Influence of the Dawesville Channel on the recruitment, distribution and emigration of crustaceans and fish in the Peel-Harvey Estuary

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FISHERIES
RESEARCH &
DEVELOPMENT
CORPORATION

Project No. 95/042

Fisheries Research and Development Corporation Report

FRDC Project 95/042

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December 1998

ISBN: 0-86905-658-1

The Dawesville Channel opening into the Harvey Estuary on the upper right. Peel Inlet is on the upper left.

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OBJECTIVES:

1. Determine the extent to which the construction of the Dawesville Channel has influenced the recruitment of the juveniles of blue swimmer crabs and western king prawns into the Harvey Estuary, and the size composition and/or growth rate of these crustaceans in the Peel-Harvey Estuary.
2. Determine the way in which greatly increased tidal action has changed the salinities of habitats within Peel Inlet and the Harvey Estuary and how this is now reflected in the composition of the crustacean and fish faunas of habitats within those regions.
3. Determine whether the Dawesville Channel now provides a major route for the emigration of western king prawns and, if so, whether any such migration is drawing on prawns that would previously have passed out through the original (Mandurah) entrance channel, within which the commercial fishery is based.

NON TECHNICAL SUMMARY:

The Peel-Harvey Estuary in south-western Australia covers an area of *ca* 136 km^2. The natural entrance channel at Mandurah is *ca* 5 km long and opens into the north-western corner of the circular Peel Inlet, which occupies an area of *ca* 75 km^2. The south-western corner of the Peel Inlet in turn opens into the elongate Harvey Estuary, which has an area of *ca* 56 km^2. The Serpentine and Murray rivers discharge into the north-eastern corner of Peel Inlet, while the Harvey River discharges into the southern end of the Harvey Estuary.

The discharge of nutrients into the Peel-Harvey Estuary from agricultural land and piggeries during the 1970s and 1980s resulted in the development of massive growths of macroalgae in Peel Inlet and prolific seasonal growths of the toxic blue-green algae *Nodularia spumigena* in the Harvey Estuary. In 1994, an artificial channel was opened between the northern end of the Harvey Estuary and the ocean at Dawesville in order to increase the amount of water exchanged between the estuary and the ocean, and thereby facilitate the flushing of nutrients out to sea, and to raise salinities in the Harvey Estuary to levels that would restrict the germination and growth of blue-green algae.

The aim of this study on the Peel-Harvey Estuary was to determine the influence of the Dawesville Channel on such features as the migratory patterns, abundances, size compositions and distributions of blue swimmer crabs and western king prawns, the species composition of the fish fauna, and the abundances, distributions and commercial catch of the main commercially-fished species. Relevant biological data were thus collected for crustaceans and fish in the Peel-Harvey Estuary between March 1995 and July 1998, *i.e.* post-Dawesville Channel, and compared with data collected for the same sampling sites in periods between July 1979 and April 1988, *i.e.* pre-Dawesville Channel.

Our results demonstrate that the blue swimmer crab and western king prawn are now present in far greater numbers and for far longer periods in the Harvey Estuary than

was the case prior to the construction of the Dawesville Channel. This can be attributed to the following. (i) Since there is now a direct connection between the sea and the Harvey Estuary, juvenile blue swimmer crabs and western king prawns have a far shorter distance to travel from the ocean into the Harvey Estuary and therefore enter this part of the Peel-Harvey system earlier. (ii) The far greater tidal water flow now entering the Harvey Estuary provides a far more effective means for transporting fauna into this part of the system. (iii) Salinities in the Harvey Estuary remain higher for longer periods and thereby provide an environment conducive to the retention of blue swimmer crabs and western king prawns for a more protracted period. The influence of increased tidal movement throughout the Peel-Harvey Estuary also accounts for the following. (i) Small juvenile blue swimmer crabs are now recruited from the ocean into the Peel-Harvey Estuary over a far longer period. (ii) Once female crabs become ovigerous, they now emigrate from the estuary earlier. (iii) Prawns often now emigrate from the estuary at a smaller size. Furthermore, the growth of crabs has become more rapid since the opening of the Dawesville Channel, and this has resulted in an earlier attainment of sexual maturity.

Prior to the construction of the Dawesville Channel, the compositions of the fish faunas in the different basin regions of the Peel-Harvey Estuary differed from each other and did not change markedly throughout the year. However, since the opening of the Dawesville Channel, the compositions of the fauna in the different basin regions have become far more similar and undergo pronounced seasonal cyclical changes. The cyclicity is presumably related to the increased strength of environmental cues that is provided by the marked exchange of water that now occurs between the ocean and the Peel-Harvey Estuary during each tidal cycle. The number and the overall abundance of fish species in the Harvey Estuary, and particularly in its southern region, are now greater than prior to the opening of the Dawesville Channel, presumably reflecting the absence of toxic blue-green algal blooms, the maintenance of higher salinities for longer periods and an increased recruitment of marine species as a result of tidal water flow through the Dawesville Channel. Yet, there is evidence that the levels of recruitment of the juveniles of each of the main commercial fish species (*Mugil cephalus, Aldrichetta forsteri, Cnidoglanis macrocephalus, Sillaginodes punctata* and *Sillago schomburgkii*) into the Peel-Harvey Estuary as a whole is now less than prior to the construction of the Dawesville Channel. Such a decline may be attributable to the reduction in the amount of both food and levels of protection from predation that would have occurred as a result of the marked reduction in the volume of marcoalgae in this estuary since the construction of the Dawesville Channel.

The commercial catch of the blue swimmer crab within the Peel-Harvey Estuary has increased since the construction of the channel, partly as a result of greater densities of these crabs within this system. In contrast, although the abundance of western king prawns in the Peel-Harvey Estuary has also risen since the opening of the Dawesville Channel, the commercial catch of this species has declined markedly. This reflects the fact that many prawns, which would previously have emigrated out through the Mandurah Entrance Channel, now move out through the Dawesville Channel, in which the flow is too strong and the water too deep for commercial fishers to use their beam-tide trawls efficiently. A recent pronounced change in the demand for fin fish, such as sea and yellow eye mullet, and the effects of heavy fishing pressure on cobbler, means that the downward trends in the catches of these species must be treated with caution. The increased catches of King George and yellow fin whiting are at least partly related to fishers targeting these species to a far greater extent since western king prawns have become less accessible to capture (see above).

Background

Estuaries provide very important nursery habitats for many marine species of crustaceans and fish (*e.g.* Blaber & Blaber, 1980; Potter *et al.,* 1983a; Claridge *et al.,* 1986). Many of these species are of commercial and/or recreational importance and some of these are also fished within estuaries (Cronin & Mansueti, 1971; McHugh, 1976; Pollard, 1976; Lenanton & Potter, 1987; Loneragan *et al.*, 1987a).

In Western Australian estuaries, a number of species are commercially and recreationally important, such as the blue swimmer crab, western king prawn, sea mullet, yellow eye mullet, King George whiting and yellow fin whiting, which are all marine species, and the cobbler and southern school prawn, which complete their life cycles in estuaries. Furthermore, some of these species are exposed to heavy commercial exploitation. Indeed, the collective total value of the commercial fishery in the Peel-Harvey Estuary, 55 km to the south of Perth, and Comet Bay into which this estuary discharges, is conservatively worth $2.5 m, with the western king prawn alone contributing $1.4 m (CAES, Fisheries Western Australia). This makes the fishery in the Peel-Harvey Estuary one of the three most valuable estuarine fisheries in Australia. Creel census' also demonstrate that Western Australian estuaries are very important recreational fishing waters for crabs, prawns and fish. Indeed, 75% of the 65,000 recreational fishers that target blue swimmer crabs operate in the Peel-Harvey, Swan and Leschenault estuaries and the vast majority of fishers that target western king prawns and southern school prawns are found within these estuaries.

The commercial and recreational crustacean and fish species in the estuaries of temperate Western Australia are currently being subjected to two main influences, namely heavy fishing pressure and the effects of eutrophication. For example, there is evidence that the abundance of the commercially important cobbler in certain estuaries has suffered from overfishing and that the stock of this species in another estuary is being conserved by the presence of closed fishing waters (Laurenson *et al.,* 1993). Current work also indicates that, in another system, the numbers of black bream have declined dramatically through overfishing (*c.f.* Lenanton, 1977; Valesini *et al.*, 1997).

The extreme eutrophication found in some Western Australian estuaries is manifested by the presence of massive growths of certain macrophytes and also, in one case, the proliferation of blue-green algal blooms at certain times of the year. Catch data provide strong evidence that massive growths of macroalgae in the Peel-Harvey Estuary in the 1970s and 1980s were accompanied by an increase in the abundance of fish (Lenanton *et al.*, 1984; Steckis *et al.*, 1995). However, blue-green algal blooms in this estuary led both to the movement of the more mobile fish out of affected areas and occasionally to the death of some individuals of the more benthic and less mobile species of crustaceans and fish (Potter *et al.,* 1983b; Steckis *et al.,* 1995). Furthermore, the coating of the substrate by the macroalgal species *Cladophora montageana* in the Peel-Harvey Estuary during the 1970s led to a collapse of the fishery for western king prawns in those years (Potter *et al.,* 1991).

Eutrophication in the Peel-Harvey Estuary has been so extreme that both its impact and the attempts to ameliorate those effects have attracted world wide attention. In an attempt to alleviate this problem, the Western Australian government invested $53 million in constructing the Dawesville Channel between the sea and the northern end of the Harvey Estuary, in order to flush out to sea the nutrients that were present in the Peel-Harvey Estuary. It was also envisaged that the increases in salinity, that would result from an increased intrusion of sea water into this part of the system, would restrict the growth of blue-green algae, which bloom in late spring and early summer, when salinities are considerably below full-strength sea water (Hodgkin & Hamilton, 1993; McComb & Lukatelich, 1985).

While a number of studies, carried out in the late 1970s and early 1980s, have examined the way in which crustaceans and fish utilise the Peel-Harvey Estuary (Potter *et al.,* 1983a, b, c, 1991; Loneragan *et al.,* 1987b), there have been no studies on the way in which the Dawesville Channel is now influencing the crustacean and fish fauna. Work on the blue swimmer crab and western king prawn showed that the distributions of these species within the Peel-Harvey Estuary are related both to the distance from estuary mouth and the salinity (Potter *et al.,* 1983c, 1991). We thus hypothesise, as the construction of the Dawesville Channel would greatly reduce the distance of the Harvey Estuary from the sea and increased the salinity in that part of the estuary, it would lead to a greatly enhanced recruitment of crabs and prawns into the Harvey Estuary. The same hypothesis also pertains to the marine species of fish, especially those with a preference for high salinities.

Need

Since the opening of the Dawesville Channel, freshwater discharge flows out from the Serpentine and Murray rivers and along the southern shore of the Peel Inlet and out through the newly-constructed channel (T. Rose, Water and Rivers Commission, pers. comm.). The Dawesville Channel is thus having an effect on water movements in Peel Inlet, as well as the Harvey Estuary. This is particularly relevant to the commercial fishery for the western king prawn as this fishery is dependent on beam tide trawling within the Mandurah Entrance Channel at the northern corner of Peel Inlet. Since western king prawns have normally emigrated out through the Mandurah Channel into their spawning grounds in Comet Bay, the additional migratory route provided by the newly-constructed Dawesville Channel into waters *ca* 40 km south of Comet Bay, may thereby mitigate against such individuals reaching their traditional spawning grounds. This would thus be likely to affect the spawning success of this important commercial species and thereby greatly influence the inshore trawl fishery for western king prawns that is based in those waters. Any decrease in the numbers of this important recreational and commercial species in the estuary would have an impact on the local economy. Indeed, there is circumstantial evidence that the low catches of western king prawns in the autumn and winter of 1994 were due to some prawns emigrating from the Peel Inlet out through the Dawesville Channel, rather than through the original entrance channel, in which the beam tide trawl prawn fishery is based.

The similarities between the morphology of the Peel-Harvey Estuary and systems elsewhere in Australia, such as the Coorong in South Australia and the Gippsland Lakes in Victoria, demonstrate that many of the findings from the present study will have relevance throughout southern Australia.

Objectives

1. Determine the extent to which the construction of the Dawesville Channel has influenced the recruitment of the juveniles of blue swimmer crabs and western king prawns into the Harvey Estuary, and the size composition and/or growth rate of these crustaceans in the Peel-Harvey Estuary.

2. Determine the way in which greatly increased tidal action has changed the salinities of habitats within Peel Inlet and the Harvey Estuary and how this is now reflected in the composition of the crustacean and fish faunas of habitats within those regions.

3. Determine whether the Dawesville Channel now provides a major route for the emigration of western king prawns and, if so, whether any such migration is drawing on prawns that would previously have passed out through the original (Mandurah) entrance channel, within which the commercial fishery is based.

Methods

Sampling sites and techniques

The locations of the sites in the Peel-Harvey Estuary, that were used for sampling blue swimmer crabs, western king prawns and fish in 1995 to 1998, are shown in Figure 1 and the times of sampling and the sampling methods, *i.e.* seine net or otter trawl, are provided in Table 1. N.B. Three replicate samples were always taken on each sampling occasion in each region, irrespective of the type of sampling method employed. Most of the sites corresponded to those used for sampling crabs and prawns in 1979 to 1983 and several of the sites corresponded to those used for sampling fish in 1979 to 1981. However, it should be recognised that the sampling regime in 1995 to 1998 contained additional sampling sites, particularly in the case of fish (Fig. 1). Sampling was carried out at the same sites on each sampling occasion, irrespective of whether or not macrophytes were present at those sites. This extensive sampling regime is considered as encompassing the typical types of habitats found in the shallow waters of all regions of the Peel-Harvey Estuary and which would be expected to act as nursery areas for crustaceans and fish. Prior to sampling, salinity (*‰*) and water temperature (^{o}C) were recorded near the bottom of the water column at each site in the shallow waters.

The 10.5 m seine net, which was used to sample crabs and prawns in shallow waters at night, consisted of two 4.5 m long wings, each comprising 6 mm mesh and a 1.5 m long pocket made of 3 mm mesh. The net fished to a maximum depth of 1.5 m. On each sampling occasion, this seine net was trawled by hand along shallow banks at each site for a period of 5 minutes. The distance covered by each trawl ranged from 75 to 130 m, the precise distance covered depending on the strength of tidal water flow and the composition of the substrate. The number of crabs and prawns in each sample is each expressed as a density, *i.e.* number per 100 m^2.

The 102.5 m seine net, which was used to sample crabs and fish in shallow waters during the day, consisted of two 50 m long wings (44.5 m of 25.4 mm mesh and 5.5 m of 13 mm mesh) and a 2.5 m bunt of 9.5 mm. This net was identical to that used by Potter *et al.* (1983a) and Loneragan *et al.* (1987b) during their studies in the Peel-Harvey Estuary between 1979 and 1981, except that the mesh in a small section of the wings was 13 mm, rather than 15.9 mm, the latter size no longer being manufactured. The net fished to a depth of 1.8 m and swept an area of 1670 m^2. The number of individuals of each species in each of the samples collected from each region is expressed as a density, *i.e.* number per 1000 m^2.

Since the seine net was laid carefully but rapidly in a semi-circle from a boat, had a small mesh size, fished the full height of the water column and was immediately pulled onto the beach, it would have caught the vast majority of crabs and fish that were present in the area encircled by that net. Although sea mullet occasionally 'jumped' over the net, the numbers of such fish were recorded. It is also noteworthy that sampling using a 21.5 m seine net with an even smaller mesh *i.e.* 3 mm, yielded the same suite of species, and that any species that was abundant in the samples collected by one net was also abundant in the samples obtained using the other net.

The otter trawl net, which was used to sample crabs in offshore and slightly deeper waters, had a 2.6 m wide mouth and was 0.5 m high and 5 m deep. The warp and bridle lengths were 50 and 13 m, respectively. The wings consisted of 51 mm mesh, while the bunt was made of 25 mm mesh. The net was towed at *ca* 50 m min^{-1} for a distance of *ca* 250 m, during which the trawl covered an area of *ca* 650 m^2. The number of crabs in each sample is expressed as a density, *i.e.* number per 100 m^2.

Gill netting was carried out during the study of the fish fauna conducted in 1979 to 1981. Although it was intended also to carry out gill netting during the current study, the gill nets that were set for only three hours on the first two sampling occasions collected such large numbers of crabs that they destroyed beyond recognition many of the fish that had been gill netted and caused very extensive damage to the gill nets themselves. The use of gill nets would thus have provided unrepresentative data on the fish fauna in deeper waters and resulted in far too heavy a cost in terms of time spent repairing nets or in purchasing new nets.

Comparisons between the faunas prior to and following the construction of the Dawesville Channel

The densities of crabs and prawns and the number of species and density of fish recorded during the present study in periods between March 1995 and July 1998, *i.e.* after the opening of the Dawesville Channel, are compared with those recorded during the studies of

Potter *et al.* (1983a, b, c; 1991) and Loneragan *et al.* (1986) in periods between April 1979 and June 1988, *i.e.* prior to the construction of that channel. Comparisons between the crabs, prawns and fish in the two periods utilised data derived from samples collected using comparable seine nets at the same sampling sites (Table 1; Fig. 1). In the case of fish, the abundances were calculated by summing the mean density of fish on each sampling occasion in each region and adjusting the totals so that, in each period, they correspond to a constant number of samples, *i.e.* 100 samples for the whole estuary (Table 2) and 50 samples for the Harvey Estuary (Table 3).

The densities of blue swimmer crabs and western king prawns in different regions and months and of fish species in different regions and seasons, in the periods prior to and after the construction of the Dawesville Channel, were subjected to one-way analysis of variance (ANOVA) to determine whether the densities differed between periods. N.B. The mean densities used for these analyses represented the means for the corresponding months or seasons in each of the two periods. Since Cochran's C-test showed that the densities were heteroscedastic, they were Log_{10} (n+1) transformed prior to use in ANOVA. Since the number of species and densities were usually still hetroscedastic, only values with $P < 0.01$ were considered to be significant. When ANOVA showed that there was a significant difference, Scheffé's *a posteriori* test was used to determine in which region(s), month(s) or season(s) the densities in the two periods were significantly different.

Measurements and indices of reproductive condition of the blue swimmer crab (*Portunus pelagicus*)

The total number of crabs in each sample, collected between April 1995 and July 1998, was recorded. The carapace width (CW) of each crab, *i.e.* the distance between the tips of the two lateral spines of the carapace, was measured to the nearest 1 mm. The wet weight of each crab was recorded to the nearest 0.1 g.

The fact that, when a crab has a CW > 30 mm, the abdomen is far more oval in female than male crabs, was used to sex crabs whose CW was > 30 mm. Since the shape of the abdomen does not differ markedly in crabs with a CW < 30 mm, the pleopods of the smaller crabs, whose characteristics differ markedly between females and males, irrespective of their size, were dissected out and examined under a dissecting microscope. In the case of these smaller crabs, the sexes were distinguished on the basis that the male crab has two pairs of uniramous pleopods, whereas the female crab has four pairs of biramous pleopods (Warner, 1977). A record was made of whether female crabs were unberried or berried, *i.e.* ovigerous (Smith, 1982). The fact that, in female *P. pelagicus*, the abdomen of the juveniles is triangular, whereas that of the adults is almost circular and free of the ventral shell, was used to determine whether or not the individual female crabs had undergone a pubertal moult and thus whether they had either copulated or not copulated previously (Van Engel, 1958; Ingles & Braum, 1989).

The size at which 50% of female crabs reach maturity (CW_{50}) was determined from data obtained for a wide size range of female crabs in which each crab had been recorded as either having not undergone or having undergone a pubertal moult, and thus had either not reached a size or had reached the size at which copulation occurs, respectively. A logistic function was fitted to the percentage of those female crabs which, in each 5 mm carapace width interval, had undergone a pubertal moult, by using a non-linear technique (Saila *et al.*, 1988), employing a non-linear sub-routine in SPSS (SPSS Inc., 1988). The logistic equation was $PL = [1 + e^{(a + bL)}] - 1$, where PL is the proportion of crabs that have undergone a pubertal moult at length interval L, and a and b are constants. The CW_{50} was derived from the equation $CW_{50} = -a/b$. Since those female crabs which have undergone a pubertal moult, *i.e.* have mated, will not typically commence growing again until after egg extrusion (spawning), which generally takes place within two weeks (Yatsuzuka, 1962; Ingles & Braum, 1989), this CW_{50} corresponds to the CW_{50} at first maturity.

