Marine Biology 94, 631–641 (1987)

Marine Biology
International Journal on Life in Oceans and Coastal Waters

Influence of environmental variables on the fish fauna of the deeper waters of a large Australian estuary

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Abstract

Fish were collected by gill nets from the deeper waters of the Entrance Channel, basins and rivers of the large Peel-Harvey estuarine system (south-western Australia) in the wet (June to November) and dry (December to May) periods between August 1979 and July 1981. Simple-regression analysis showed that the number of species, abundance and biomass of fish in the rivers rose with increases in the salinity and temperature of both the surface and bottom of the water column. No such significant correlations were found in the Entrance Channel and basins (Peel Inlet and Harvey Estuary), where salinity changes were far less marked. The number of species at sites throughout the estuary was inversely correlated with distance from the estuary mouth. Multiple-regression equations showed that, compared with the other environmental variables tested, bottom salinity had a greater influence on the number of species and abundance both in the rivers and in the system as a whole. These results indicate that salinity has a greater effect on the fauna in the deeper waters than in the shallows (cf. Loneragan *et al.,* 1986). The larger fish which characterise the deeper waters may thus be less tolerant to low salinities than the smaller fish typically found in the shallows. Both classification and ordination separated the faunal composition of the rivers from those of the Entrance Channel and basins. The fauna of the two narrow and deeper sites in the rivers separated into wet- and dry-period components. Differences between the faunal composition of the riverine regions and those of the Entrance Channel and basins have been related to the much more variable and lower minimum salinities in the rivers. Species characteristic of the rivers included *Amniataba caudavittatus,* which is estuarine *sensu stricto* in south-western Australia, the semi-anadromous *Nematalosa vlaminghi* and the highly euryhaline *Mugil cephalus.* The indicator species for the Entrance Channel and basins were all marine species (*Cnidoglanis macrocephalus, Hyporhamphus melanochir, Gerres subfasciatus* and *Pomatomus saltator*).

Introduction

Estuaries in many parts of the world are used extensively by the juveniles of marine teleosts (e.g. Day *et al.,* 1981; Haedrich, 1983; Claridge *et al.,* 1986), a generality which also applies to the large Peel-Harvey and Swan estuaries in south-western Australia (Potter *et al.,* 1983b). Moreover, some marine species remain for many months within these latter two temperate-region systems and reach a size suitable for commercial and recreational exploitation (Potter *et al.,* 1983a, b; Chubb *et al.,* 1984; Lenanton, 1984; Lenanton *et al.,* 1984; Nel *et al.,* 1985). The commercial and recreational fisheries in the Peel-Harvey and Swan estuaries are based mainly on catches of yellow-eye mullet (*Aldrichetta forsteri*), sea mullet (*Mugil cephalus*), cobbler (*Cnidoglanis macrocephalus*) and Perth herring (*Nematalosa vlaminghi*). Commercial catches of these species are mainly taken in offshore and deeper waters (Lenanton *et al.,* 1984), whereas smaller fish tend to predominate in the shallows (Potter *et al.,* 1983b; Loneragan *et al.,* 1986).

The community structure of the fish fauna in estuaries can be influenced by salinity (e.g. Gunter, 1961; Weinstein *et al.,* 1980; Allen, 1982; Potter *et al.,* 1986), temperature (Hoff and Ibara, 1977; Quinn, 1980; Allen, 1982) and distance from the estuary mouth (Quinn, 1980). In the Peel-Harvey Estuary, the number of species, density and biomass of fish in the shallows are more highly correlated with distance from the estuary mouth and temperature, than with salinity (Loneragan *et al.,* 1986). However, salinity was more important in determining the species composition of the fish assemblages in the different regions of the estuary. In any discussion of the role of salinity, it is important to recognize that the tolerance of fish to extremes in this variable differs considerably among species (Kinne, 1964; Whitfield *et al.,* 1981) and between different size classes of the same species (Kinne, 1964; Holliday, 1971).

