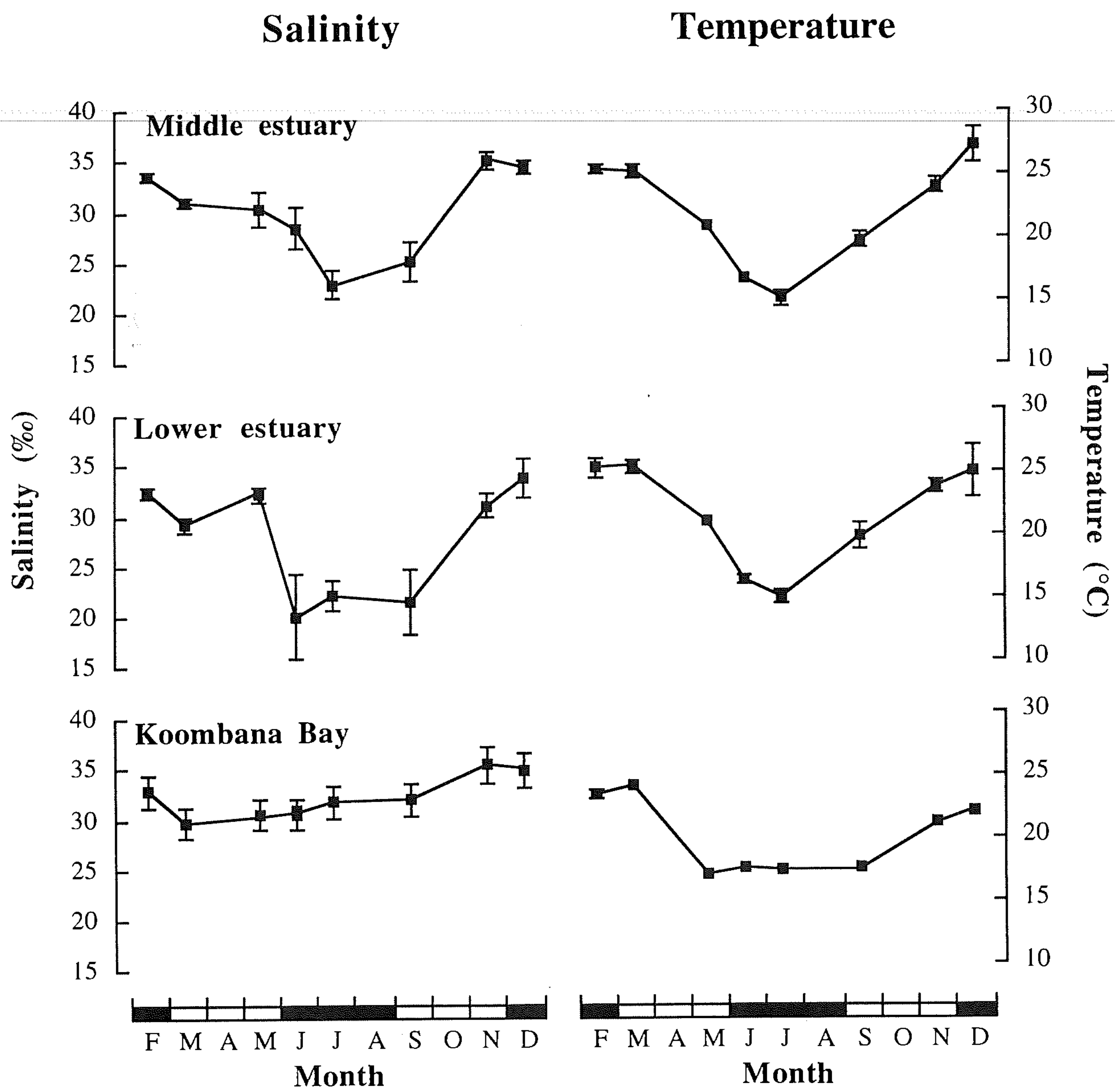


Figure 38 Mean salinities and temperatures ±1SE taken in the middle of the water column in the middle and lower regions of Leschenault Estuary and for the eastern and western regions of Koombana Bay combined between February and December 1994. In this and Fig. 39, black rectangles and open rectangles on the x-axis denote summer and winter months, and spring and autumn months, respectively.