Male crabs were separated into three categories, namely (i) those that were small (CW < 60 mm) and thus below the minimum size at which maturity is usually reached in other populations of blue swimmer crabs, *i.e.* they were juveniles, (ii) those that were large (CW > 120 mm) and were thus of a size that would be expected to have reached maturity, *i.e.*

they were adults and (iii) those in which the carapace widths lay between 60 and 120 mm and would thus either constitute juveniles or adults. The choice of the above three categories of carapace widths was based on data recorded for the size of juveniles and adults in different populations of blue swimmer crabs by Meagher (1971), Ingles & Braum (1989) and Reeby *et al.* (1990). The carapace widths of male crabs belonging to the first and second of these categories were plotted against the lengths of the dorsal surface of the propodus of their largest chela. Regression lines were fitted by the least sum of squares method to these two data sets, assuming $Y = mX + b$, where Y is the length of the chela propodus, X is the carapace width and m and b are constants. These two lines were fitted iteratively until the intersection point, which resulted in the minimum residual sum of squares, was found. The point at which the lines intersect was then assumed to provide a good approximation of the carapace width at which there is a pronounced change in the pattern of growth of the largest chela, a feature which, in males, is known to be associated with its pubertal moult (Ingles & Braum, 1989; Reeby *et al.*, 1990). The next step involved determining whether the point for the relationship between the length of the largest chela propodus and the carapace width of each crab was closer to the regression line that related these two variables in 'juvenile' crabs or in 'adult' crabs, as defined above. The logistic curve was then fitted to percentage values for those crabs which, in each 5 mm carapace width interval, corresponded to the latter group of crabs.

Measurements of the western king prawn (*Penaeus latisulcatus*)

The total number of prawns in each sample, collected from March 1995 to May 1997, was recorded. The carapace length (CL), *i.e.* the length between the base of the orbital spine at the rear end of the orbit and the posterior margin of the carapace, was recorded to the nearest 1 mm for each prawn in each sample, except when the number of prawns was large, in which case the lengths of a random subsample of 100 prawns were recorded. Since the prawns caught in the estuary are all essentially less than the size at which they reach maturity (Potter *et al.*, 1991), no attempt was made to sex these prawns.

Measurements, life cycle categories and community analyses of fish

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 in each sample was measured to the nearest 1 mm, except when the number of individuals of a species was large, in which case the lengths of a subsample of 100 randomly-selected representatives of that species were recorded.

On the basis of the distribution and biology of the fish species that are found in south-western Australian estuaries (see Potter *et al.*, 1990, 1993; Potter & Hyndes, 1999), each of the fish species collected by Loneragan *et al.* (1986) in the shallow waters of the Peel-Harvey Estuary between January 1980 and November 1981, and each of those obtained during the present study from January 1996 to October 1997, have been allocated to one of the following life cycle categories, namely (i) marine straggler (S), *i.e.* species which are found irregularly and in low numbers in estuaries, (ii) marine estuarine-opportunist (O), *i.e.* species that enter estuaries each year and usually in large numbers, (iii) estuarine and marine (E/M), *i.e.* species that are capable of completing their lifecycle in both marine and estuarine waters, (iv) estuarine (E), *i.e.* species that are restricted entirely to estuaries or (v) semi-anadromous (A), *i.e.* species that feed mainly at sea but migrate into the upper estuary to spawn.

The mean number of species and the mean density of individuals of each fish species in the samples from the shallow waters in each of the five regions in the corresponding seasons in 1980 and 1981 and in 1996 and 1997 were classified by hierarchical agglomerative cluster analysis, using group-average linking, and ordinated separately using non-metric multi-dimensional scaling (MDS) in the PRIMER v4.0 package (Clarke & Warwick, 1994). Prior to classification and ordination, the densities of each fish species were fourth-root transformed and a similarity matrix was constructed using the Bray-Curtis similarity coefficient. Analysis of similarities (ANOSIM) was used to test whether the species compositions of the samples from the five different regions and the four different seasons were significantly different from each other and similarity percentages (SIMPER) was used to determine which species contributed most to any dissimilarities that were found between samples from different regions or seasons (Clarke & Green, 1988; Clarke, 1993; Clarke & Warwick, 1994).

Commercial catch data

Data on the annual catch of blue swimmer crabs, western king prawns, sea mullet, yellow eye mullet, cobbler, King George whiting and yellow fin whiting obtained by commercial fishers, were extracted from the Fisheries Western Australia Catch and Effort Statistics (CAES). These annual catch data were extracted from statutory monthly catch and effort statistics (CAES) returns provided by commercial fishers. The data within the CAES database are regarded as the most accurate and current data available for analysis. Data within the CAES database are continually being maintained, both by addition of new statistical returns and by modification of records to correct errors of data entry or interpretation that are detected during on-going analysis and data quality control by the research section responsible for studying each fishery. N.B. In their current form, the effort data for crustaceans and fish in the Peel-Harvey Estuary are not considered sufficiently reliable to provide reliable catch per unit effort values (S. Ayvazian, Fisheries Western Australia, pers. comm.).

Results/Discussion

Salinities and water temperatures

Prior to the construction of the Dawesville Channel, salinities in the shallow waters of each region of the Peel-Harvey Estuary showed the same seasonal trends, with high values, *i.e.* > 30 ‰, being recorded between at least January and April, and appreciably lower values being recorded in winter (Fig. 2). However, the extent to which salinities fell during periods of heavy freshwater discharge and the duration of those lower salinities varied amongst regions. Thus, for example, in the Mandurah Entrance Channel, the mean monthly salinities never fell below 20 ‰, whereas in the Serpentine River and both the northern and southern regions of the Harvey Estuary, they declined to below this level in either four or five months (Fig. 2).

Although salinities in the shallow waters of each region in the Peel-Harvey Estuary also showed pronounced seasonal changes after the opening of the Dawesville Channel, there were pronounced differences in the salinities in the corresponding months prior to and after the construction of the channel (Fig. 2). Particularly relevant is the fact that, following the opening of the Dawesville Channel, the salinities in all regions of the Peel-Harvey Estuary recovered far more rapidly after periods of heavy freshwater discharge (Fig. 2). Consequently, low salinities *i.e.* < 20 ‰, are now present for a far shorter period than was the case before the construction of the Dawesville Channel.

Prior to the construction of the Dawesville Channel, the trends exhibited by water temperatures in each region paralleled those displayed by salinities. Thus, water temperatures declined from maxima of *ca* 22 to 28 °C in summer to minima of *ca* 12 to 17 °C in winter (Fig. 3). After the construction of the Dawesville Channel, water temperatures continued to exhibit the same seasonal trends (Fig. 3).

Seasonal trends in the abundance of the blue swimmer crab (*Portunus pelagicus*)

Crabs were either absent or in very low abundance in the samples collected using a seine net in the shallow waters of the Mandurah Entrance Channel during the winter of 1995 (Fig. 4). The mean monthly densities in the shallow waters then rose markedly to 7.7 crabs per 100 m^2 in September and remained at between 3.2 and 6.1 crabs per 100 m^2 from October 1995 to January 1996 and then ranged from 1.0 to 2.5 crabs per 100 m^2 between February and May 1996. As in the previous year, crabs were subsequently either absent or in very low numbers in the samples obtained during the ensuing three winter months (Fig. 4). Although the densities of crabs increased in September 1997, thereby paralleling the situation in 1996, they did not reach the same levels in this and the ensuing spring and early to mid summer months as in the previous year.

The trends exhibited by the densities of crabs in the shallow waters of the northern region of the Harvey Estuary essentially parallel those just described for the Mandurah Entrance Channel (Fig. 4). Thus, crabs were in sparse in samples collected in the winters of both 1995 and 1996, but then increased markedly in density in the September of both of those years. In general, the mean monthly densities were greatest during the spring and early summer months. Although the mean monthly densities in the shallow waters of Peel Inlet and the southern region of the Harvey Estuary also followed marked seasonal trends, the conspicuous rise that likewise took place in the spring in those regions occurred rather later, *i.e.* in October or November *vs* September (Fig. 4).

Since the trends exhibited by the mean monthly densities in the shallow waters of each of the four regions of the Peel-Harvey Estuary were similar to those in each of the corresponding regions during both years of the current study, the data on the densities in each of those regions in corresponding months of the two years were pooled (Fig. 5). These data were then compared with data that had been pooled in precisely the same manner for the corresponding regions prior to the construction of the Dawesville Channel, *i.e.* between April 1995 and May 1997 (Fig. 5). Comparisons between the data sets for the above two periods showed that the monthly trends exhibited by the mean monthly densities of crabs in the Mandurah Entrance Channel prior to and after the construction of the Dawesville Channel did not differ markedly. However, this was not the case in the other three regions of the estuary and particularly in the two regions in the Harvey Estuary. Thus, prior to the construction of the Dawesville Channel, very few crabs were caught in the Harvey Estuary. Indeed, appreciable numbers of crabs were caught in the Harvey Estuary in only one month, *i.e.* April, and even then this only occurred in the northern part of the estuary, whereas in the period after the construction of the Dawesville Channel, considerable numbers of crabs were collected in the northern region of the Harvey Estuary in September to December and in the southern region of this estuary between October and December (Fig. 5). It is also noteworthy that, while the mean monthly densities in Peel Inlet in the months between December and May were similar or greater in the period prior to than after the construction of the Dawesville

Channel, greater numbers of crabs were caught in Peel Inlet in the spring after the opening of this channel (Fig. 5).

Appreciable numbers of crabs were caught by otter trawls in the offshore, deeper waters of the Mandurah Entrance Channel in each of the eight months that trawling was carried out in those waters during the present study (Fig. 6). Although crabs were also always caught in this channel in corresponding months of the year, prior to the construction of that channel, the numbers in some months, *i.e.* April, July and December, were very low and, in six of the eight months, were lower than after the construction of the Dawesville Channel. As was the case in shallow waters, the trends exhibited by the abundance of crabs in offshore, deeper waters of both regions of the Harvey Estuary, in the periods prior to and after the construction of the Dawesville Channel, differ markedly. Thus, while crabs were not caught in four out of eight months in the northern region of the Harvey Estuary and in five out of eight months in the southern region of the Harvey Estuary in the period prior to the Dawesville Channel, they were caught on all but one sampling occasion in these two regions after the construction of that channel, *i.e.* on all occasions except for July (Fig. 6). Although the differences between periods were far less pronounced in Peel Inlet, it may be relevant that the highest densities in this part of the system were recorded after the construction of the Dawesville Channel. Furthermore, the densities were far greater in July, after the construction of the channel, when salinities were appreciably higher (Figs 2, 6).

Although the overall mean density of crabs in Peel Inlet and the Harvey Estuary collectively in each month between January and May was greater prior to than after the construction of the Dawesville Channel, the differences in each month except April were relatively small (Fig. 7). However, the situation changed dramatically after May. Thus, in June to November, the mean overall densities of crabs in the Peel Inlet and Harvey Estuary were essentially negligible prior to the opening of the channel, whereas, after the opening of that channel, there were appreciable numbers of crabs in each of those months except July and August (Fig. 7). Furthermore, the mean overall density of crabs in December was far lower prior to the opening of the channel. The high overall densities recorded in the estuary in each month between September and November were mainly attributable to the substantial numbers of crabs collected in the Harvey Estuary during that period (Fig. 7).

The densities in Peel Inlet and Harvey Estuary in each month between December and May, when, in the pre- and post-Dawesville periods, substantial numbers of crabs were recorded in Peel Inlet and usually also in the Harvey Estuary (Fig. 7), were subjected to ANOVA. ANOVA showed that the overall densities in the two regions throughout these months collectively did not differ significantly between the pre-Dawesville and post-Dawesville periods. Furthermore, the densities in both regions collectively in individual months between December and May only differed significantly in December, when the densities in the post-Dawesville period were far greater than in the pre-Dawesville period. ANOVA also showed that, in none of the above months, was there a significant difference in the densities in Peel Inlet in the pre- and post-Dawesville periods. Moreover, such differences were only found in the Harvey Estuary in May and December. The densities were greater in the post-Dawesville than pre-Dawesville periods in May and crabs were only caught in December in the post-Dawesville period (Fig. 7). It should also be re-emphasised that crabs were rarely or ever caught in Peel Inlet and Harvey Estuary between July and November in the pre-Dawesville period and that moderate or large catches of crabs were obtained in the post-Dawesville period in each of these months (Fig. 7).

In order to obtain a very broad estimate of the number of crabs in both Peel Inlet and the Harvey Estuary in each month prior to and after the construction of the Dawesville Channel, the assumption has been made that the mean densities recorded for the samples in each region are broadly representative of that region (Fig. 7). The mean overall densities for crabs in the two regions collectively for all months of the year were 1.6 and 4.2 crabs per 100 m^2 prior to and after the construction of the Dawesville Channel, respectively. These data, together with those presented above, demonstrate that the overall catches of crabs were greater in the post-Dawesville period and that this was attributable to increased catches of crabs in the Harvey Estuary.

Seasonal trends in the size distributions of the blue swimmer crab (*Portunus pelagicus*)

Prior to the construction of the Dawesville Channel, the first of the new female and male 0+ recruits appeared in small numbers in February, at which time their carapace lengths ranged from 10 to 59 mm and produced for both sexes a modal length class of 30 - 39 mm (Fig 8). The distributions of the carapace widths of these 0+ crabs and the cohort of larger and presumably 1+ crabs did not overlap in this month and exhibited little overlap in April (Fig. 8). The modal carapace width classes of female crabs increased from 30 - 39 mm in February to 70 - 79 mm in March and then to 80 - 89 mm in June. The size of this cohort did not increase markedly over winter. The modal carapace width class in September and November remained at 80 - 89 mm and then increased to 110 - 119 mm in January and February and 130 - 139 mm in April (Fig. 8). This cohort declined in numbers in the ensuing months and had essentially disappeared by July and August. Since spawning occurs in summer (Potter *et al.*, 1983c), the trends exhibited by the above size-frequency data demonstrate that, prior to the construction of the Dawesville Channel, young crabs started to be recruited into the Peel-Harvey Estuary in late summer and then grew during the subsequent autumn months, after which there was a cessation in growth in winter, followed by further growth in the following late spring to mid autumn (Fig. 8). Since the crabs then moved out of the estuary during winter, they were thus, at the time of this emigration, approximately one and a half years old. The trends exhibited by the size-frequency data for male crabs throughout the year were essentially the same as those described above for female crabs (Fig. 8).

Although the overall trends exhibited by the size-frequency data for crabs after the opening of the Dawesville Channel were similar to those prior to the construction of that channel, there were some notable differences. Firstly, after the opening of the Dawesville Channel, the overall prevalence of small 0+ crabs, *i.e.* with carapace widths less than 40 mm, was far greater and these small crabs were recruited into the estuary over a far longer period, *i.e.* January to August *vs* February to April (Fig. 8). Secondly, the modal size class of both sexes of crabs in this period increased more rapidly in the months between September and January, which implies that growth was more rapid following the opening of the Dawesville Channel (Fig. 8).

When the size-frequency data for crabs in the Harvey Estuary are considered on their own, it is evident that large numbers of crabs which, from the above interpretation of carapace width frequency data, are approximately nine months old, enter this part of the Peel-Harvey Estuary in September (Fig. 9). The modal carapace widths increased from 70 - 79 mm in September to 100-109 mm in November and 110 - 119 mm in December.

Reproductive biology of the blue swimmer crab (*Portunus pelagicus*)

The smallest female crab, which had undergone a pubertal moult and had therefore already mated, had a carapace width of 89 mm (Fig. 10). The percentage contribution of crabs which had undergone a pubertal moult, and could therefore be regarded as adult, rose from *ca* 25% in the 90 - 94 mm carapace width class to just over 50% in the 95 - 99 mm carapace width class to *ca* 75% in the 100 - 104 mm carapace width class (Fig. 10). All female crabs with a carapace width greater than 125 mm had undergone a pubertal moult. The logistic curve, fitted to the percentage frequency of females which had undergone a pubertal moult, yielded a CW_{50} of 98 mm (Fig. 10).

Based on data derived from the change in morphology that occurs in the chelipeds of male crabs at maturity (see Methods), the smallest crab to have reached maturity had a carapace width of 76 mm (Fig. 10). Although maturity was attained by only a few male crabs with carapace widths of 75 - 79 mm, it had been reached by nearly 45% of those with a carapace width of 80 - 84 mm and by the vast majority of crabs above 85 mm (Fig. 10). The logistic curve, fitted to the percentage frequency of males whose chela had undergone a morphological change, yielded a CW_{50} of 84 mm (Fig. 10).

The data on the prevalence of ovigerous female crabs *vs* all female crabs that had undergone a pubertal moult in samples collected monthly between February 1980 and May 1981 and between May 1995 and July 1998 have been pooled into corresponding months of the year for each of these periods (Fig. 11). Prior to the construction of the Dawesville Channel, no ovigerous crabs were found between July and October (Fig. 11). The percentage contributions of ovigerous female crabs to all female crabs that had undergone a pubertal moult, rose from less than 0.5% in November and December to 31.7% in January, before declining to 25.9% in February and 6.4% in March and then to 5.6% in April. A small number of ovigerous crabs were caught in both May and June (Fig. 11). In contrast to the above situation, the mean monthly prevalence of ovigerous crabs, after the construction of the Dawesville Channel, was greatest in November and December as opposed to in January and February in the period prior to the construction of that channel (Fig. 11). Furthermore, following the opening of the Dawesville Channel, the maximum monthly prevalence of ovigerous crabs, *i.e.* 4.9% in December, was far lower than the maxima recorded in January and February prior to the construction of that channel, and few ovigerous crabs were caught after February (Fig. 11).

Seasonal trends in the abundance of the western king prawn (*Penaeus latisulcatus*)

The seasonal trends exhibited by the catches of western king prawns obtained by seine net in the shallow waters in different regions of the Peel-Harvey Estuary resemble, to some extent, but are less extreme than those described above for the blue swimmer crab in those same waters (*cf* Figs 4, 12). N.B. The prawn data also contain the densities of this species in the Serpentine River, a region which seasonally becomes markedly hypersaline and which is known to contain an abundance of prawns in summer and autumn (Potter *et al.*, 1991). Thus, in the Mandurah Entrance Channel and the northern region of the Harvey Estuary, the densities of prawns were low in late winter but then rose during spring and tended to remain relatively high until either late summer or autumn (Fig. 12). Although prawns were almost invariably caught in each month in the Peel Inlet, they were generally absent between late autumn and late spring in the Serpentine River (Fig. 12), which discharges into Peel Inlet (Fig. 1) and within which the salinities decline to very low levels in that period (Fig. 2).

As was the case with blue swimmer crabs, the density data for western king prawns in the shallow waters in each region have been pooled for the corresponding months of the year in the periods both prior to and after the construction of the Dawesville Channel (Fig. 13). Comparisons between the two data sets show that, while prawns were present in the Mandurah Entrance Channel in most months, the mean monthly densities were invariably far greater in the Mandurah Entrance Channel between October and February following the construction of the Dawesville Channel, whereas the reverse was the case in May to August (Fig. 13). It is thus highly relevant that the above months represent the main period during which prawns are recruited into the Peel-Harvey Estuary. Analysis of the size of prawns in the catches in the different months shows that, while a substantial number of juvenile prawns are recruited into the estuary through the Mandurah Entrance Channel in spring and early summer, the numbers of large prawns that pass out through that channel in late autumn and winter are now far lower than before the construction of the channel. There is also evidence that a larger number of small prawns migrate out through the Mandurah Entrance Channel in summer than was previously the case (Fig. 13).

Prior to the construction of the Dawesville Channel, prawns were not caught in the shallow waters of Peel Inlet in October and November and were virtually absent in that region in September, while after the construction of that channel, prawns were caught on each sampling occasion (Fig. 13). There was no pronounced difference in the density data for the Serpentine River and Goegrup Lake collectively, prior to and after the construction of the Dawesville Channel.

The very marked differences between the densities of western king prawns in the Harvey Estuary, prior to and following the construction of the Dawesville Channel, parallel very closely those described earlier for the blue swimmer crab (*c.f.* Figs 5, 13). Thus, while prawns were frequently absent in the samples collected monthly in the Harvey Estuary prior to the construction of the Dawesville Channel, they were obtained in every month from the northern region of this estuary and in all but one month in the southern region of this estuary after the construction of that channel (Fig. 13).

The overall mean density of prawns in the Peel Inlet and Harvey Estuary collectively, in each corresponding month between January and June, were relatively high and similar (Fig. 14). However, the situation changed dramatically after July. Thus, from September to December, the mean overall densities of prawns in the Peel Inlet and Harvey Estuary were essentially negligible prior to the opening of the channel, whereas, after the opening of this channel, they were appreciable in each of those months (Fig. 14). The high overall densities recorded in the estuary in each month between September and December were largely attributable to the substantial numbers of prawns collected from the Harvey Estuary during that period.