This paper describes the community structure of fish assemblages in the deeper waters of the Peel-Harvey Estuary. We have tested whether the number of species, abundance, biomass and species composition of fish in different regions were correlated with salinity, temperature and distance from the estuary mouth. Since the riverine regions of the estuary undergo pronounced seasonal changes in salinity and are characterised by the formation of marked haloclines (Potter *et al.,* 1983b; and present Fig. 2), particular attention has been focused on determining whether salinity has an influence on the above biotic variables. Finally, the results of the current study are compared with those given previously for the fish fauna in the shallow waters of the Peel-Harvey Estuary (Loneragan *et al.,* 1986).

Materials and methods

Sampling

Fish were collected by gill nets between August 1979 and July 1981 at six sites (1, 3, 5, 8, 9, 10) in the Peel-Harvey Estuary, Western Australia (Fig. 1). These sites were chosen so that they were located in waters that were deeper, but in the same general region as those previously used by Loneragan *et al.* (1986) in a study of the fish fauna in the shallows. While the depth of the waters in the basins (Peel Inlet and Harvey Estuary) rarely exceeds 2 m, it reaches 3 m in the Serpentine River and 8 m in the Murray River. Sampling was carried out every six weeks until September 1980, and then at bimonthly intervals. Gill nets were set approximately 30 min after sunset and retrieved 3 h later. While the top and bottom of the water column were fished by one net at Sites 1 and 10, this required the use of two nets, one sunken and one floating, at Sites 3, 5, 8 and 9. The sunken and floating gill nets each consisted of eleven 20 m-long panels with stretch mesh sizes of 38, 44, 55, 57, 63, 70, 76, 83, 89, 96 and 102 mm. Catches at Sites 1 and 10 were doubled to correspond to the catch in two nets. The total number and wet weight of the catch of each species were recorded. Numbers and biomass data were log-transformed to overcome any skewness. The salinity and temperature of the surface and bottom waters, and the depth of the water column were also recorded at the time of sampling.

Analysis of physico-chemical and biotic data

Data for the salinity and temperature of the surface and bottom waters, and the number of species, abundance and biomass of fish in gill nets were treated in the manner described by Loneragan *et al.* (1986). Thus, means were calculated for each of the two wet periods, which cover the months from November to June when 90% of the rainfall and freshwater flow occurs (McComb *et al.,* 1981), and for each of the two dry periods which encompass the remaining months, i.e., December to May. A paired *t*-test was used to test whether the salinity and temperature of the surface and bottom waters differed at each site in the wet and dry periods. Three-way analyses of variance (ANOVA) were used to determine whether the above physico-chemical and biotic variables differed among sites (fixed) and between periods (fixed, wet and dry) and years (fixed 1979/1980 and 1980/1981). Typically there were three samples per cell for the wet period in 1979/1980 and the dry period in 1980/1981, and four samples per cell for the dry period of 1979/1980 and the wet period of 1980/1981. Because variances for the salinity, temperature, number of species, log-numbers and log-biomass were shown to be homogeneous using Cochran's C-test, the use of ANOVA is valid. When ANOVA showed significant differences amongst means, an *a posteriori* Student-Newman-Keuls (SNK) test was used to determine which means were significantly different at the 0.05 level of probability (see Underwood, 1981). Data for each of the three main effects (site, period, year) were pooled when the results of ANOVA showed that this was appropriate. Where the data for a main effect have been pooled, the resultant mean is referred to as the overall mean.