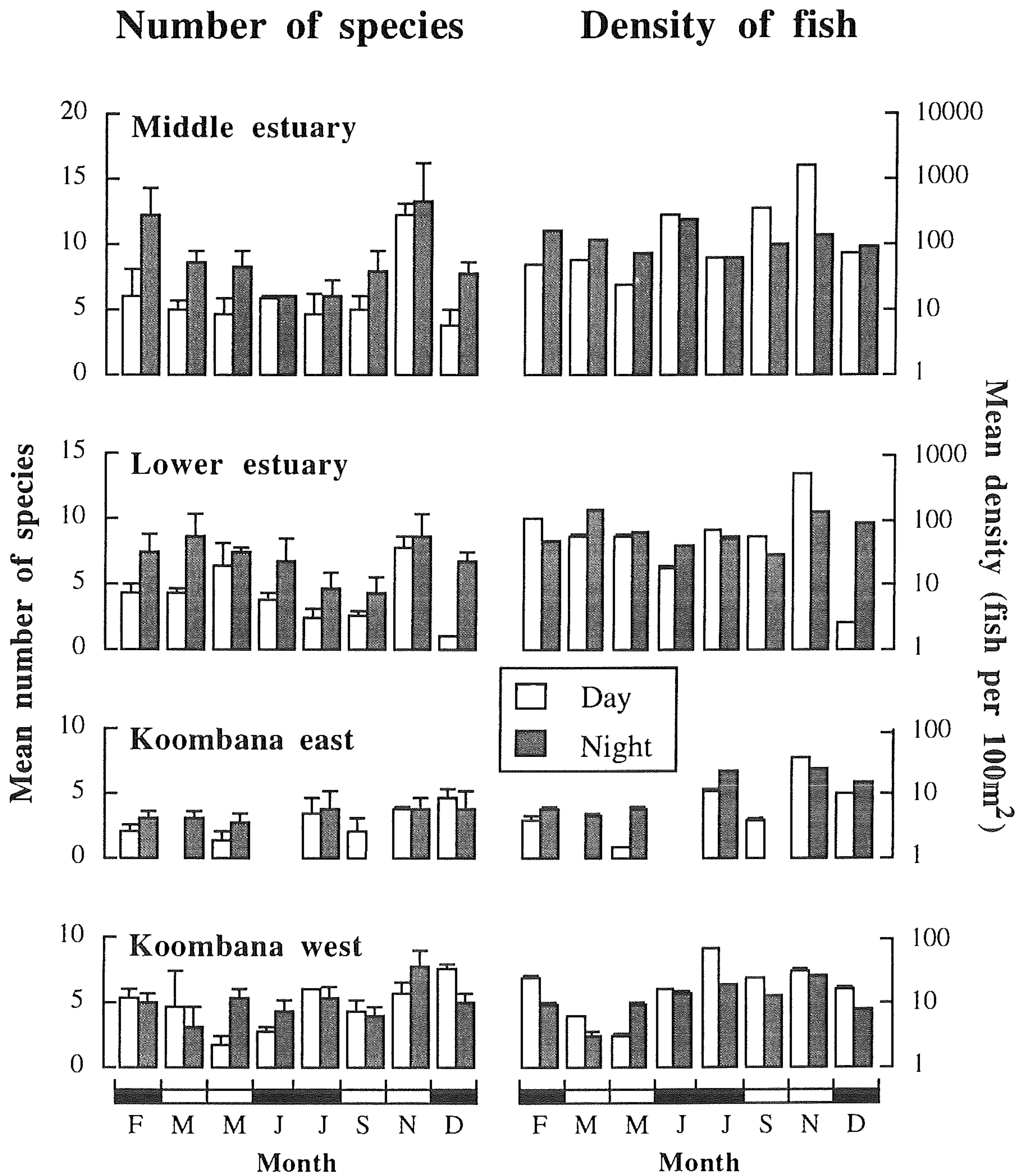


Figure 39 Mean number of species and mean density of fish ±1SE in the lower and middle regions of Leschenault Estuary and in the eastern and western regions of Koombana Bay during day and night between February and December 1994. x-axis as in Fig. 38.