The densities of western king prawns in Peel Inlet and the Harvey Estuary, in each month between December and June when substantial numbers of prawns were recorded in both of these regions of the estuary (Fig. 14), were subjected to ANOVA. The results showed that the overall densities in the two regions throughout these months collectively did not differ significantly between the pre-Dawesville and post-Dawesville periods. Furthermore, the densities for both regions collectively in individual months between December and May also did not differ significantly. In addition, ANOVA showed that, in none of the above months except March, was there a significant difference in the densities of prawns in Peel Inlet in the pre- and post-Dawesville periods, when the densities were significantly greater in the pre-Dawesville period than in the post-Dawesville period (Fig. 14). Moreover, significant differences in the Harvey Estuary were only found between the two periods in March and December. The densities were greater in the post-Dawesville than pre-Dawesville periods in March and prawns were only caught in December in the post-Dawesville period (Fig. 14). It should also be re-emphasised that prawns were either not caught or were caught in only low numbers in the Peel Inlet and Harvey Estuary between July and December in the pre-Dawesville period and that moderate or large catches of prawns were obtained in these months in the post-Dawesville period (Fig. 14).

In order to obtain a very broad estimate of the densities of prawns in both the Peel Inlet and Harvey Estuary in each month prior to and after the construction of the Dawesville Channel, the assumption has been made that the mean densities recorded for the samples in each region are broadly representative of that region (Fig. 14). The mean overall densities for prawns in Peel Inlet and the Harvey Estuary collectively for all months of the year, taking into account the differences in the areas in these two basins, were 2.6 and 4.4 prawns per $100m^2$ prior to and after the construction of the Dawesville Channel, respectively.

Seasonal trends in the size distributions of the western king prawn (*Penaeus latisulcatus*)

Prior to the construction of the Dawesville Channel, a few small prawns, *i.e.* < 7 mm carapace length, were recruited into the Peel-Harvey Estuary in April and October (Fig. 15). However, no consistent trends were exhibited by the modal size classes during successive months. Although the carapace widths of most prawns were < 26 mm, some larger prawns with carapace lengths of 26 to 36 mm were caught in March, April and May. These larger prawns left the estuary in winter. Although the patterns exhibited by the size-frequency data were similar in the Peel-Harvey Estuary after the construction of the Dawesville Channel, it is clear that the proportion of small prawns was greater, and thus the proportion of larger prawns had become less (Fig. 15).

When the size-frequency data for prawns in the Harvey Estuary are considered on their own, it is evident that small prawns, *i.e.* less than 8 mm carapace length, were caught in this part of the system in all months except August, November and December (Fig. 16). Although prawns with carapace lengths greater than 16 mm were relatively abundant in January to May, such prawns were essentially not collected in June to August. A prominent cohort of prawns with modes of *ca* 7 - 8 mm were present in May, June and July and is presumably represented by the cohort which, in September, had a mode of 12 - 13 mm (Fig. 16). The modes of another cohort which appeared in September increased from 5 - 6 mm in that month to 7 - 8 mm in October and 13 - 14 mm in November (Fig. 16).

Composition of the fish fauna prior to and following the construction of the Dawesville Channel

The species composition and overall abundance of fish in the shallow waters of the Peel-Harvey Estuary have been determined for the periods prior to and following the construction of the Dawesville Channel, *i.e.* January 1980 to November 1981 and January 1996 to November 1997, respectively. This has been achieved by using data collected from samples obtained by employing a comparable seine net in the same regions of the estuary in both periods and after adjusting the catch data so that, in both periods, it corresponded to precisely the same number of samples, *i.e.* 100 samples. The data in Table 2 show that the overall abundance recorded in the shallows of the Peel-Harvey Estuary in January 1996 to November 1997, *i.e* after the opening of the Dawesville Channel, was only just over a third of that in January 1980 to November 1981, *i.e.* 12,908 *vs*. 38,027. However, the reverse trend occurred with number of species. Thus, 47 species were recorded for these waters post-Dawesville, compared with 39 species pre-Dawesville Channel (Table 2).

There is strong circumstantial evidence from catch per unit effort data that the abundance of fish in the Peel-Harvey Estuary increased markedly in the 1970s and 1980s, following massive increases in the biomass of macroalgae (Steckis *et al.*, 1995). Thus, it is concluded that the lower abundance of fish in the Peel-Harvey Estuary, following the construction of the Dawesville Channel, is almost certainly related to the very marked reduction that has occurred in the biomass of macroalgae in this estuary during recent years as a result of the beneficial effects of a far greater exchange of estuarine water with the sea (Wilson *et al.,* 1997). Such a view is consistent with the fact that *Pelates sexlineatus* and *Apogon rueppellii*, which are typically associated with macroalgae throughout their life cycle (G. Hyndes, Murdoch University, pers. comm.), ranked first and second, respectively, in terms of abundance and collectively contributed 50.9% to all fish caught prior to the opening of the Dawesville Channel, but subsequently ranked tenth and seventh, respectively, and collectively contributed only 4.3% to the total fish catch after the opening of that channel

(Table 2). The marine estuarine-opportunists *Torquigener pleurogramma* and *Hyperlophus vittatus*, which previously ranked sixth and fourth, respectively and collectively contributed only 12.5% to the total numbers of fish caught, now rank first and second, respectively, and collectively contribute 58.7% to the total catch (Table 2).

The three most abundant commercial fish species, *i.e. Aldrichetta forsteri*, *Sillago schomburgkii* and *Mugil cephalus,* which ranked seventh, twelfth and fourteenth, respectively, and collectively contributed 7.0% to the total catch of fish prior to the construction of the Dawesville Channel, ranked fifth, eighteenth and twenty third after the opening of that channel and contributed only 4.6% collectively to the total catch (Table 2).

The number of species in the Harvey Estuary has increased from 27 to 34, the majority of which are marine species (Table 3). The marine estuarine-opportunist *T. pleurogramma*, which ranked nineteenth and contributed only 0.2% to the total number of fish prior to the construction of the Dawesville Channel, ranked first and comprised 64.5% of the catch after the opening of that channel (Table 3). This increase probably reflects both the increased intrusion of tidal water, and thus the maintenance of higher salinities for longer periods, and the closer proximity of the Harvey Estuary to the ocean since the opening of the Dawesville Channel.

The contrast between the downward trend in both the number of species and density of fish between western Peel Inlet and the southern Harvey Estuary in the pre-Dawesville period and the relative constancy of these two variables in the four basin regions in the post-Dawesville period (Fig. 17), is entirely consistent with the effect that would be expected to be produced by the construction of a channel at Dawesville. In other words, the presence of both a channel between the ocean and the Harvey Estuary and a far greater tidal movement within both basins of the Peel-Harvey Estuary would be expected to facilitate far greater dispersion of fauna throughout both basins. However, ANOVA was unable to detect any significant differences between the number or densities of fish species in the four regions in either the pre-Dawesville and post-Dawesville periods. In the context of this lack of significance, it should be recognised that the number of samples collected in the pre-Dawesville period were far less than in the post-Dawesville period. Thus, since the catches of some species varied markedly in the small number of samples obtained in the Peel-Harvey Estuary, prior to the construction of the Dawesville Channel, the standard errors for the densities in this earlier period were often very large. The same problem of sample size in the pre-Dawesville Channel period exists when comparisons were made between catches in corresponding regions in the pre- and post-Dawesville periods. However, when comparisons were made between regions in each of the four seasons, rather than the whole year, the number of species and density of fish were occasionally significantly greater in the two Peel Inlet regions in the pre-Dawesville Channel period, whereas the reverse was never true in the post-Dawesville period, and the number of species was significantly greater in the post-Dawesville period in the southern Harvey Estuary in one season, whereas the reverse was never the case in the pre-Dawesville period.

When the species compositions of each of the samples from the corresponding sites in the Peel-Harvey Estuary in the summer to spring periods of 1980 - 1981 and 1996 - 1997 were subjected to classification, all of the samples from the pre-Dawesville Channel period formed a group that was separate from those in the post-Dawesville Channel period (Fig. 18). Furthermore, the samples from within the basins showed a pronounced tendency to separate according to region in the pre-Dawesville Channel period, whereas those from the post-Dawesville Channel period essentially separated according to season (Fig. 18). The results obtained using ordination of the same samples paralleled those just described for classification (Figs 19, 20).

ANOSIM demonstrated that, prior to the opening of the Dawesville Channel, the composition of the fish fauna in the Mandurah Entrance Channel and in each of the four basin regions of the Peel-Harvey Estuary differed significantly from each other, except in the case of the northern Harvey Estuary *vs* southern Harvey Estuary. However, even in the case of the two regions in the Harvey Estuary, the points for three of the four southern Harvey samples were discrete from those of all of the northern Harvey samples and ANOSIM did show that the samples from the two regions were significantly different when the analysis was restricted to comparing just those two regions. Moreover, no significant differences were detected between the compositions in the different seasons. After the opening of the Dawesville Channel, the composition of the fish fauna of the Mandurah Entrance Channel differed significantly from all of the basin regions except for the western Peel Inlet. However, the compositions of the four basin regions were not significantly different from each other, except in the case of the eastern Peel Inlet *vs* the northern Harvey Estuary. Furthermore, and again in contrast to the situation prior to the opening of the Dawesville Channel, the composition of the fish fauna after the opening of the Dawesville Channel differed significantly amongst all seasons, except in the case of summer *vs* autumn.

SIMPER showed that, prior to the opening of the Dawesville Channel, the samples from the Mandurah Entrance Channel was distinguished from those in the basin regions by the presence of greater densities of *Favonigobius lateralis*, *Amoya bifrenatus* and *Apogon rueppellii*, while differences between the western and eastern regions of the Peel Inlet were mainly due to the presence of greater densities of *A. rueppellii* and *Pelates sexlineatus* in the former region and of *Gerres subfasciatus*, *Mugil cephalus* and *Gymnapistes marmoratus* in the latter region. In comparison with all other regions, the northern Harvey and southern Harvey regions were characterised by a greater abundance of *Hyporhamphus regularis*. SIMPER indicated that, after the opening of the Dawesville Channel, the samples from the Mandurah Entrance Channel were distinguished from those of the basin regions by the presence of larger numbers of *Hyperlophus vittatus*, *F. lateralis*, *Sillago schomburgkii* and *Aldrichetta forsteri*. Summer and autumn were both characterised by greater densities of *Sillaginodes punctata,* while spring was distinguished from the other seasons by the presence of higher densities of *Torquigener pleurogramma* and *H. vittatus*.

Densities of main commercial fish species in shallow waters

Sea mullet (*Mugil cephalus*)

Although sea mullet was caught in each season and was represented by relatively large numbers in spring in the pre-Dawesville period, this species was caught in only two seasons, *i.e.* winter and spring after the construction of the Dawesville Channel and, even in those seasons, it was represented only by small catches (Fig. 21). ANOVA showed that the mean densities of sea mullet in the pre- and post-Dawesville periods differed significantly and Scheffé's *a posteriori* test showed, that when sea mullet were present in a season in both periods, the densities were greater before than after the construction of the Dawesville Channel in spring but not winter. The catches of sea mullet in the Peel Inlet and Harvey Estuary were lower than those in the Mandurah Entrance Channel. The relatively low numbers of the juveniles of this species caught in the basins can be attributed to the tendency in south-western Australia for the juveniles of this species to migrate from the sea into the tributary rivers of estuaries (Chubb *et al.*, 1981).

Yellow eye mullet (*Aldrichetta forsteri*)

The mean densities of yellow eye mullet in the Peel-Harvey Estuary were similar before and after the opening of the Dawesville Channel, except in spring when substantially greater numbers of this species were caught in the pre-Dawesville period (Fig. 21). As with sea mullet, the majority of yellow eye mullet were caught within the Mandurah Entrance Channel. The densities in spring were significantly greater in the pre-Dawesville Channel period.

Cobbler (*Cnidoglanis macrocephalus*)

Cobbler were caught in all seasons before the opening of the Dawesville Channel, albeit in relatively small numbers. However, since the opening of the Dawesville Channel, cobbler have been caught only in autumn and then only in the Peel Inlet and in very small numbers (Fig. 21). The low numbers of this species since the opening of the Dawesville Channel is almost certainly related to overfishing during the 1980s and 1990s (Steckis *et al.*, 1995). The commercial fishery for this species undergoes pronounced fluctuations brought about by the targeting of this species when they are abundant, thereby reducing their numbers, and then allowing the population to recover in subsequent years.

King George whiting (*Sillaginodes punctata*)

The densities of *Sillaginodes punctata* in the pre- and post-Dawesville Channel periods were not significantly different. The far higher overall catches of *S. punctata* in summer and autumn than in winter and the absence of this species in spring suggests that this sillaginid migrates into the estuary when salinities are increasing and migrates out of the estuary when salinities are decreasing. Although a preference for higher salinities could account for the greater densities recorded for *S. punctata* in the Harvey Estuary since the construction of the Dawesville Channel, the far closer proximity of the Harvey Estuary to the ocean could be the major factor bringing about this increase in this part of the system.

Yellow fin whiting (*Sillago schomburgkii*)

The densities of *Sillago schomburgkii* are far lower since the construction of the Dawesville Channel (Fig. 22). This point is emphasised by the fact that the densities of this species were significantly greater in each season in the pre-Dawesville than post-Dawesville Channel periods.

Commercial fishery for crustaceans and fish

Blue swimmer crab (*Portunus pelagicus*)

The annual total catch of blue swimmer crabs in the Peel-Harvey Estuary varied markedly between 1,976 and 1993, with minimum values of 1,386 Kg being recorded in 1982 and maximum values of > 50,000 Kg being recorded in 1988 (Fig. 23). Since the opening of the Dawesville Channel, the annual catches have ranged from *ca* 41,000 Kg in 1995 and 1996 to 94,628 Kg 1997. The latter catch thus exceeded the catch in any of those years for which catch data are readily available prior to the opening of the Dawesville Channel.

The above trends provide very strong circumstantial evidence that the overall abundance of crabs in the Peel-Harvey Estuary in the years following the construction of the Dawesville Channel is now greater than prior to the opening of that channel. Such an increase in crab abundance can be related, in part, to the far greater numbers of this portunid that are now found in the Harvey Estuary (see earlier).

Western king prawn (*Penaeus latisulcatus*)

The annual catches of western king prawns in the Peel-Harvey Estuary were very low in 1976 to 1978, a feature which has been attributed to the fact that the macroalgae *Cladophora montagneana* was very abundant and covered the substrate surface of Peel Inlet and thus prevented the prawns from burrowing (Potter *et al.*, 1991). Annual catches in subsequent years prior to the opening of the channel, *i.e.* 1979 to 1993, ranged from 14,560 Kg in 1979 to 36,509 Kg in 1993 (Fig. 23). Since the opening of the Dawesville Channel, annual catches have been very low, *i.e.* < 2,214 Kg. These low catches are attributable to the fact that large numbers of western king prawns, which would previously have moved out through the Mandurah Entrance Channel where the commercial fishery for this species is based, now move out through the Dawesville Channel, in which the water is too deep and moves too rapidly for the effective use of the beam-tide trawls traditionally employed for catching this species in the Peel-Harvey Estuary (see also Conclusions).

Fish (*Mugil cephalus, Aldrichetta forsteri, Cnidoglanis macrocephalus, Sillaginodes punctata* and *Sillago schomburgkii*)

The annual commercial catches of sea mullet between 1972 and 1988 were frequently greater than 150,000 Kg, whereas subsequently they have usually been less than 150,000 Kg (Fig. 23). Since the decline in catches in recent years can at least partially be attributed to a decline in the demand for this species as bait for the rock lobster fishery, caution must be taken in attempting to relate the low catches of sea mullet in 1995 –1997 to the influence of the Dawesville Channel. The trends shown by the annual catches of yellow eye mullet parallel those of sea mullet (Fig. 23). Here again, caution must be exercised in drawing conclusions from the catch data because, as with the sea mullet, the demand for this species as bait has declined. However, it is worth noting that the recruitment of small 0+ recruits of *M. cephalus*, and to a lesser extent *A. forsteri,* into the shallows was less in 1996 and 1997 than in 1980 and 1981.

The catches of cobbler vary greatly (Fig. 23). The 'boom and bust' in the fishery for this species has been attributed to the effects of targeting this species when it is abundant, thereby bringing about a marked decline in its numbers. Subsequent non-targeting of this species over the next few years then allow the numbers to increase.

The annual catches of both King George and yellow fin whiting have varied greatly (Fig. 23). However, since the construction of the Dawesville Channel there has been a rise in the catches of both King George and yellow fin whiting. This represents the effect of four or five commercial fishers, who now heavily target these two species (B. Toussaint, Professional Fisher, pers. comm.). The marked increase in the effort concentrated on these species occurred when these fishers found that they could no longer catch large numbers of western king prawns in the Mandurah Entrance Channel (see earlier). The contrasts between the considerable commercial catches of *S. schomburgkii* and the very small number taken in the seine net in the shallows (Fig. 22) is surprising. Since the majority of *S. schomburgkii* caught in the seine nets were 0+ and 1+ fish, these low catches suggest that there was poor recruitment of the juveniles of this species in 1996 and 1997.

Benefits

The results obtained during this study will enable the Western Australian Fisheries Department to develop management plans for the highly-exploited blue swimmer crab, western king prawn and also certain fish species in the Peel-Harvey Estuary. The commercial and recreational fisheries for the above species will benefit because those plans will ensure that resources are distributed equitably amongst those fisheries.

Commercial estuarine fishers in south-western Australia will be major beneficiaries of this work.

Further Development

Sampling should be carried out at intervals in the future to ascertain whether the trends described for crustaceans and fish in the Peel-Harvey Estuary soon after the construction of the Dawesville Channel are maintained in the longer term.

Conclusions

Objective 1. Determine the extent to which the construction of the Dawesville Channel has resulted in increased recruitment of juvenile blue swimmer crabs and western king prawns into the Harvey Estuary, and has influenced the size composition and/or growth rate of these crustaceans in the Peel-Harvey Estuary.

Objective 2. Determine the way in which greatly increased tidal action has changed the salinities in habitats within Peel Inlet and the Harvey Estuary and how this is now reflected in the composition of the crustacean and fish faunas of habitats within those regions.

The construction of the Dawesville Channel, between the ocean and the northern end of the Harvey Estuary, has resulted in the following. (i) There is now, for the first time, a direct connection between the sea and Harvey Estuary, whereas previously the intrusion of tidal water flow occurred through the Mandurah Entrance Channel, which is located many kilometres further away at the north-western corner of Peel Inlet. This means that juvenile crabs, prawns and fish now have a far shorter distance to travel from the ocean into the main body of the Harvey Estuary. (ii) The tidal water flow now occurring in the Harvey Estuary is far greater than previously. This thus provides a far more effective means for transporting fauna into and out of this part of the system. (iii) The salinities in the Harvey Estuary now remain higher, *i.e.* > 20‰, for longer periods. Thus, the environment within the Harvey Estuary is far more conducive to the retention, for a more protracted period, of those marine components of the fauna which have a "preference" for moderate to high salinities. The above features account for the following. (i) The juveniles of the blue swimmer crab and western king prawn now start entering the Harvey Estuary at a smaller size, at an earlier time and over a more protracted period. (ii) These two crustacean species remain for a far longer period in the Harvey Estuary. (iii) The presence now of far greater numbers of blue swimmer crabs and western king prawns in the Harvey Estuary means that the overall abundance of both of these two species in the Peel-Harvey Estuary as a whole is now greater. (iv) Once female crabs become ovigerous, they emigrate from the estuary to the sea more rapidly than previously. (v) The number of species and overall abundance of fish in the Harvey Estuary is now greater. (vi) The recruitment of the juveniles of commercial fish species has declined. (vii) Since the ability to catch western king prawns commercially has declined, commercial fishers now target fish species such as King George and yellow fin whiting.

Greatly increased tidal action throughout the whole of the two basin regions of the Peel-Harvey Estuary accounts for the following. (i) Crabs and prawns now tend to leave the Peel-Harvey Estuary at a slightly smaller size. (ii) The species composition of fish within the different regions of the estuary is now influenced to a far greater extent by seasonal changes than by regional differences as was the case prior to the construction of the Dawesville Channel.

Objective 3. Determine whether the Dawesville Channel now provides a major route for the emigration of western king prawns and, if so, whether any such migration is drawing on prawns that would normally pass out through the original (Mandurah) entrance channel, within which the commercial fishery is based.

The appearance now of large numbers of small juvenile crabs and prawns in the northern region of the Harvey Estuary, at the same time as in the Mandurah Entrance Channel, provides strong circumstantial evidence that the Dawesville Channel is providing a major route for the entry of these small crustaceans into the Peel-Harvey Estuary. Although the increased abundance of prawns in the Harvey Estuary has resulted in an increase in the overall abundance of prawns within the whole of the Peel-Harvey Estuary, the catches obtained by commercial fishers have declined. This can be attributed to a smaller number of prawns now emigrating out through the Mandurah Entrance Channel, in which the commercial fishery is based.