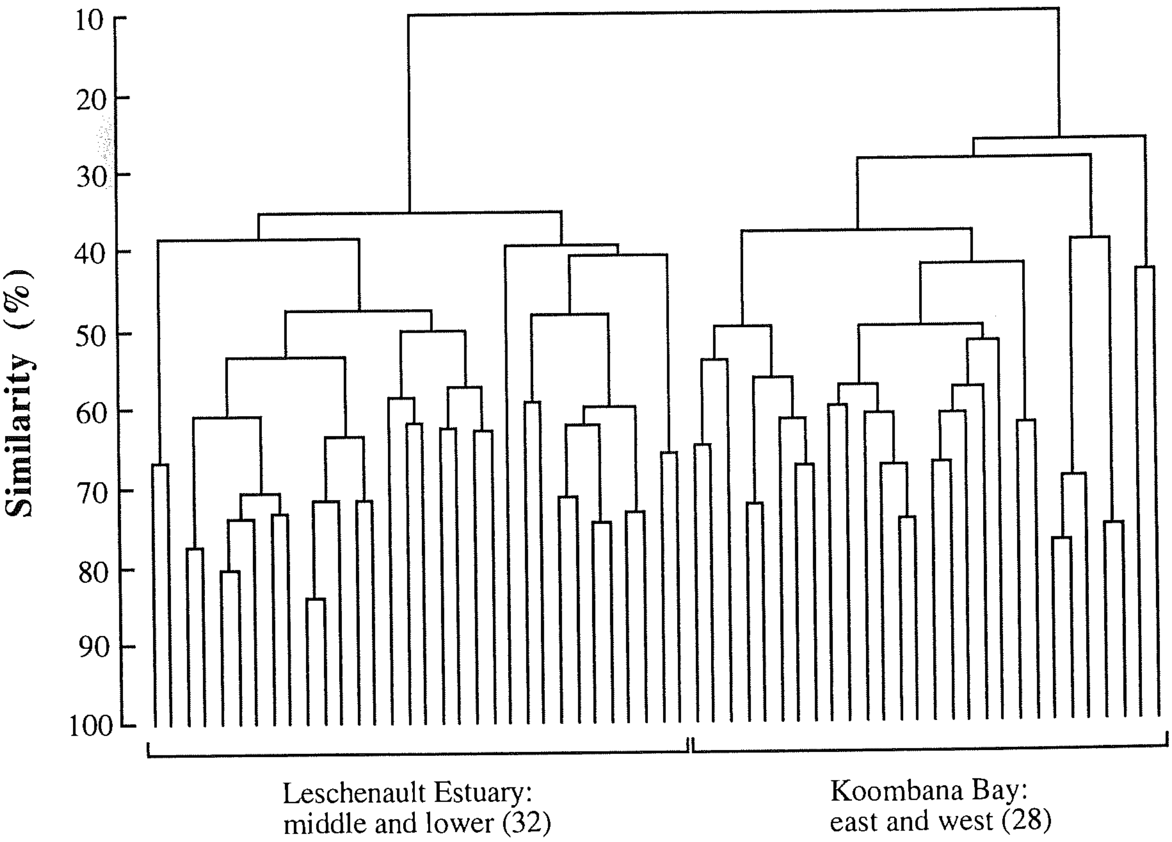


Figure 40 Classification of mean densities recorded for each fish species during the day and night in the lower and middle regions of Leschenault Estuary and the eastern and western regions of Koombana Bay between February and December 1994.

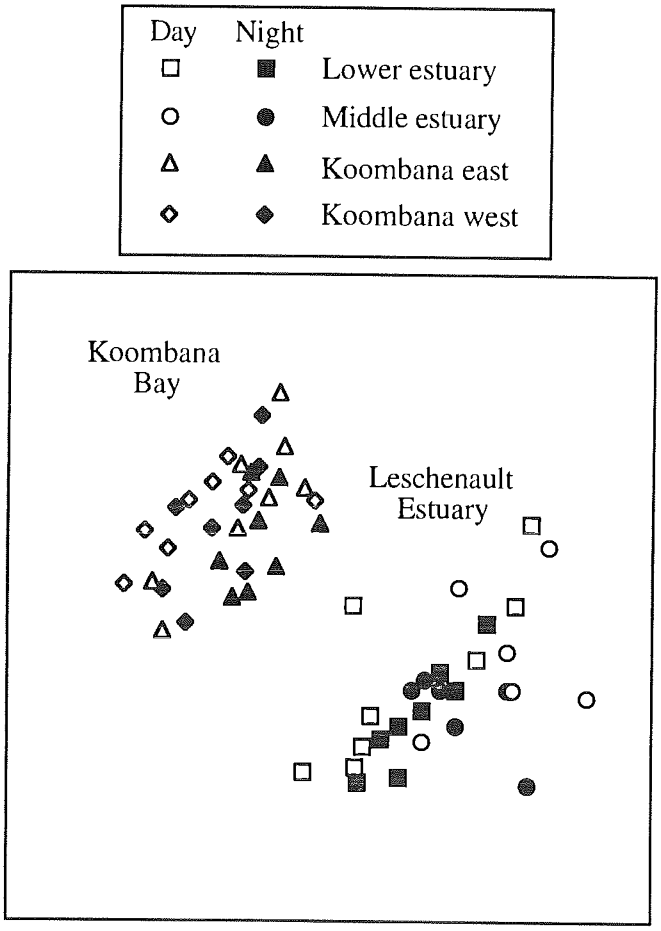


Figure 41 Ordination of mean densities recorded for each fish species during the day and night in the lower and middle regions of Leschenault Estuary and the eastern and western regions of Koombana Bay between February and December 1994.