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Appendix 1

Intellectual property

Not applicable

Appendix 2

Staff and Students

Principal Investigator	Ian Potter
Research Assistant	Simon de Lestang
Casual Research Assistant	David Fairclough
PhD Student	Glen Young

Table 1. Sampling regime employed in the Peel-Harvey Estuary in periods prior to and after the construction of the Dawesville Channel. N.B. The Dawesville Channel was opened in April 1994.

Pre-Dawesville Channel.

Method of capture	10.5m seine	102.5m seine	Otter trawl
Fauna targeted	prawns	crabs and fish	crabs and fish
Date of commencement	May 1985	April 1979	April 1979
Date of completion	June 1988	December 1981	July 1981
Frequency of sampling	4 weekly	6-8 weekly	6-8 weekly
Sampling time	Night	Day	Day
Number of regions and sites	7(23)	7(10)	6(8)
Location of regions	Mandurah Entrance Channel western Peel Inlet eastern Peel Inlet Serpentine River Murray River northern Harvey Estuary southern Harvey Estuary	Mandurah Entrance Channel western Peel Inlet eastern Peel Inlet Serpentine River Murray River northern Harvey Estuary southern Harvey Estuary	Mandurah Entrance Channel western Peel Inlet Serpentine River Murray River northern Harvey Estuary southern Harvey Estuary

Post- Dawesville Channel.

Method of capture	10.5m seine	102.5m seine	Otter trawl
Fauna targeted	crabs and prawns	crabs and fish	crabs
Date of commencement	March 1995	January 1996	June 1997
Date of completion	May 1997	October 1997	July 1998
Frequency of sampling	4 weekly	seasonally	6 weekly
Sampling time	night	day	day
Number of regions and sites	6 (18)	5 (15)	5 (15)
Location of regions	Mandurah Entrance Channel western Peel Inlet eastern Peel Inlet Serpentine River northern Harvey Estuary southern Harvey Estuary	Mandurah Entrance Channel western Peel Inlet eastern Peel Inlet northern Harvey Estuary southern Harvey Estuary	Mandurah Entrance Channel Peel Inlet northern Harvey Estuary southern Harvey Estuary

Table 2. Life cycle category (S = marine straggler, 0 = marine estuarine-opportunist, E/M = estuarine & marine, E = estuarine, A = anadromous), numerical ranking (R), numbers (N) and percentage contribution by number (%) to the total catch of each fish species in the shallow waters of the Peel-Harvey Estuary prior to and after the construction of the Dawesville Channel. The data were obtained using comparable seine nets at the same sampling sites over two years and after standardising the catch in each sample to a standard area of 1000m^2 and the number of samples to 100. See Methods for further details.

Species	Life cycle	Pre-Dawesville Channel R	N	%	Post-Dawesville Channel R	N	%
Pelates sexlineatus	O	1	13919	36.6	10	125	1.0
Apogon rueppelli	E/M	2	5433	14.3	7	431	3.3
Gerres subfasciatus	O	3	3344	8.8	6	529	4.1
Hyperlophus vittatus	O	4	2597	6.8	2	2181	16.9
Favonigobius lateralis	E/M	5	2203	5.8	8	320	2.5
Torquigener pleurogramma	O	6	2164	5.7	1	5402	41.8
Aldrichetta forsteri	O	7	1907	5.0	5	540	4.2
Atherinomorus ogilbyi	O	8	1196	3.1	15	68	0.5
Sillago bassensis	S	9	936	2.5	14	72	0.6
Atherinosoma elongata	E	10	843	2.2	4	1205	9.3
Leptatherina presbyteroides	E/M	11	821	2.2	3	1218	9.4
Sillago schomburgkii	O	12	449	1.2	18	44	0.3
Gymnapistes marmoratus	O	13	346	0.9	12	112	0.9
Mugil cephalus	O	14	290	0.8	23	13	0.1
Pseudogobius olorum	E	15	246	0.6	20	26	0.2
Amniataba caudavittata	E	16	183	0.5	32	3	<0.1
Leptatherina wallacei	E	17	123	0.3	28	8	0.1
Amoya bifrenatus	E/M	18	117	0.3	26	10	0.1
Hypohamphus regularis	E	19	110	0.3	27	9	0.1
Sillaginodes punctata	O	20	107	0.3	16	58	0.4
Pseudorhombus jenynsii	O	21	106	0.3	17	55	0.4
Allanetta mugiloides	E	22	101	0.3	29	7	0.1
Haletta semifasciata	S	23	91	0.2	31	3	<0.1
Hyporhamphus melanochir	E/M	24	86	0.2	21	18	0.2
Contusus brevicaudus	O	25	67	0.2	23	13	0.1
Rhabdosargus sarba	O	26	54	0.1	9	151	1.2
Pomatomus saltatrix	O	27	53	0.1	19	31	0.2
Afurcagobius suppositus	E	28	41	0.1	38	1	<0.1
Cnidoglanis macrocephalus	E/M	29	24	0.1	35	2	<0.1
Engraulis australis	E/M	30	14	<0.1	11	118	0.9
Callogobius depressus	O	30	14	<0.1	32	3	<0.1
Ammotretis elongata	S	32	10	<0.1	22	17	0.1
Sardinops neopilchardus	S	32	10	<0.1			
Sillago burrus	O	34	9	<0.1	13	84	0.7
Nematalosa vlaminghi	A	35	7	<0.1	35	2	<0.1
Scobinichthys granulatus	S	36	1	<0.1	32	3	<0.1
Brachaluteres jacksonianus	S	36	1	<0.1	38	1	<0.1
Urocampus carinirostris	E	36	1	<0.1	38	1	<0.1
Arripis truttaceus	O	36	1	<0.1			
Arripis georgianus	O				23	13	0.1
Sillago vittata	S				29	7	0.1
Spratelloides robustus	S				35	2	<0.1
Enoplosus armaratus	S				38	1	<0.1
Heterodontus portjacksoni	S				38	1	<0.1
Meuschenia freycineti	S				38	1	<0.1
Platycephalus speculator	E/M				38	1	<0.1
Pseudocaranx dentex	S				38	1	<0.1
Siphamia cephalotes	E/M				38	1	<0.1
Upenichthyes tragula	S				38	1	<0.1
Total number of species			39			47	
Total number of fish			38027			12908	

Table 3. Life cycle category (S = marine straggler, 0 = marine estuarine-opportunist, E/M = estuarine & marine, E = estuarine, A = anadromous), numerical ranking (R), numbers (N) and percentage contribution by number (%) to the total catch of each fish species in the shallow waters of the Harvey Estuary prior to and after the construction of the Dawesville Channel. The data were obtained using comparable seine nets at the same sampling sites over two years and after standardising the catch in each sample to a standard area of 1000m^2 and the number of samples to 50. See Methods for further details.

		Summer 1980-Spring 1981 Pre-Dawesville Channel			Summer 1996-Spring 1997 Post-Dawesville Channel		
Species	**Life cycle**	**R**	**N**	**%**	**R**	**N**	**%**
Apogon rueppelli	E/M	1	1705	43.7	12	27	0.5
Leptatherina presbyteroides	E/M	2	688	17.6	2	563	11.3
Atherinomorus ogilbyi	O	3	463	11.8	13	23	0.5
Atherinosoma elongata	E	4	179	4.6	4	199	4.0
Aldrichetta forsteri	O	5	129	3.3	15	15	0.3
Gerres subfasciatus	O	6	125	3.2	3	403	8.1
Hyperlophus vittatus	O	7	123	3.2	14	21	0.4
Hypohamphus regularis	E	8	96	2.5	20	7	0.1
Gymnapistes marmoratus	O	9	95	2.4	7	49	1.0
Pelates sexlineatus	O	10	88	2.2	12	30	0.6
Sillago schomburgkii	O	11	86	2.2	27	1	<0.1
Pseudorhombus jenynsii	O	12	18	0.5	8	41	0.8
Mugil cephalus	O	12	18	0.5	17	11	0.2
Contusus brevicaudus	O	14	14	0.4	21	5	0.1
Favonigobius lateralis	E/M	15	9	0.2	5	131	2.6
Sillaginodes punctata	O	15	9	0.2	9	36	0.7
Ammotretis elongata	S	15	9	0.2	17	11	0.2
Haletta semifasciata	S	15	9	0.2	27	1	<0.1
Torquigener pleurogramma	O	19	7	0.2	1	3209	64.5
Sillago burrus	O	19	7	0.2	15	15	0.3
Cnidoglanis macrocephalus	E/M	19	7	0.2			
Callogobius depressus	O	19	7	0.2			
Hyporhamphus melanochir	E/M	23	5	0.1	19	10	0.2
Pseudogobius olorum	E	23	5	0.1			
Rhabdosargus sarba	O	25	2	<0.1	6	106	2.1
Leptatherina wallacei	E	25	2	<0.1	23	4	0.1
Engraulis australis	E/M	25	2	<0.1	27	1	<0.1
Pomatomus saltatrix	O				10	34	0.7
Amoya bifrenatus	E/M				21	5	0.1
Allanetta mugiloides	E				23	4	0.1
Scobinichthys granulatus	S				25	2	<0.1
Sillago vittata	S				25	2	<0.1
Arripis georgianus	O				27	1	<0.1
Brachaluteres jacksonianus	S				27	1	<0.1
Enoplosus armaratus	S				27	1	<0.1
Nematalosa vlaminghi	A				27	1	<0.1
Platycephalus speculator	E/M				27	1	<0.1
Total number of species			27			34	
Total number of fish			3905			4974	

Figures

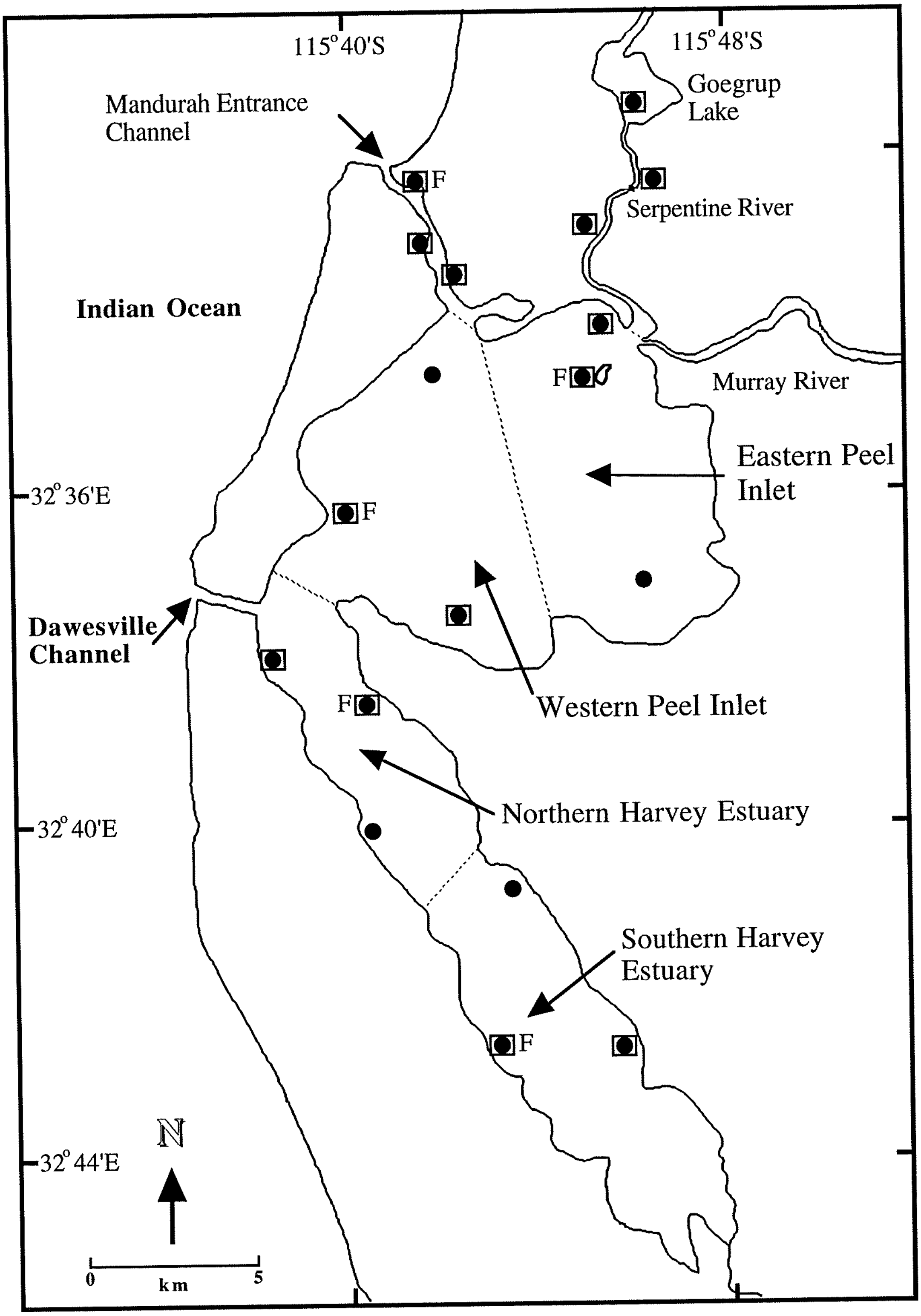


Figure 1. Location of seine net sampling sites for crustaceans and fish in the Peel-Harvey Estuary. Filled circles (●) represent sites sampled between March 1995 and July 1998, i.e. after the construction of the Dawesville Channel. The enclosure of the filled circles in a square (■) indicates that the site was also sampled for crabs and prawns in periods between April 1979 and June 1988, i.e. prior to the construction of the Dawesville Channel, while F refers to those sites that were also sampled for fish in that earlier period.

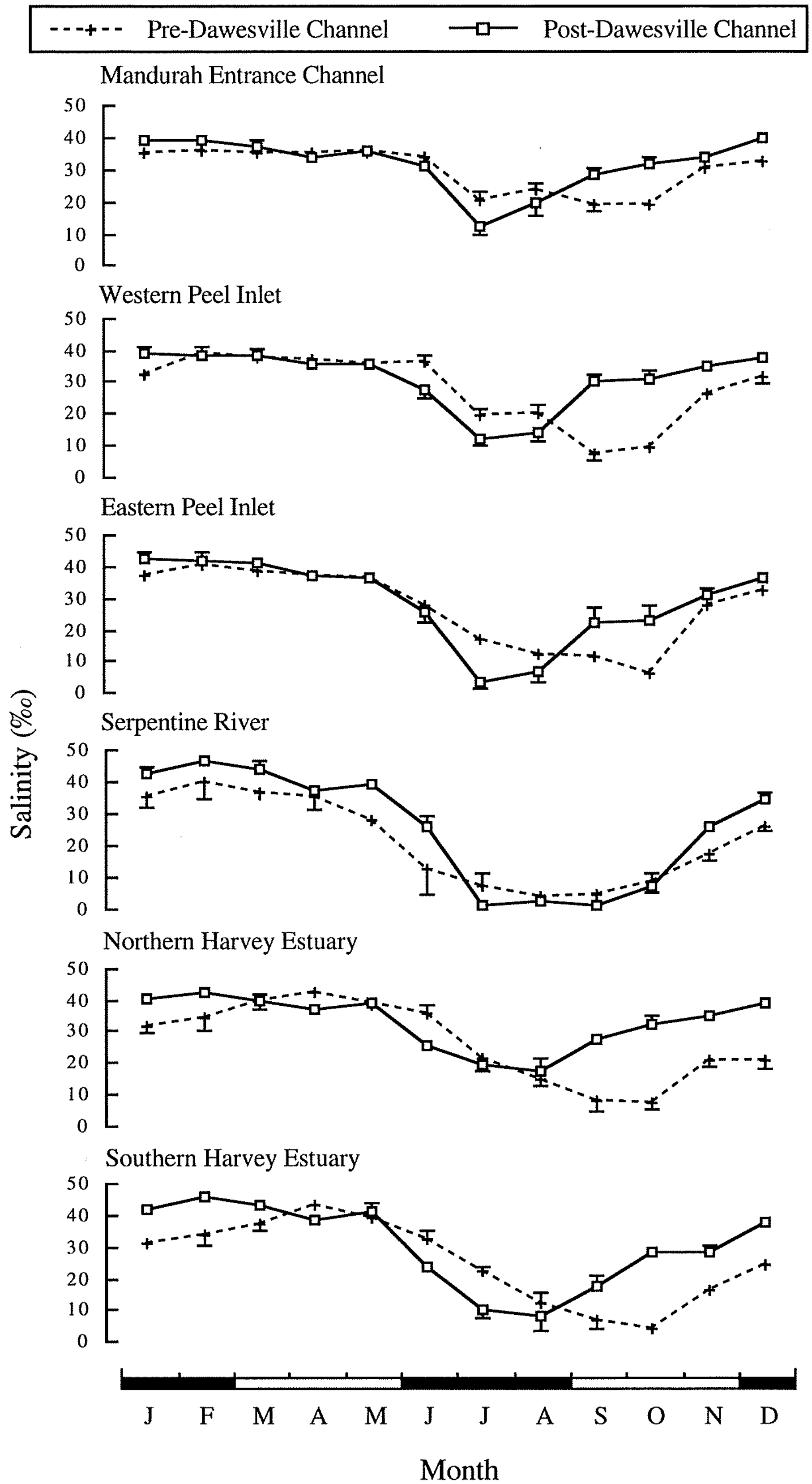


Figure 2. Mean salinities + or - 1 S.E. in six regions of the Peel-Harvey Estuary, using data recorded at the time of seine netting in shallow waters prior to (January 1980 to November 1981 and May 1985 to June 1988) and after the construction of the Dawesville Channel (March 1995 to July 1998). Data for the corresponding months in each year have been pooled. In this and subsequent figures, the black rectangles on the X axis refer to summer and winter months and the open rectangles to autumn and spring months.

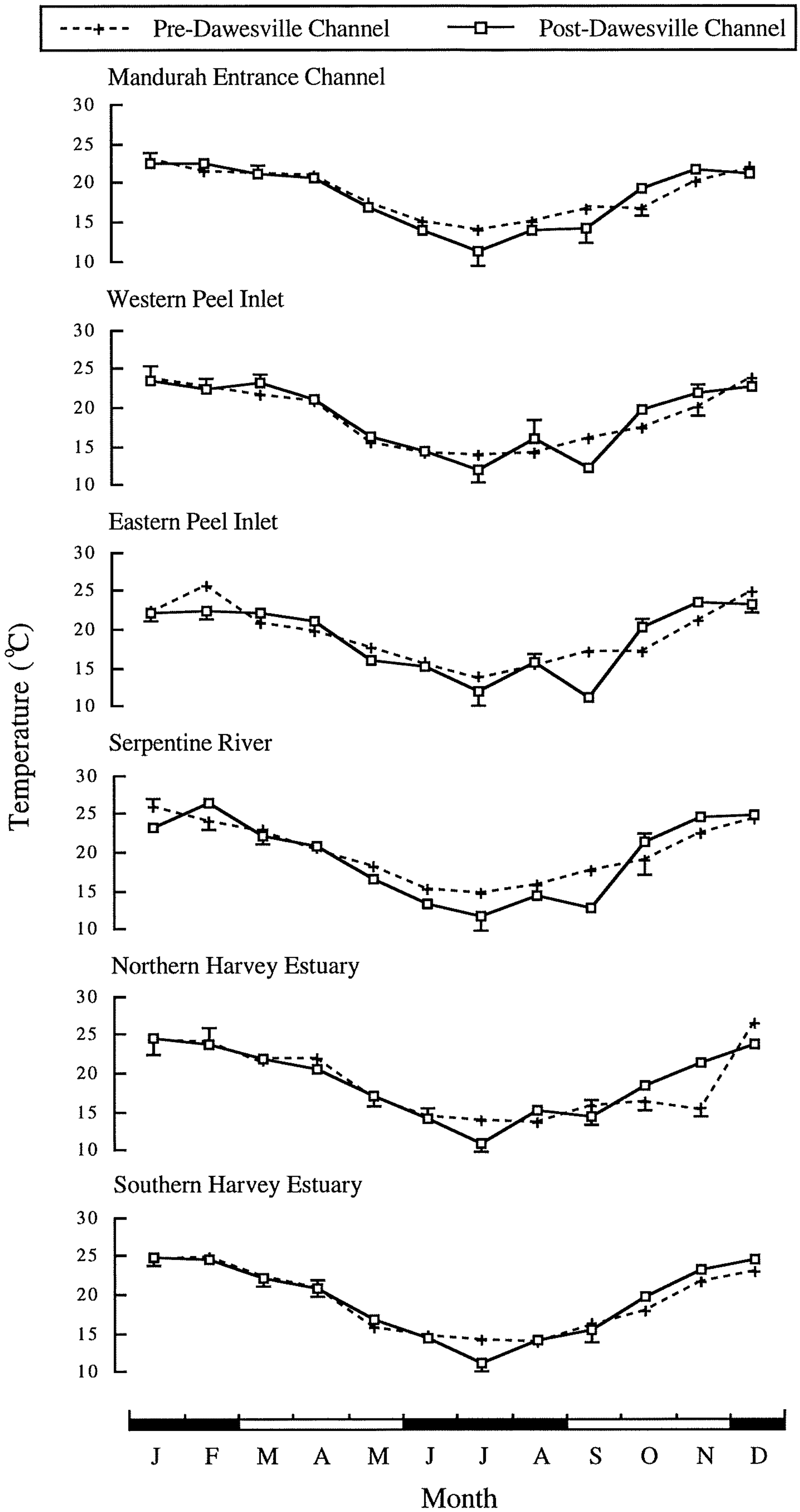


Figure 3. Mean water temperatures + or - 1 S.E. in six regions of the Peel-Harvey Estuary, using data recorded at the time of seine netting in shallow waters prior to (January 1980 to November 1981 and May 1985 to June 1988) and after the construction of the Dawesville Channel (March 1995 to July 1998). Data for the corresponding months in each year have been pooled.

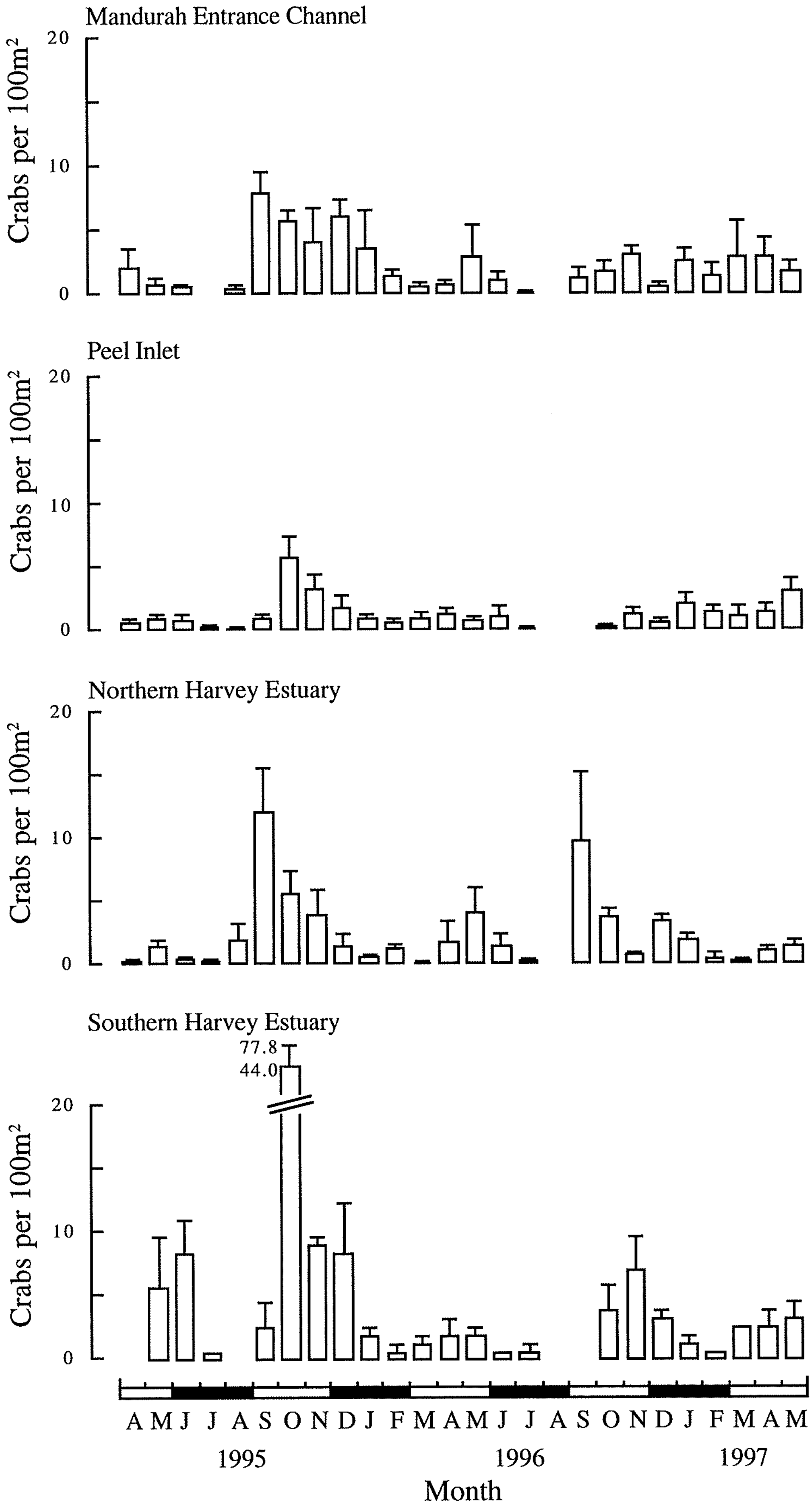


Figure 4. Mean + 1 SE for densities of *Portunus pelagicus* in the Peel-Harvey Estuary, using data derived from samples collected by seine netting in shallow waters between April 1995 and May 1997.

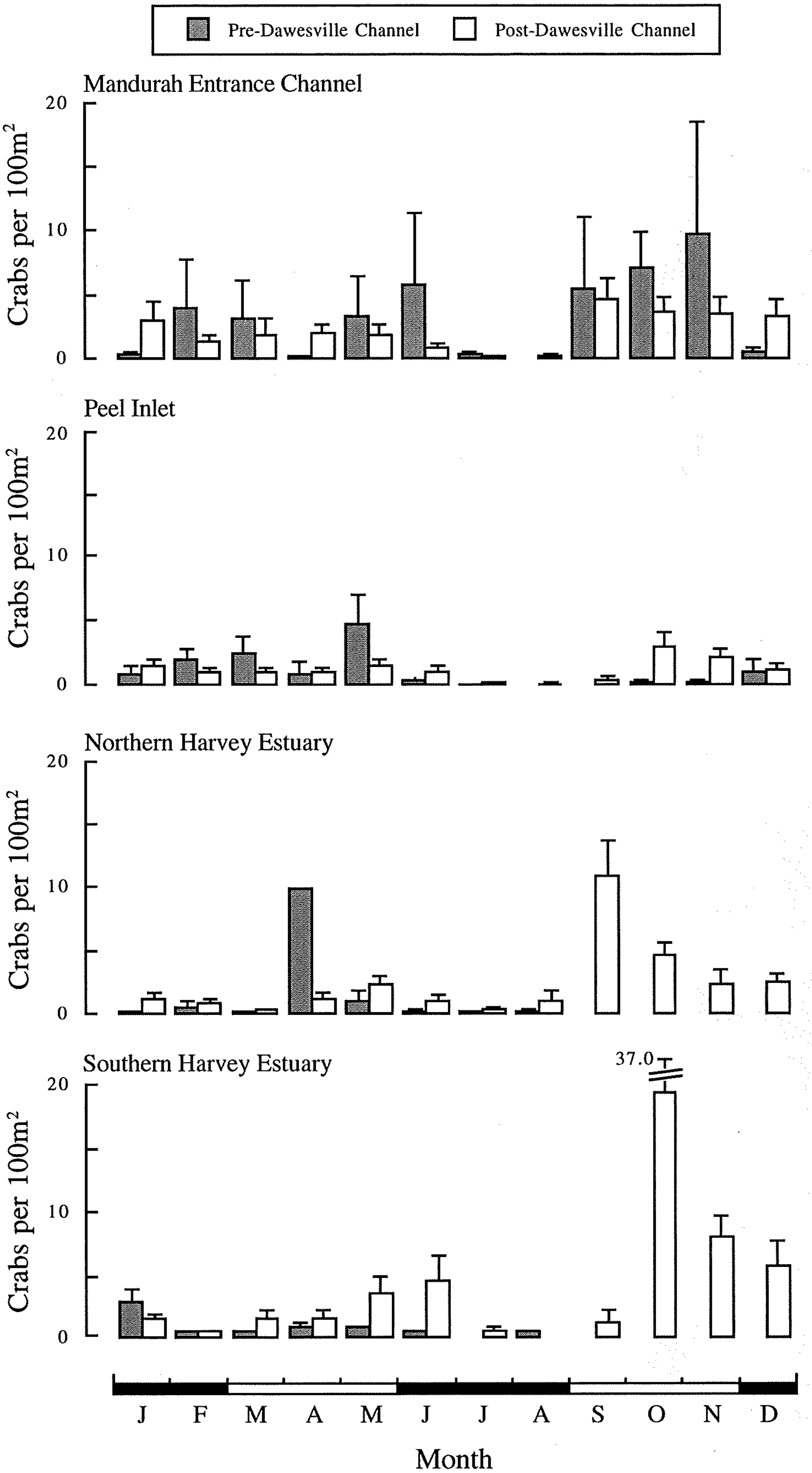


Figure 5. Mean + 1 SE for densities of *Portunus pelagicus* in the Peel-Harvey Estuary, using data derived from samples collected by seine netting in the shallow waters prior to (July 1979 to June 1983) and after the construction of the Dawesville Channel (April 1995 to May 1997). Data for the corresponding months of the year in each of the two periods have been pooled.

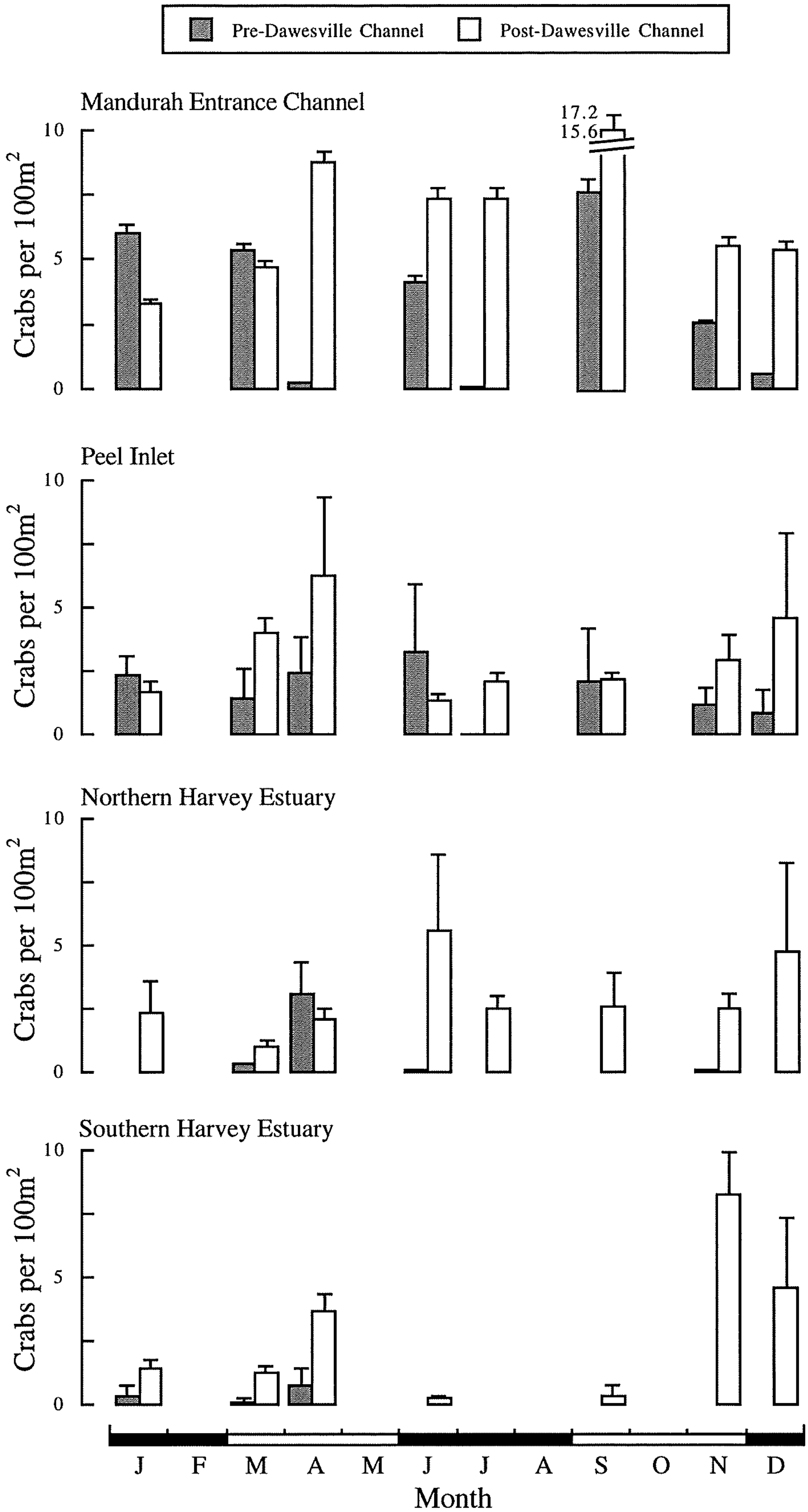
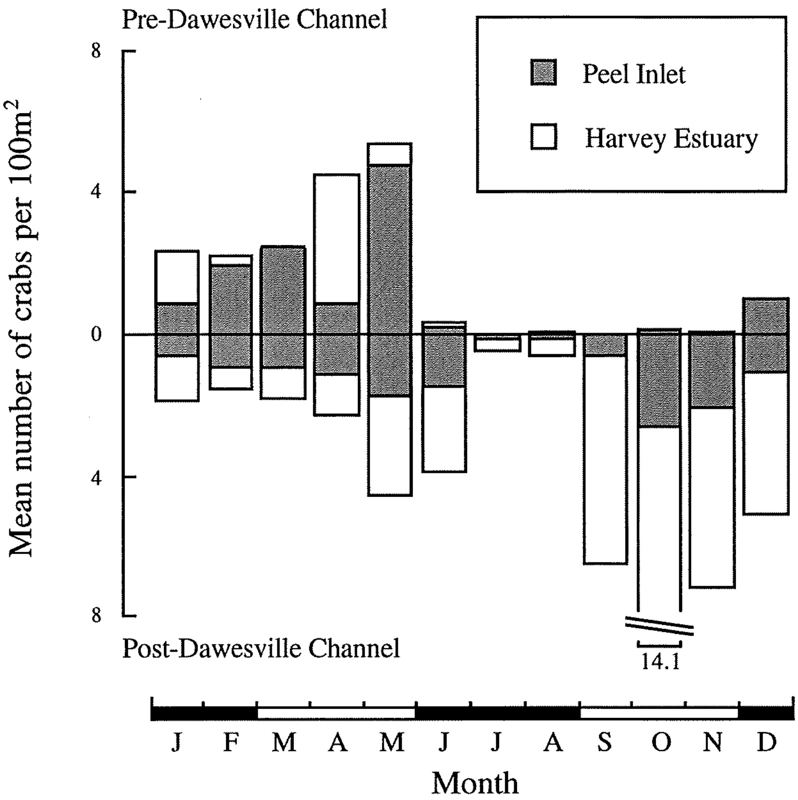


Figure 6. Mean +1 SE for densities of *Portunus pelagicus* in the Peel-Harvey Estuary, using data derived from samples collected at six-weekly intervals by otter trawling in the deeper, offshore waters prior to (July 1979 to June 1983) and after the construction of the Dawesville Channel (June 1997 and July 1998). Data for the corresponding months of the year in each of the two periods have been pooled.



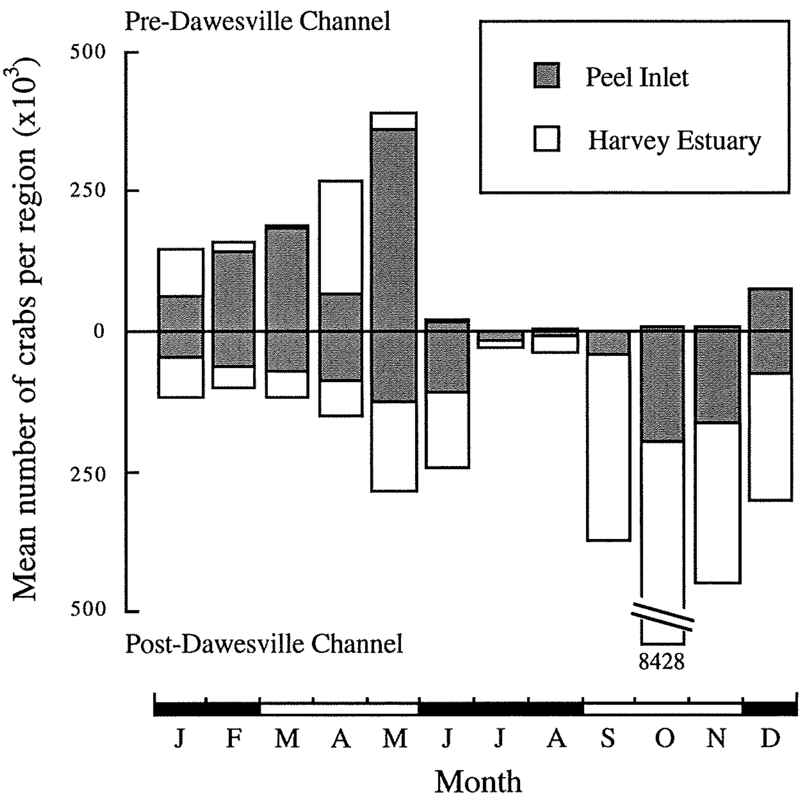


Figure 7. Mean density of crabs per 100 m^2 for *Portunus pelagicus* in the Peel Inlet and Harvey Estuary, using data derived from samples collected by seine netting in the shallow waters prior to (July 1979 to June 1983) and after the construction of the Dawesville Channel (April 1995 and May 1997). Data for the corresponding months of the year in each of the two periods have been pooled.

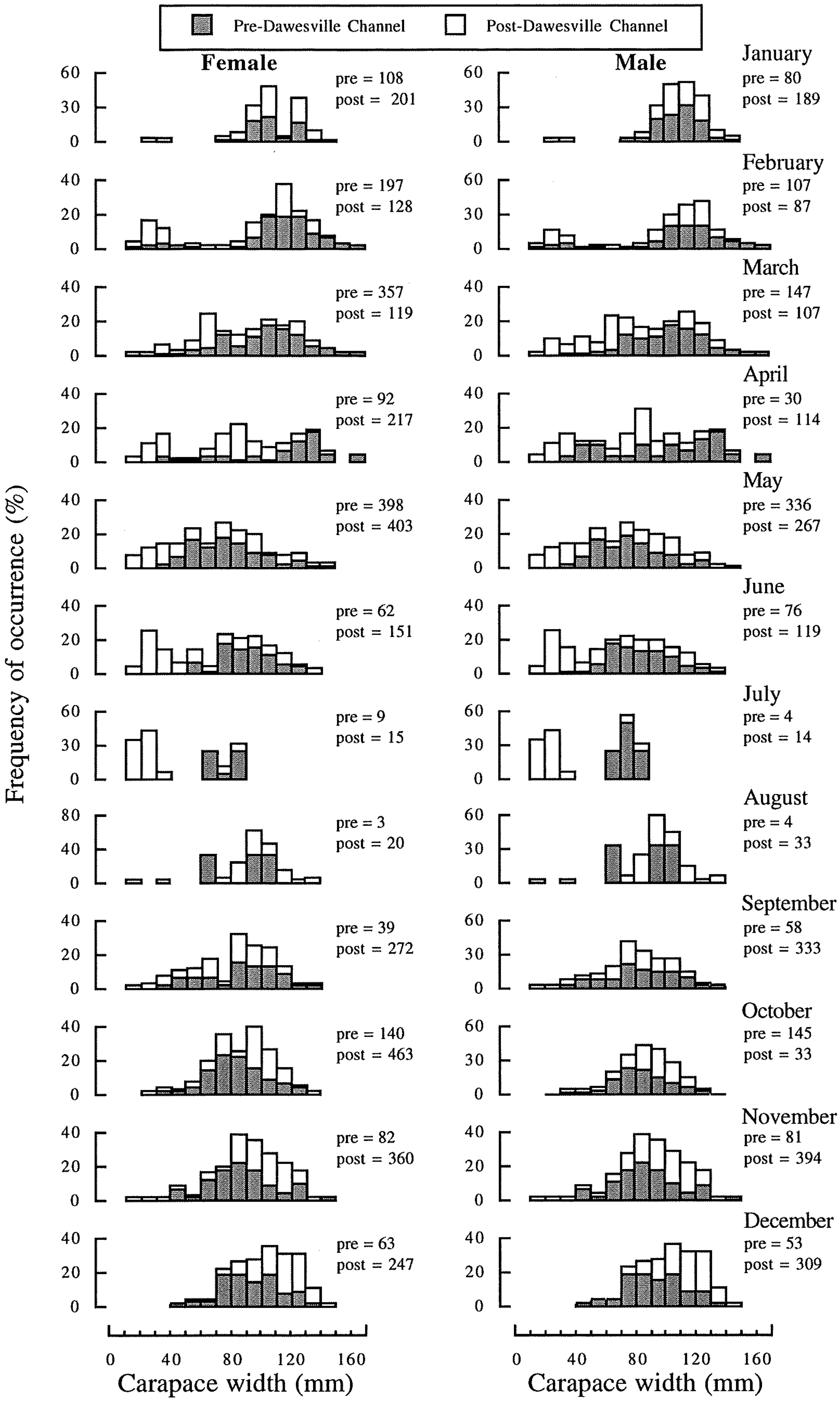


Figure 8. Carapace-width frequency histograms for female and male *Portunus pelagicus* in the Peel-Harvey Estuary, using data derived from samples collected by seine netting in the shallow waters prior to (July 1979 to June 1983) and after the construction of the Dawesville Channel (April 1995 to May 1997). Data for the corresponding months of the year in each period have been pooled.