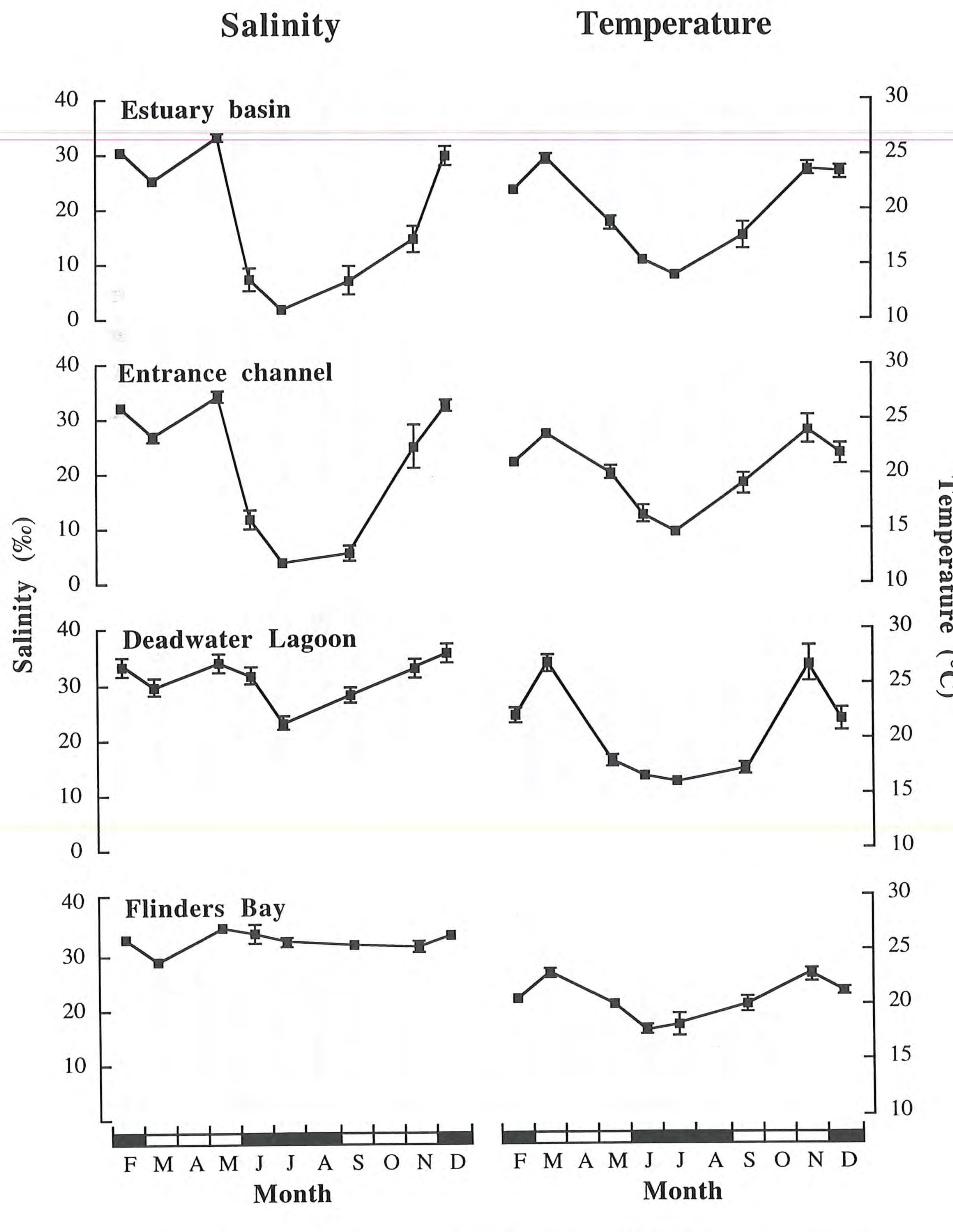


Figure 42 Mean salinities and temperatures ±1SE taken in the middle of the water column in the estuary basin, entrance channel and Deadwater Lagoon of Blackwood River Estuary and in Flinders Bay between February and December 1994. In this and Fig. 43, black rectangles and open rectangles on the x-axis denote summer and winter months, and spring and autumn months, respectively.