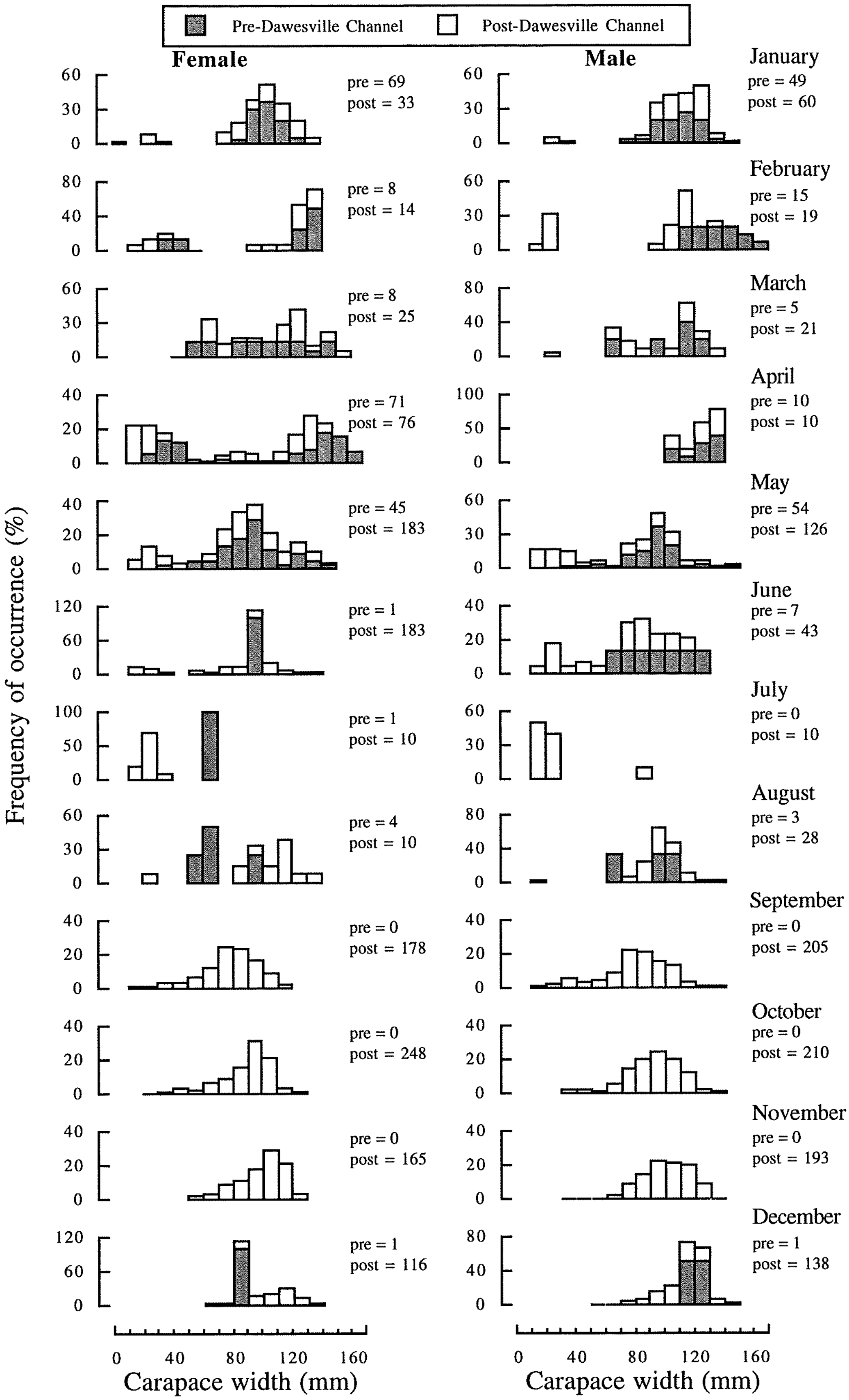


Figure 9. Carapace-width frequency histograms for female and male *Portunus pelagicus* caught in the Harvey Estuary, using data derived from samples collected by seine netting in the shallow waters prior to (July 1979 to June 1983) and after the construction of the Dawesville Channel (April 1995 to May 1997). Data for the corresponding months in each period of the year have been pooled.

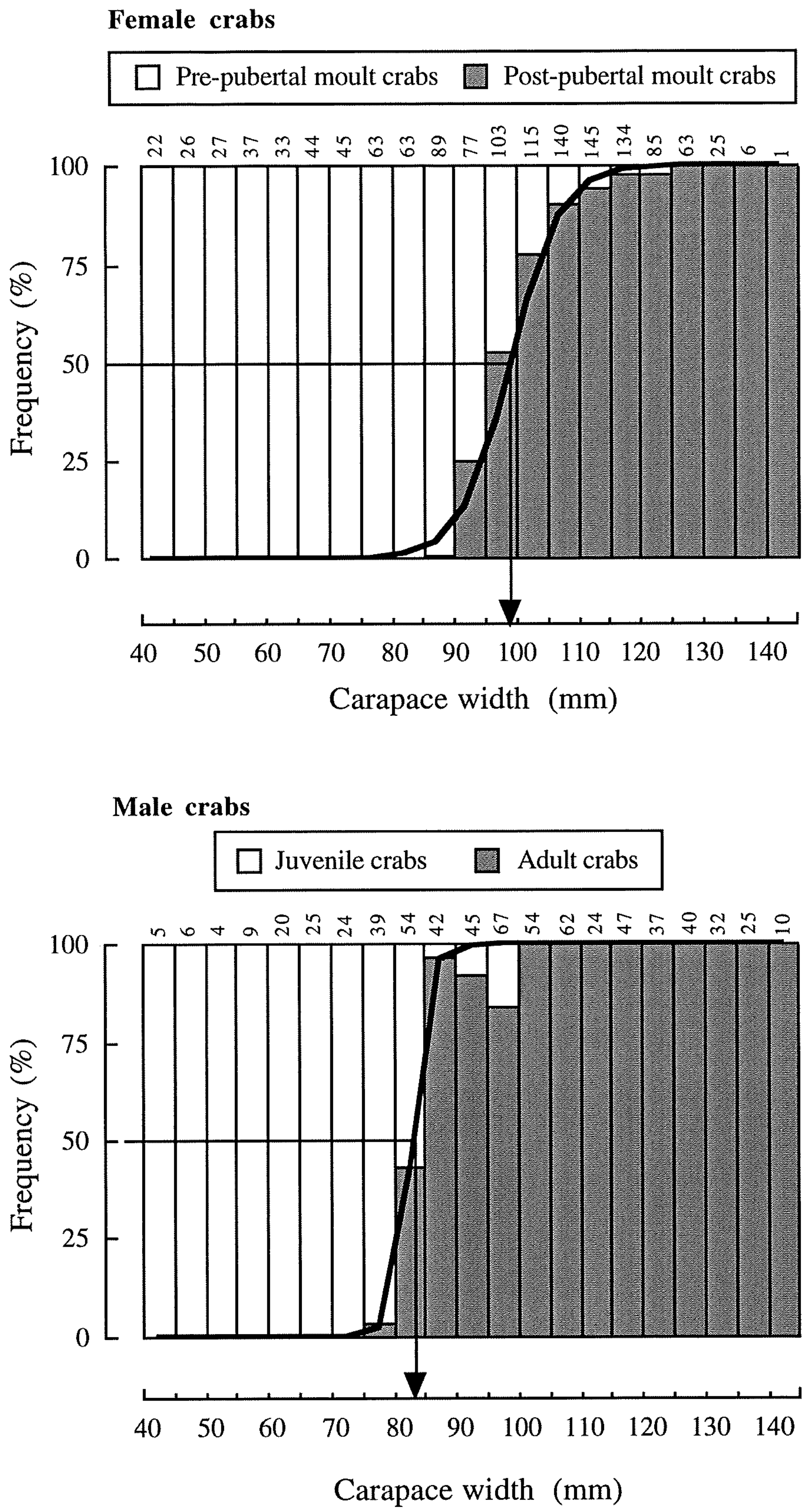


Figure 10. The logistic curve was fitted to the percentage contributions of female and male *Portunus pelagicus* that were "adult" to determine the CW_{50} at first maturity. Numbers indicate total numbers of crabs in each size interval.

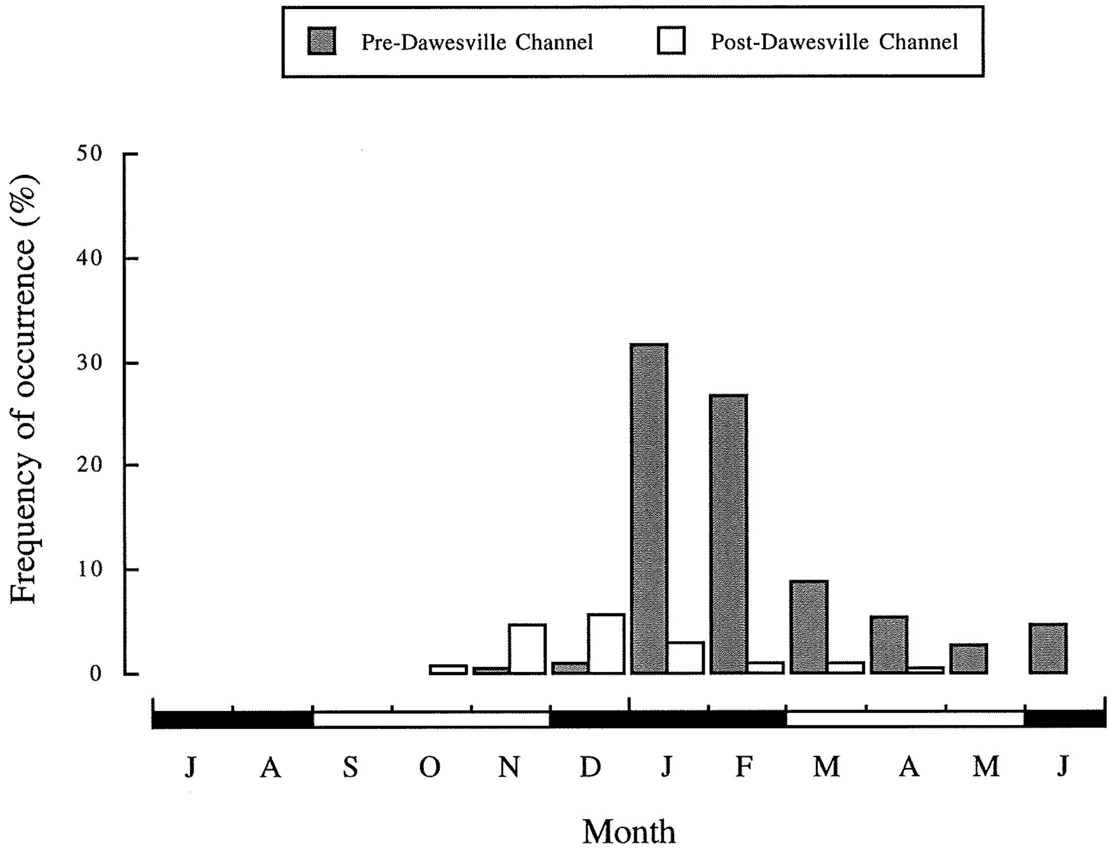


Figure 11. Monthly values for the percentages of ovigerous females of *Portunus pelagicus* amongst all female crabs that had undergone a pubertal moult in the Peel-Harvey Estuary prior to (February 1980 to May 1981) and after the construction of the Dawesville Channel (May 1995 to July 1997). Data from the corresponding months of the year in each period have been pooled.

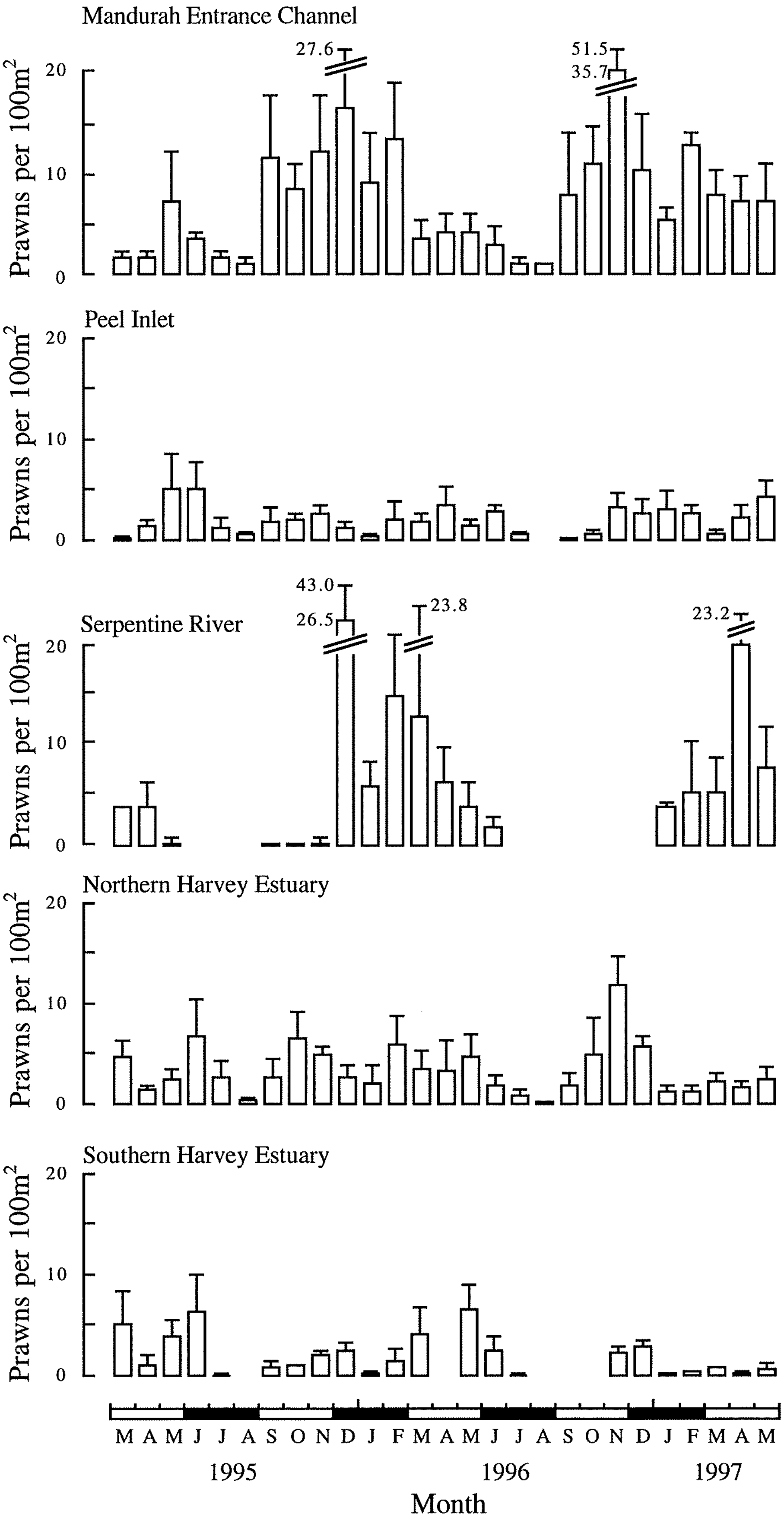


Figure 12. Mean + 1 SE for densities of *Penaeus latisulcatus* in the Peel-Harvey Estuary, using data derived from samples collected by seine netting in shallow waters between March 1995 and May 1997.

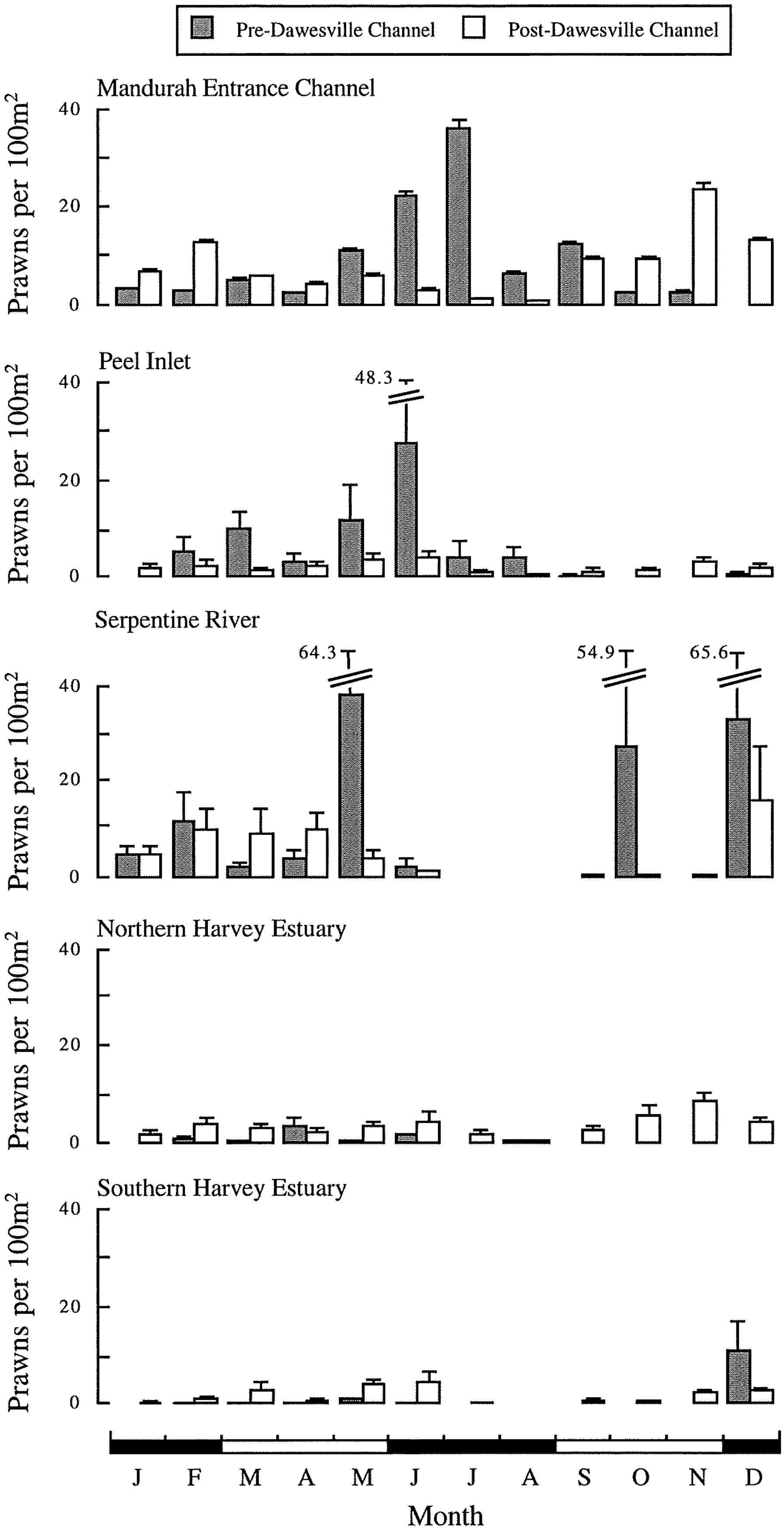
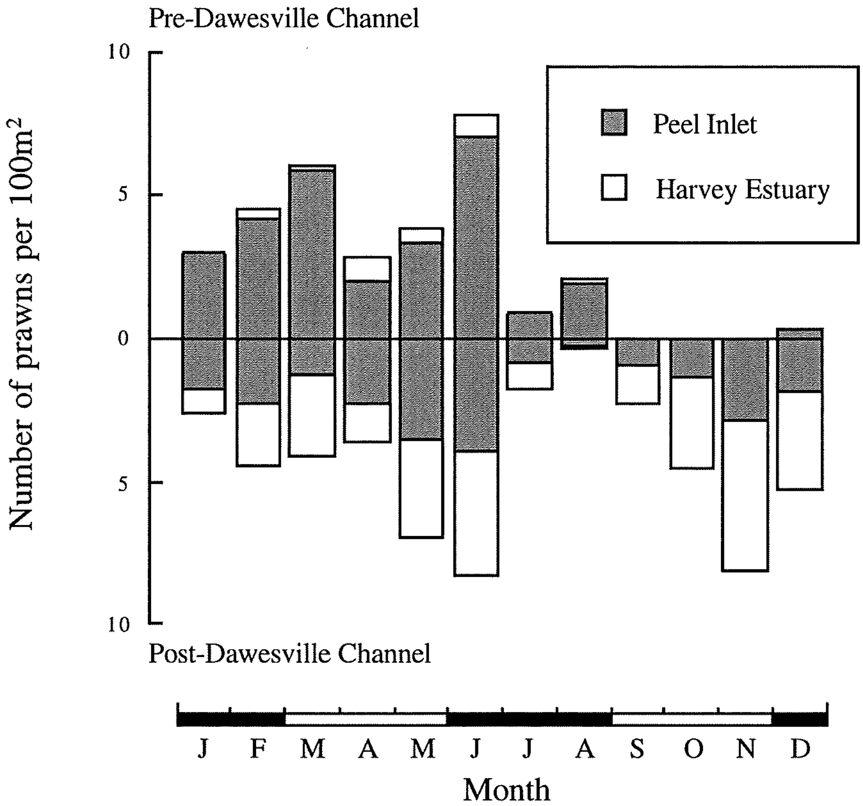


Figure 13. Mean + 1 SE for densities of *Penaeus latisulcatus* in the Peel-Harvey Estuary, using data derived from samples collected by seine netting in shallow waters prior to (May 1985 to June 1988) and after the construction of the Dawesville Channel (March 1995 to May 1997). Data from the corresponding months of the year in each period have been pooled.