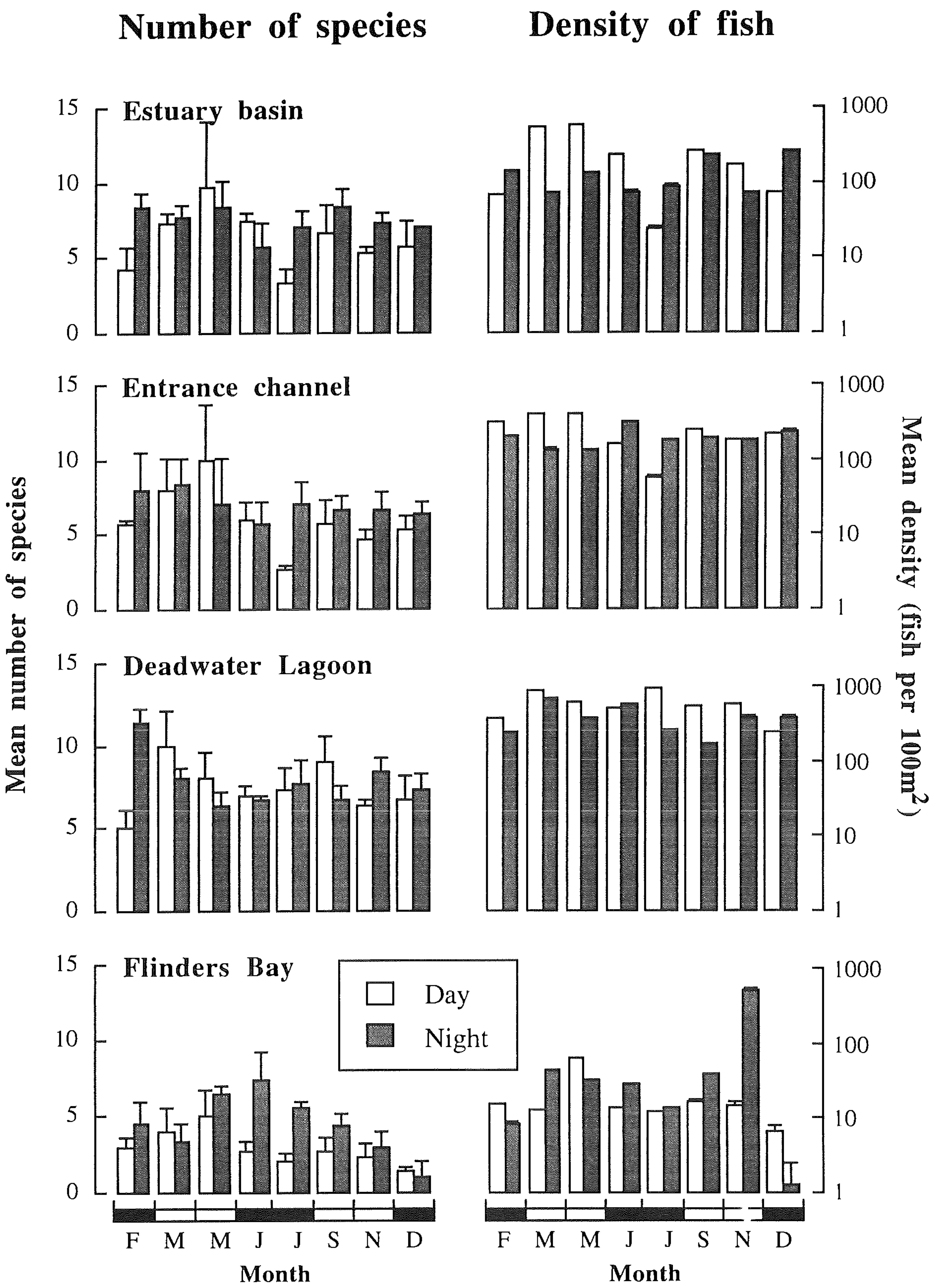


Figure 43 Mean number of species and mean density of fish ±1SE in the estuary basin, entrance channel and Deadwater Lagoon of Blackwood River Estuary and in Flinders Bay during day and night between February and December 1994. x-axis as in Fig. 42.