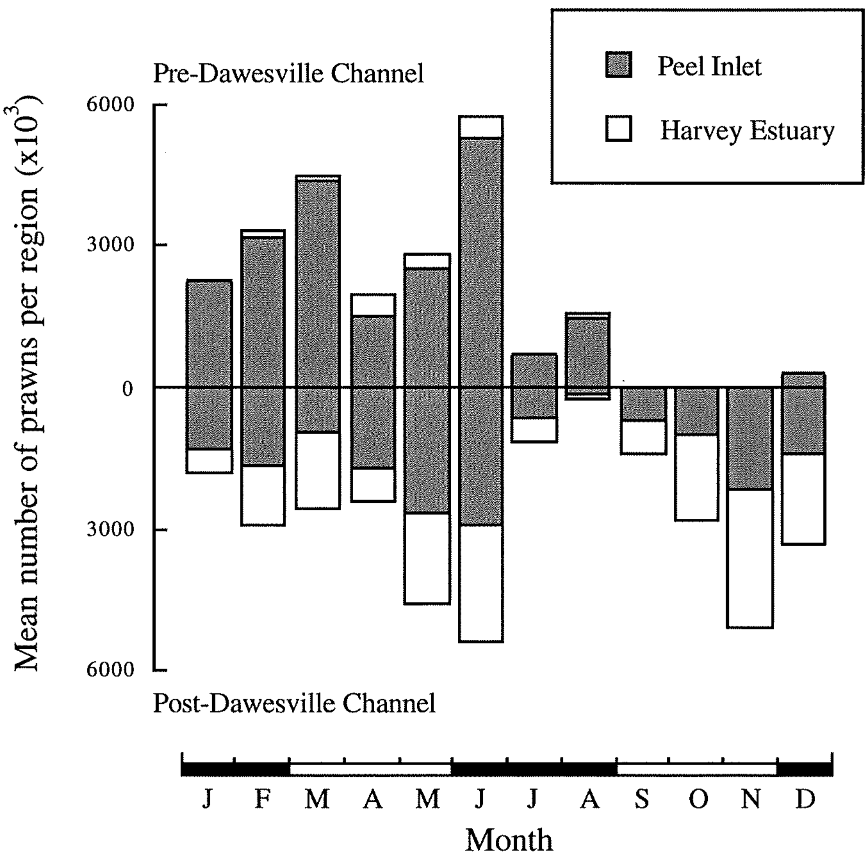


Figure 14. Mean number of *Penaeus latisulcatus* per 100 m^2in the Peel Inlet and the Harvey Estuary, using data derived from samples collected by seine netting in the shallow waters prior to (May 1985 to June 1988) and after the construction of the Dawesville Channel (March 1995 and May 1997). Data for corresponding months in each of the two years have been pooled.

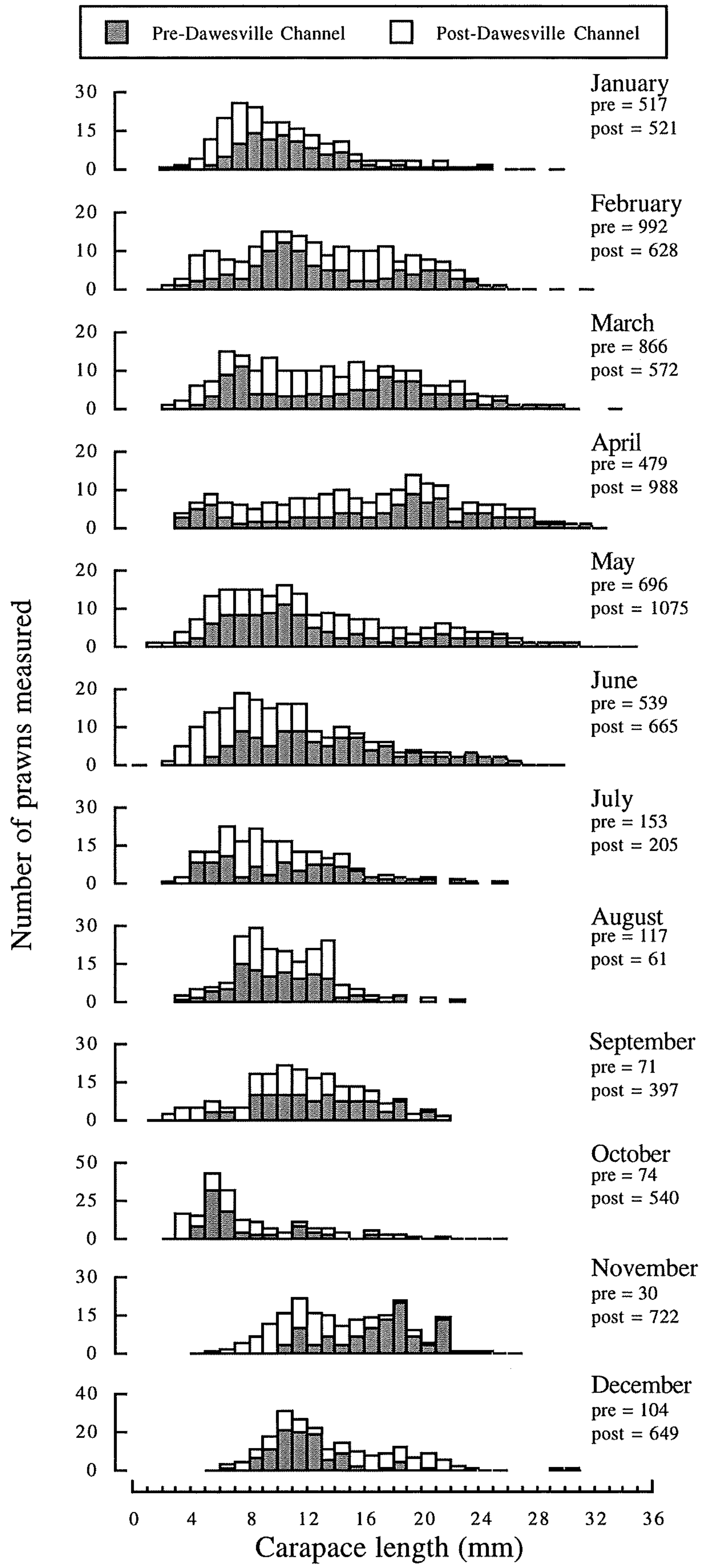


Figure 15. Carapace-length frequency histograms of *Penaeus latisulcatus* in the Peel-Harvey Estuary, using data derived from samples collected by seine netting in shallow waters prior to (May 1985 to June 1988) and after the construction of the Dawesville Channel (March 1995 to May 1997). Data from the corresponding months of the year in each period have been pooled.

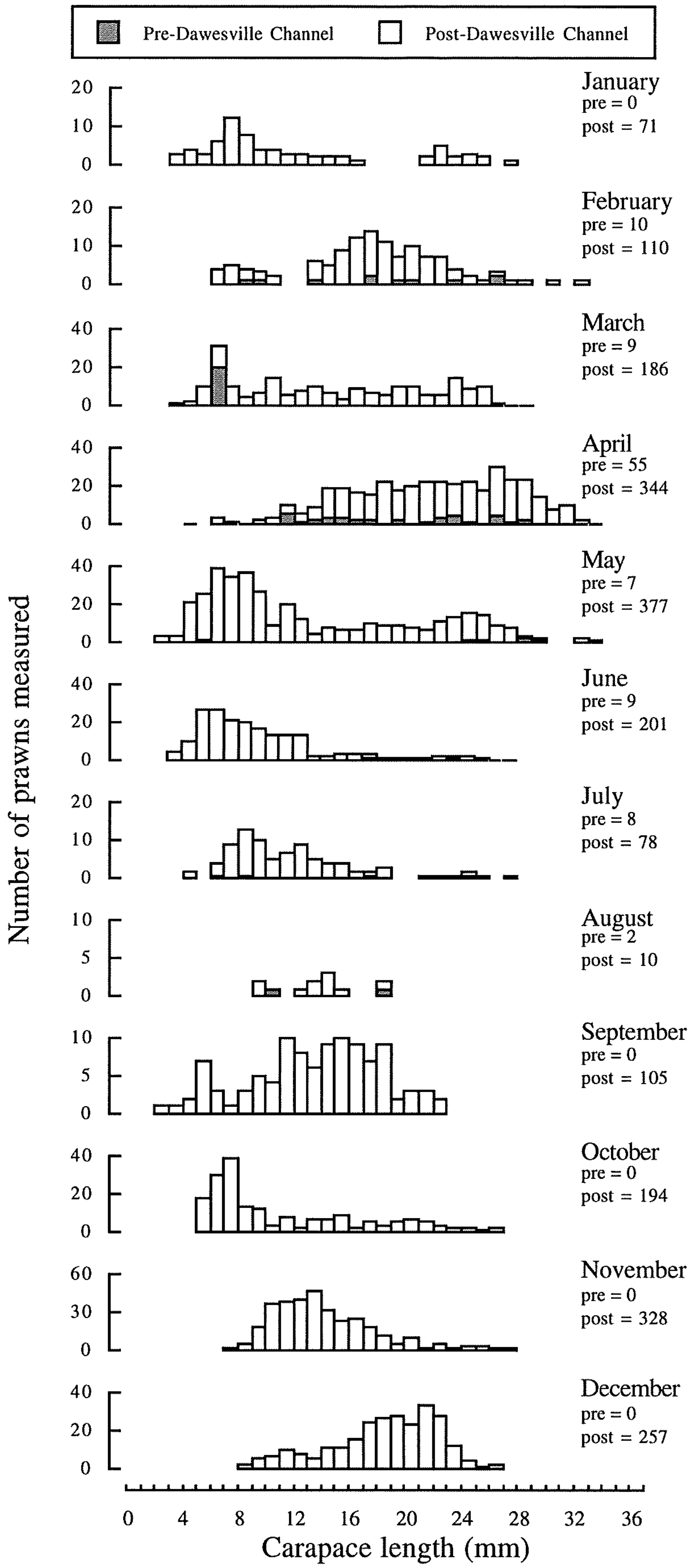


Figure 16. Carapace-length frequency histograms of *Penaeus latisulcatus* in the Harvey Estuary, using data derived from samples collected by seine netting in shallow waters prior to (May 1985 to June 1988) and after the construction of the Dawesville Channel (March 1995 to May 1997). Data from the corresponding months of the year in each period have been pooled.

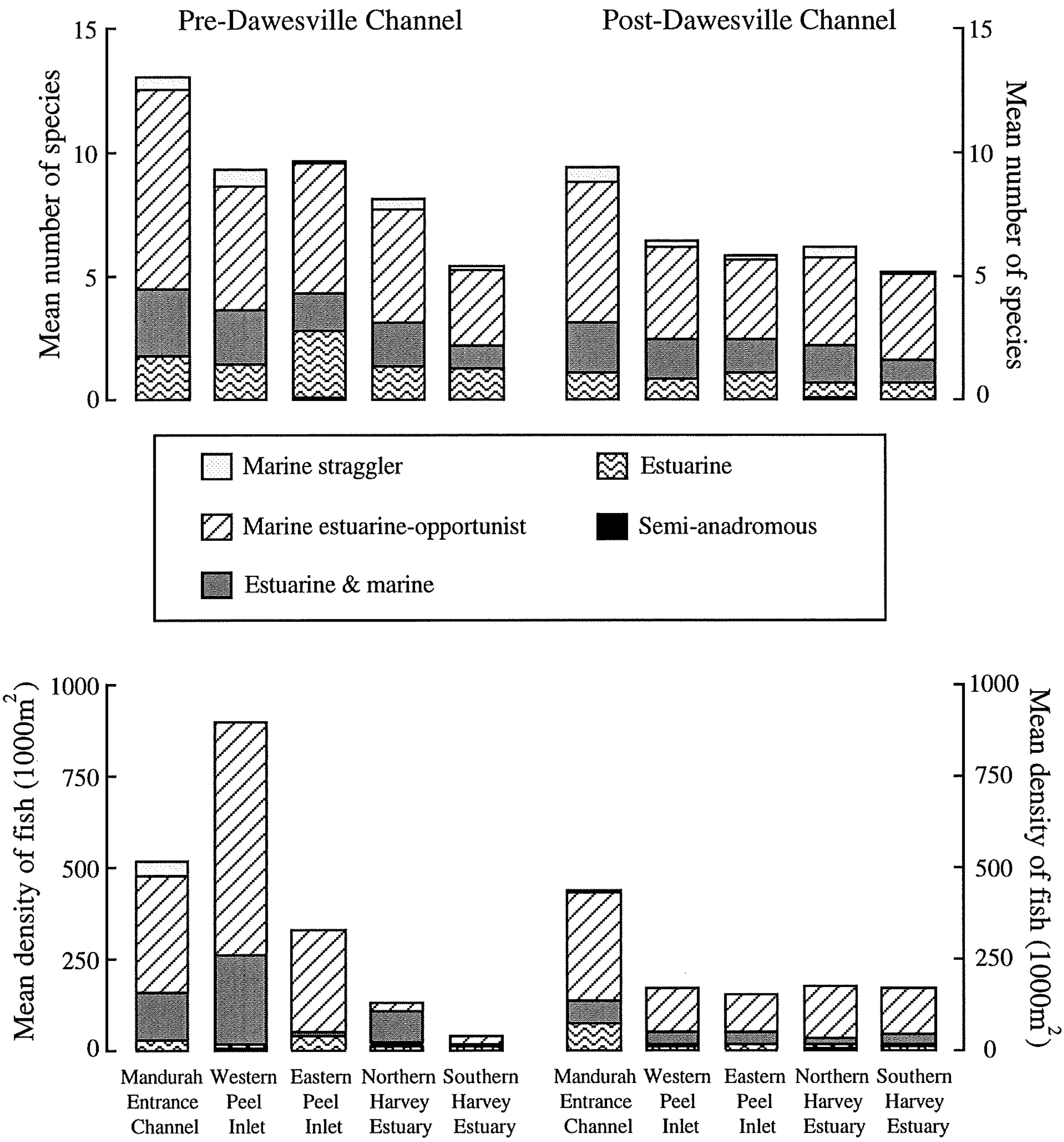


Figure 17. Mean number of species and mean density of fish according to the different life-cycle categories in the Peel-Harvey Estuary, using data derived from samples collected by seine netting in shallow waters prior to (January 1980 to November 1981) and after the construction of the Dawesville Channel (January 1996 to October 1997).

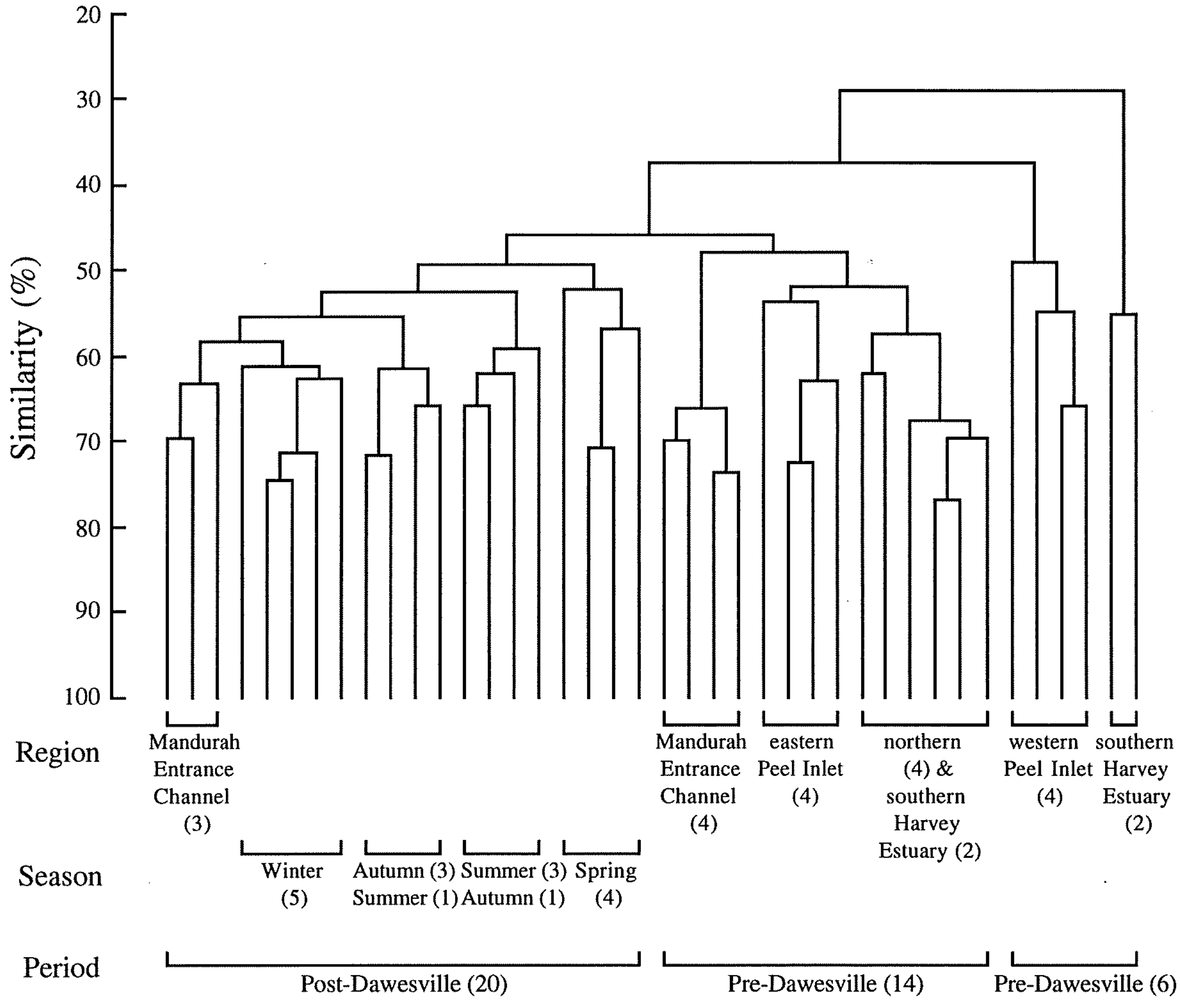


Figure 18. Classification of mean densites recorded for each fish species in the shallow waters of the Peel-Harvey Estuary prior to (January 1980 to November 1981) and after the construction of the Dawesville Channel (January 1996 to October 1997).

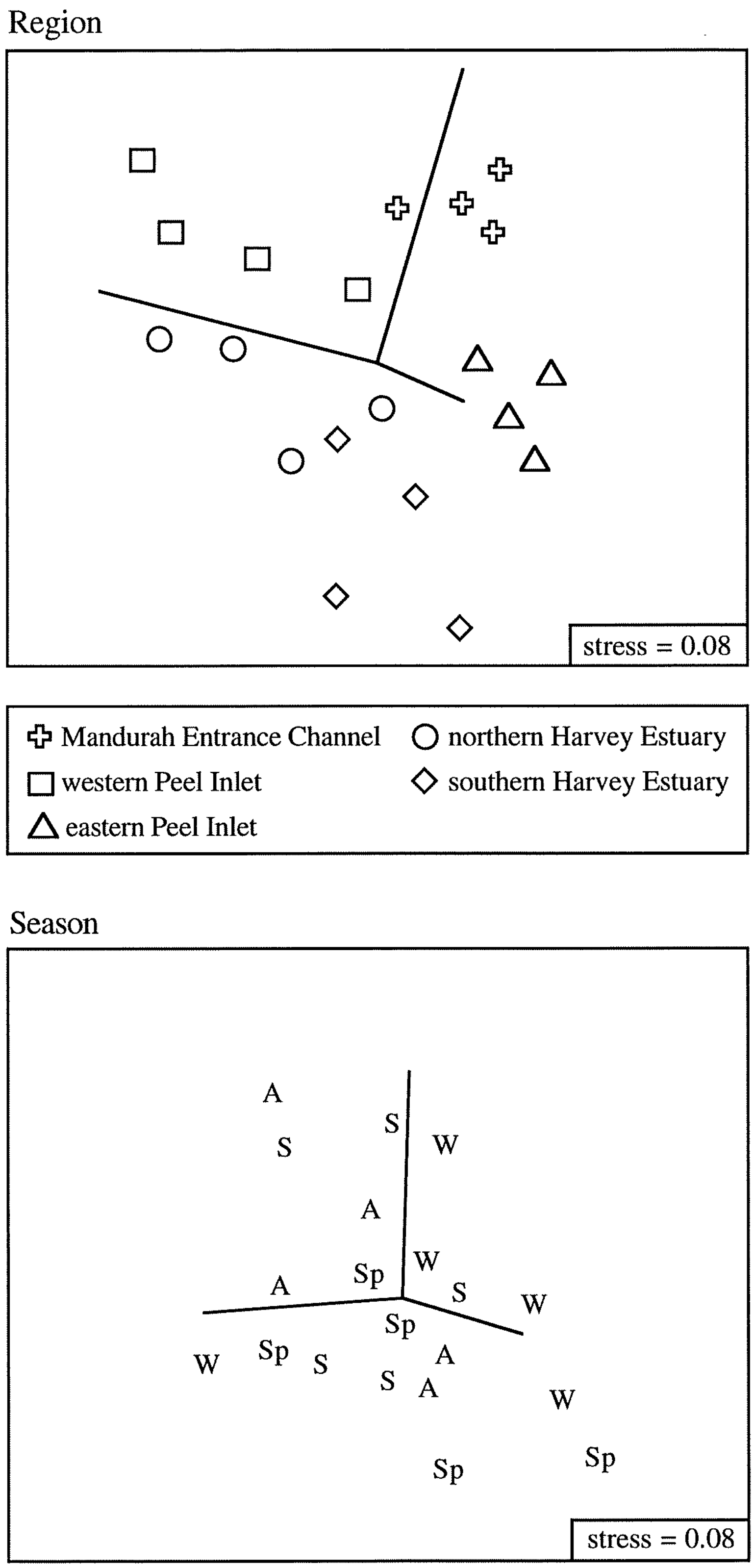


Figure 19. Three dimensional MDS ordination of mean densities recorded for each fish species in the Peel-Harvey Estuary, using data derived from samples collected by seine netting in the shallow waters prior to the construction of the Dawesville Channel (January 1980 to November 1981), shown by region and season. In this and Figure 20, S = Summer; A = Autumn; W = Winter, Sp = Spring.

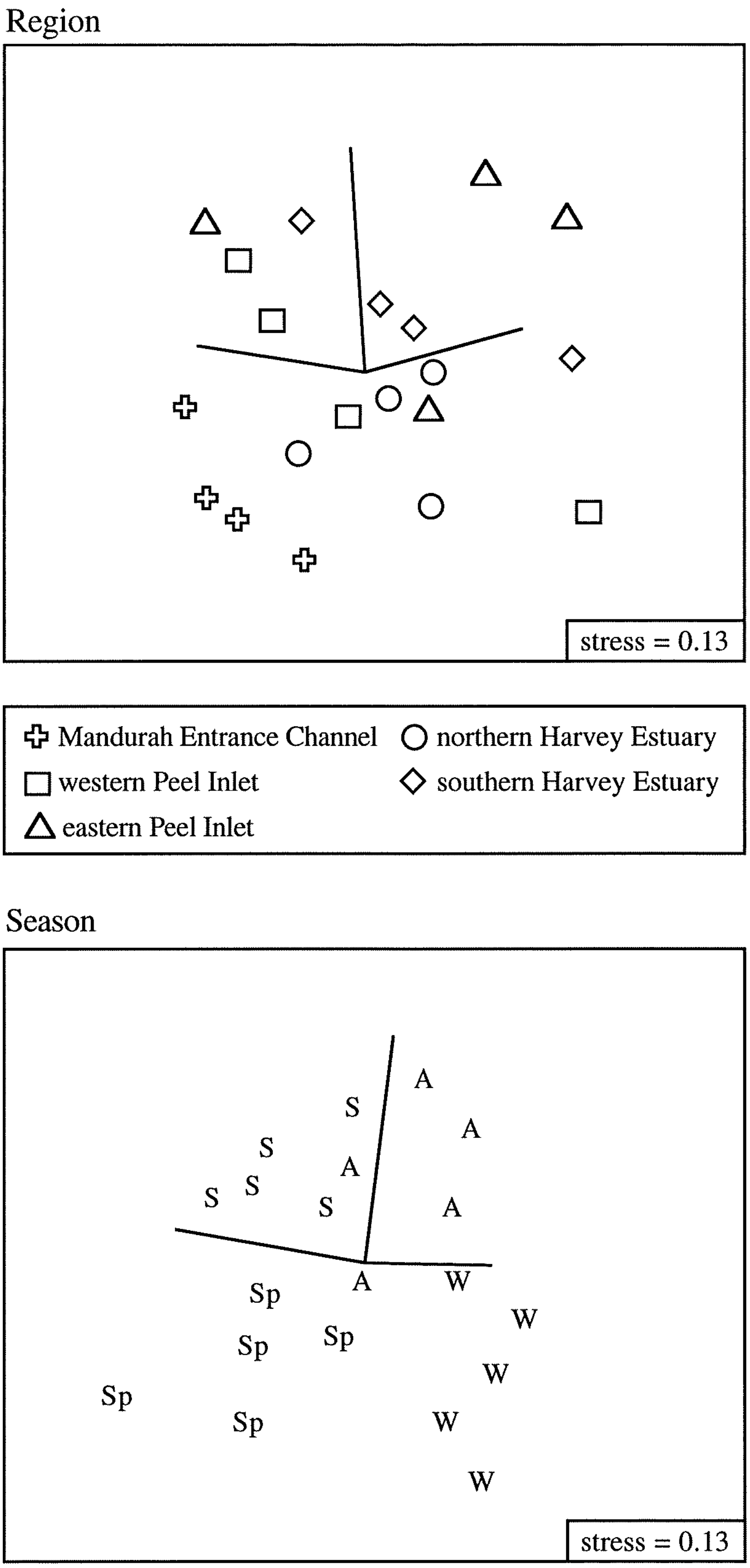


Figure 20. Three dimensional MDS ordination of mean densities recorded for each fish species in the Peel-Harvey Estuary, using data derived from samples collected by seine netting in the shallow waters after the construction of the Dawesville Channel (January 1996 to October 1997), shown by region and by season.

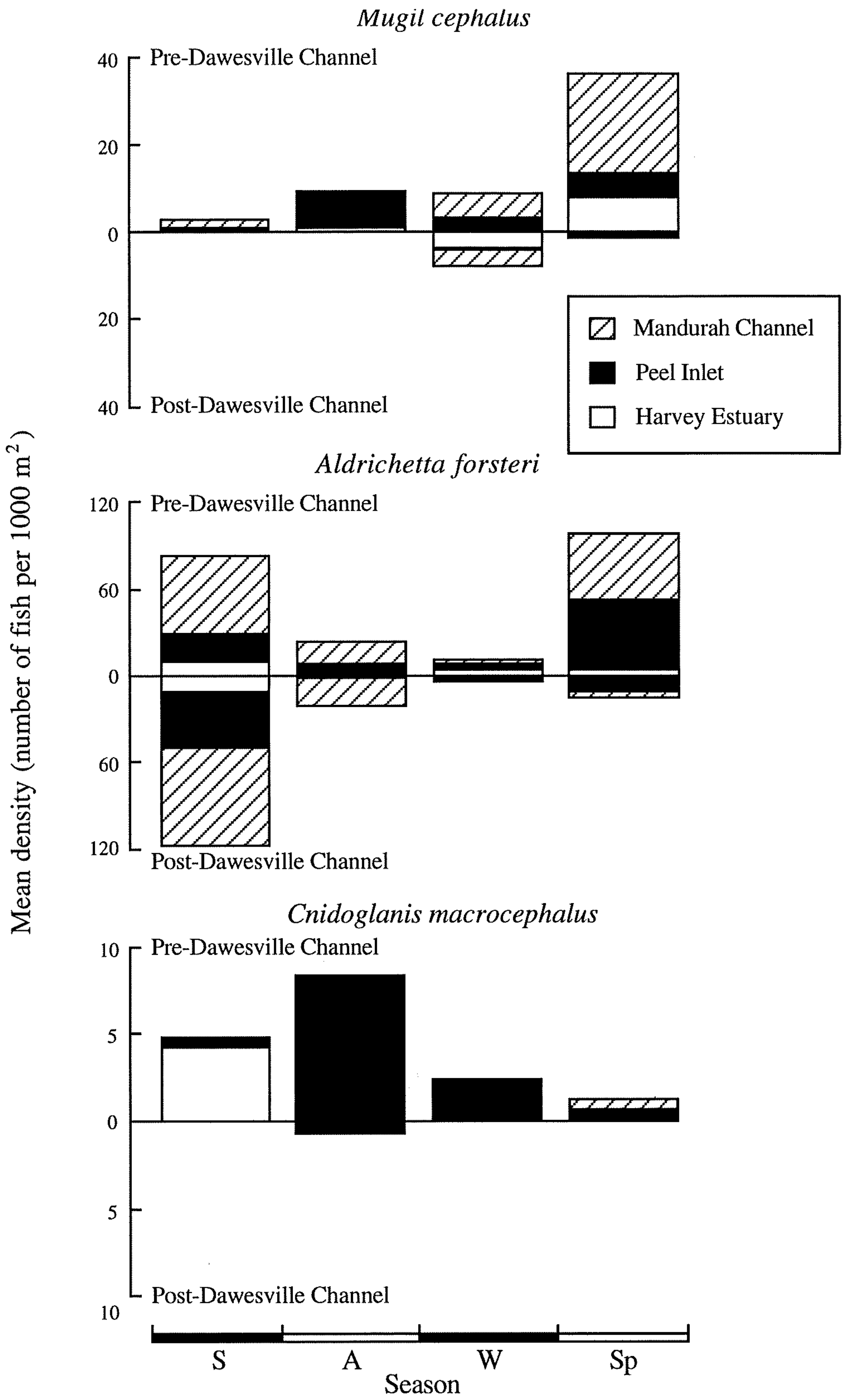


Figure 21. Mean density of *Mugil cephalus*, *Aldrichetta forsteri* and *Cnidoglanis macrocephalus* in the Mandurah Entrance Channel, Peel Inlet and Harvey Estuary, using data derived from samples collected by seine netting in the shallow waters prior to (January 1980 to November 1981) and after the construction of the Dawesville Channel (January 1996 to November 1997). Data for the corresponding seasons of the year in each of the two periods have been pooled.

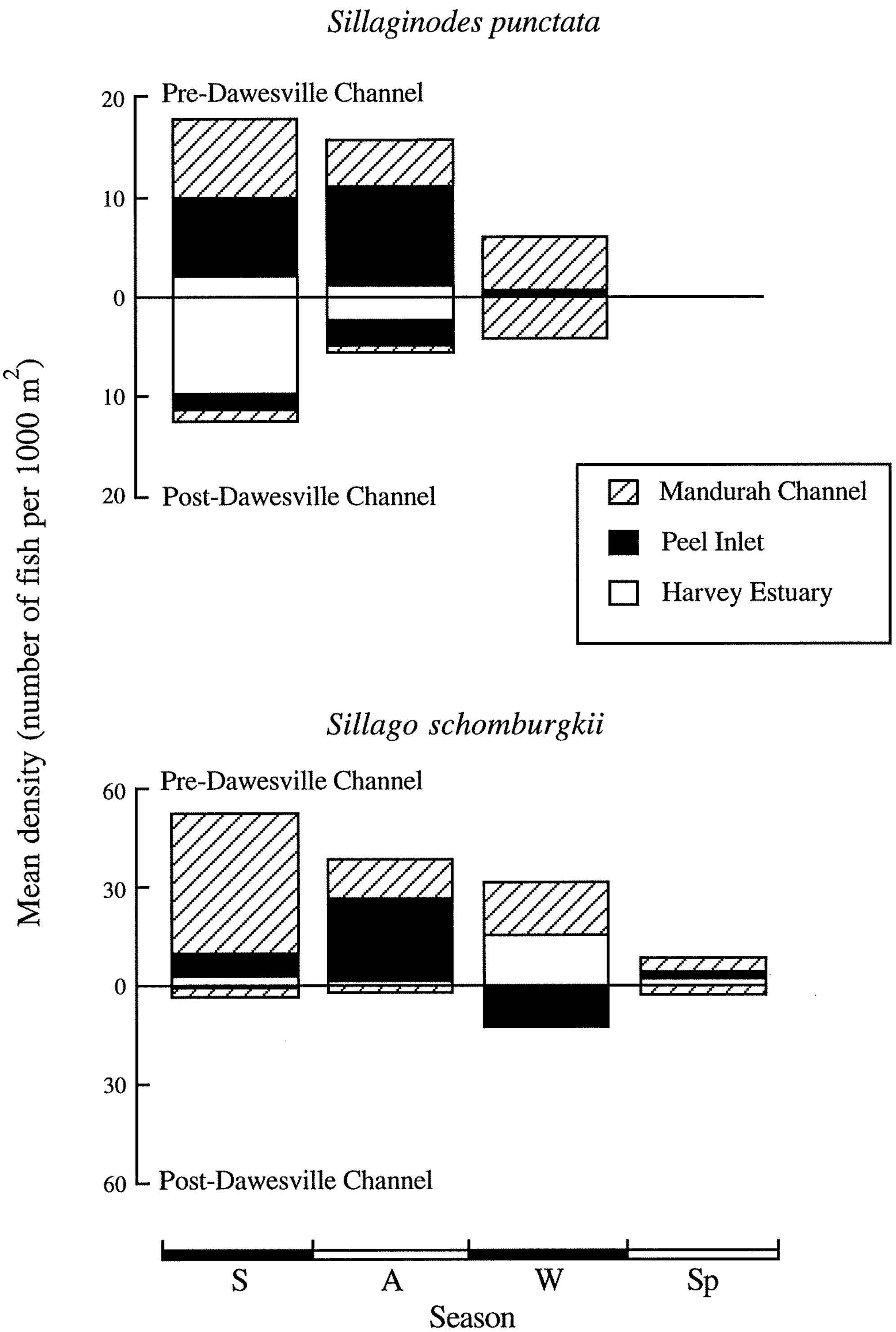


Figure 22. Mean density of *Sillaginodes punctata* and *Sillago schomburgkii* in the Mandurah Entrance Channel, Peel Inlet and Harvey Estuary, using data derived from samples collected by seine netting in the shallow waters prior to (January 1980 to November 1981) and after the construction of the Dawesville Channel (January 1996 to November 1997). Data for the correpsonding seasons of the year in each of the two periods have been pooled.

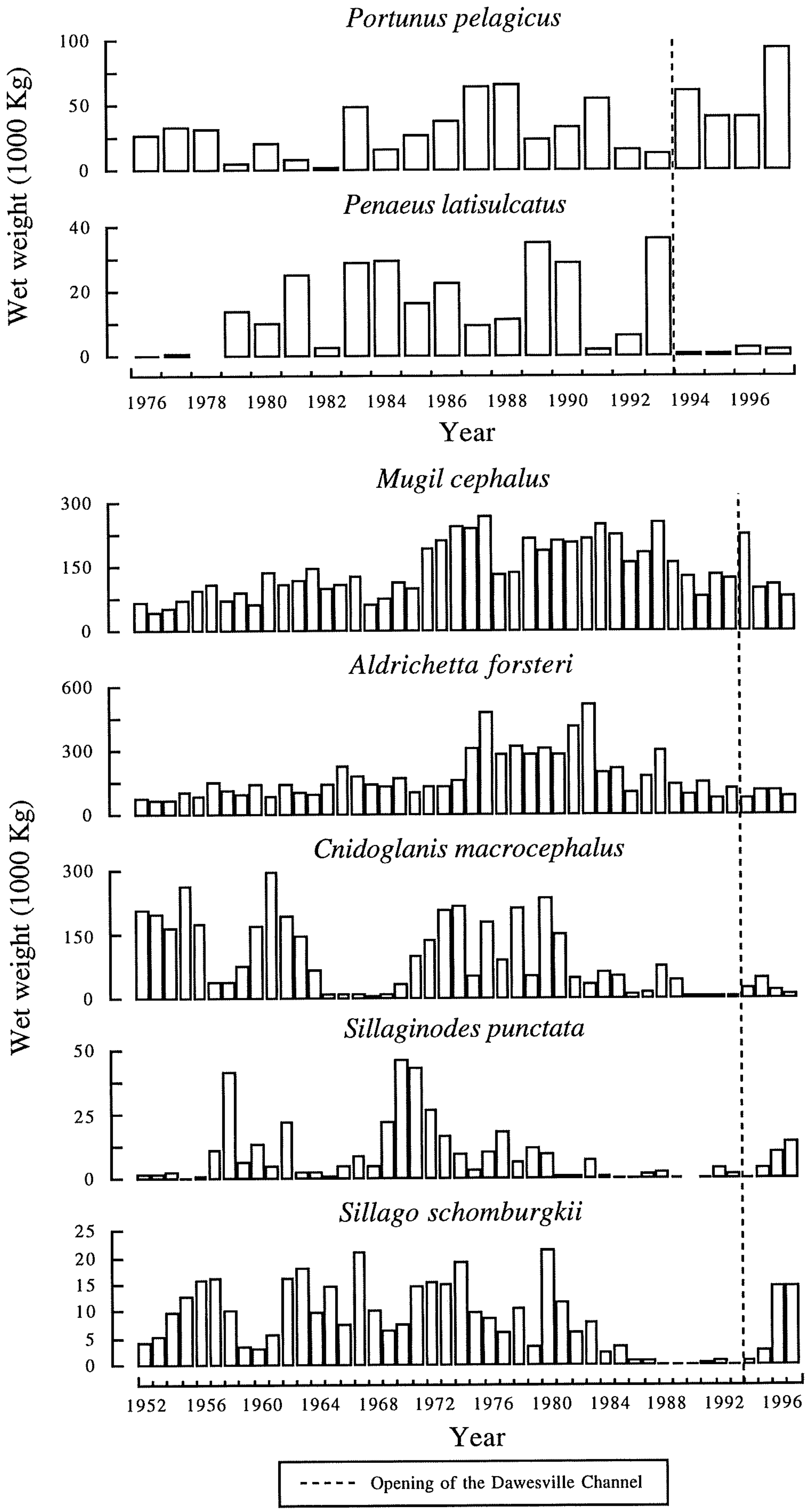


Figure 23. Total annual commercial catches for *Portunus pelagicus*, *Penaeus latisulcatus*, *Mugil cephalus*, *Aldrichetta forsteri*, *Cnidoglanis macrocephalus*, *Sillaginodes punctata* and *Sillago schomburgkii* in the Peel-Harvey Estuary.