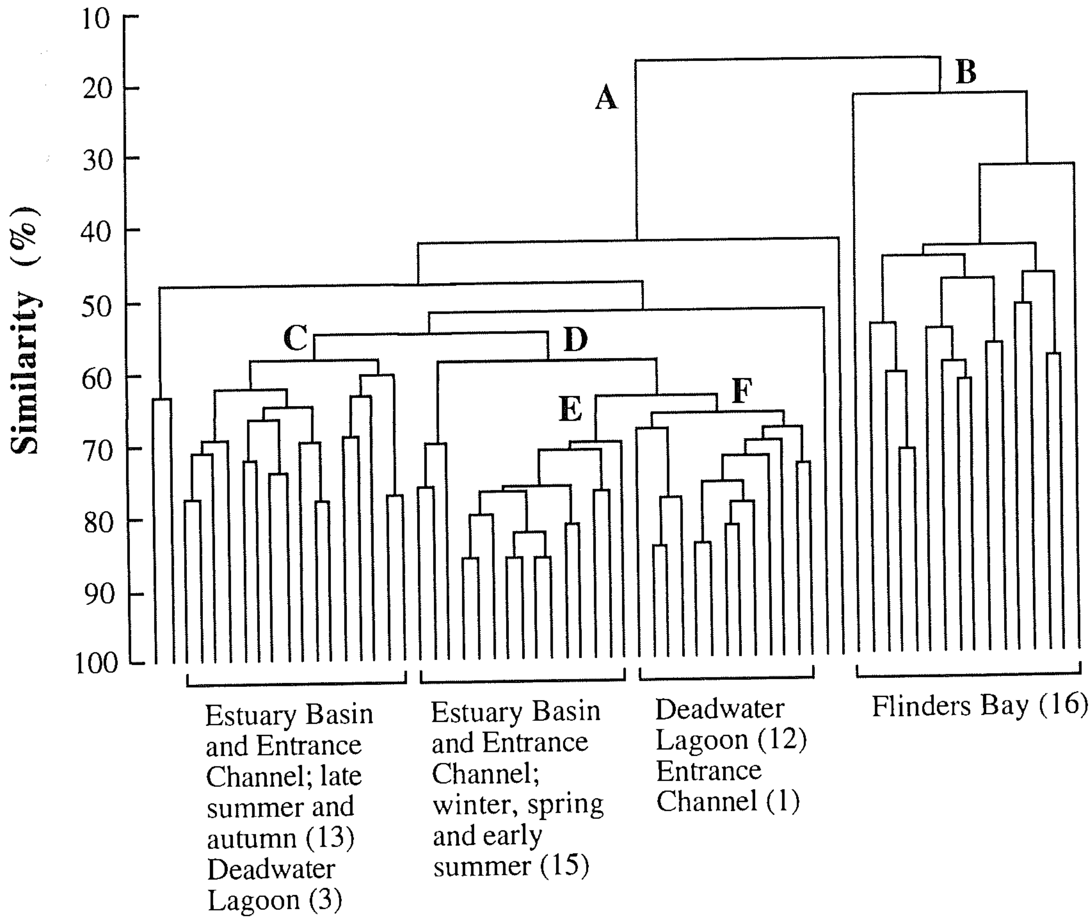


Figure 44 Classification of mean densities recorded for each fish species during the day and night in the estuary basin, entrance channel and Deadwater Lagoon of Blackwood River Estuary and in Flinders Bay between February and December 1994.

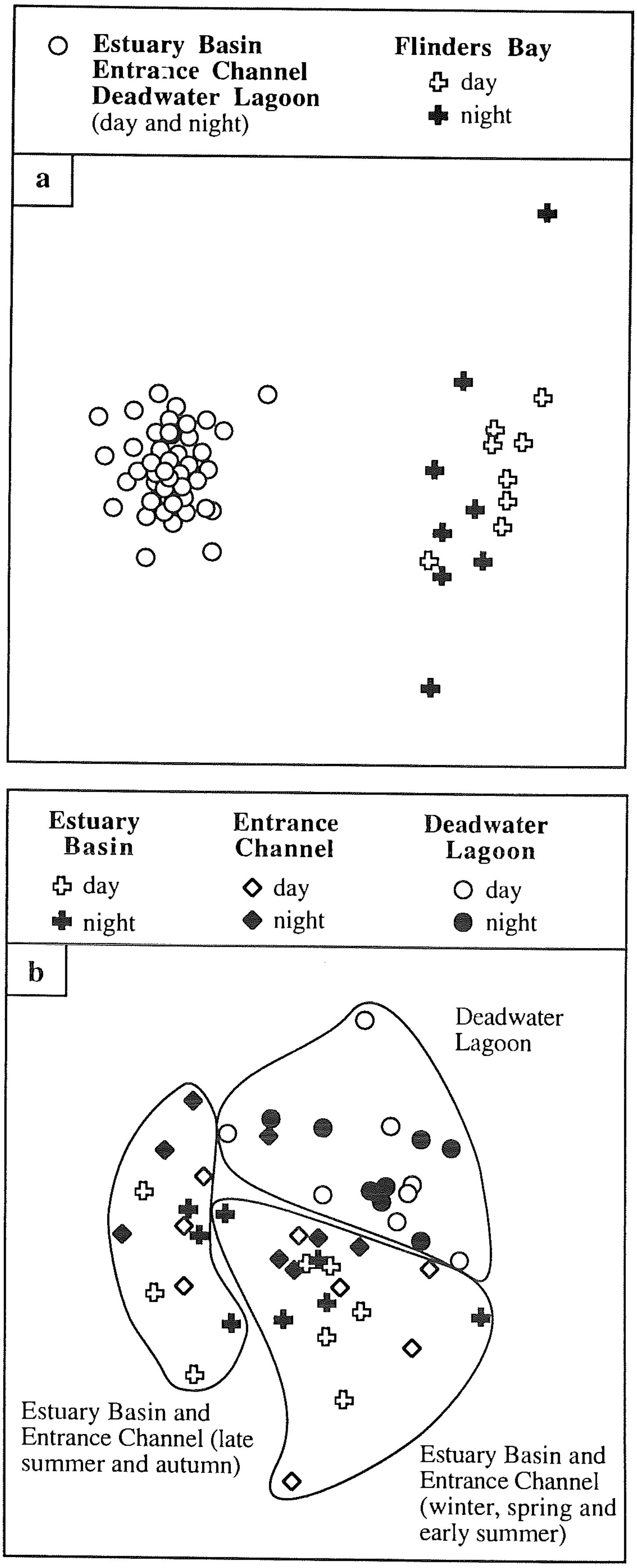


Figure 45 Ordination of mean densities recorded for each fish species in (**a**) Blackwood River Estuary during day and night and in Flinders Bay between Febrary and December 1994 and (**b**) in the estuary basin, entrance channel and Deadwater Lagoon regions of Blackwood River during day and night between February and December 1994.