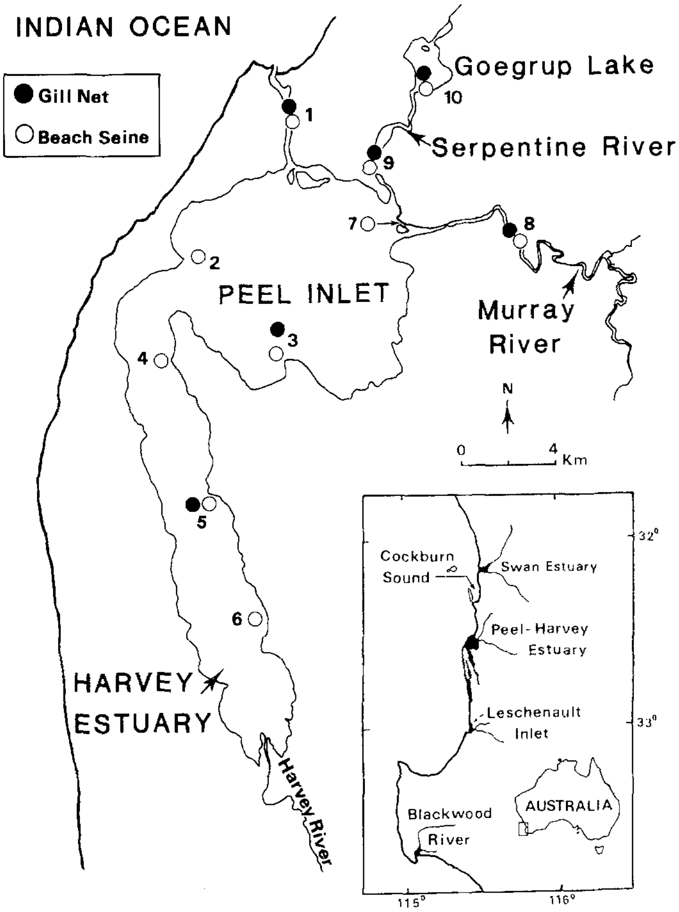


Fig. 1. Map showing location of six gill-net sampling sites in Peel-Harvey Estuary used in this study and ten beach-seine sampling sites used by Loneragan *et al.* (1966)

The coefficient of variability (see Zar, 1974) was calculated as a percentage for the salinity and temperature of both the surface and bottom waters at each site for the duration of the study, i.e., between August 1979 and July 1981.

Correlation coefficients were calculated between each of the three biotic variables (number of species, log-numbers and log-biomass) in the individual samples and each of the five environmental variables (salinity and temperature of the surface and bottom waters, and the distance from the estuary mouth). Multiple stepwise-regression equations were also used to relate in turn each of the biotic variables and the five environmental variables. Only the significant environmental variables were entered in the equations.

Classification and ordination

The classification and ordination techniques used for this study were essentially the same as those employed for the study of fish assemblages in the shallow waters of the Peel-Harvey Estuary (Loneragan *et al.*, 1986). However, because fewer sites were sampled with gill nets, the current study has used the species-abundance data for each sampling occasion, rather than the mean abundance data for each wet and dry period. Two-way indicator species analysis (TWINSPAN; Hill, 1979a) was used to classify the data, and detrended correspondence analysis (DECORANA; Hill, 1979b; Hill and Gauch, 1980) was used for ordination. The term "indicator species" refers to those species selected by TWINSPAN as predominant for a group of samples. Rare species, i.e., those occurring in less than three of the 87 gill net samples, were not included in the data set for classification and ordination. Six abundance categories (0, 1 to 4, 5 to 9, 10 to 49, 50 to 99, > 100) were used for classification (TWINSPAN), and transformed abundance data [$\ln(x+1)$] were employed for ordination (DECORANA).

Correlations were calculated between the ordination scores for each of the 87 gill net samples on both Axes 1 and 2, and the salinity and temperature of the surface and bottom waters, and the distance from the estuary mouth.

The data on species abundance in each sample were also ordinated for each site separately [$\ln(x+1)$ transformation] and the ordination score on Axis 1 for each sample was then plotted against the date when the sample was taken. Pronounced changes in sequential ordination scores reflect marked changes in faunal composition.

Results

Salinity and temperature

Since fluctuations in tidal height are small in south-western Australia (Hodgkin and Lenanton, 1981), the daily variations in salinity at any one point in the estuary are also small. Surface salinities varied seasonally and ranged from less than 2‰ at Sites 8, 9 and 10 in August 1980 to 49‰ at Site 9 in April 1980 (Fig. 2). Significant differences between surface and bottom salinity were found at Site 8 in the Murray River in both the wet ($p < 0.05$) and dry ($p < 0.05$) periods, and at Site 1 in the Entrance Channel in the wet periods ($p < 0.01$). Marked haloclines, when bottom salinities exceeded surface values by at least 10‰, were usually present at Site 8, with the difference between surface and bottom waters reaching 27‰ in June and November of 1980. The difference between surface and bottom salinities also exceeded 10‰ on four occasions at Site 1 in the Entrance Channel, twice at Site 9 in the Serpentine River and once at Site 10 in Goegrup Lake on the Serpentine River (Fig. 2). Halocline formation at Sites 3, 5, 9 and 10 tended to be restricted to the months between May and November. The halocline at all sites was generally within 1 m of the surface.

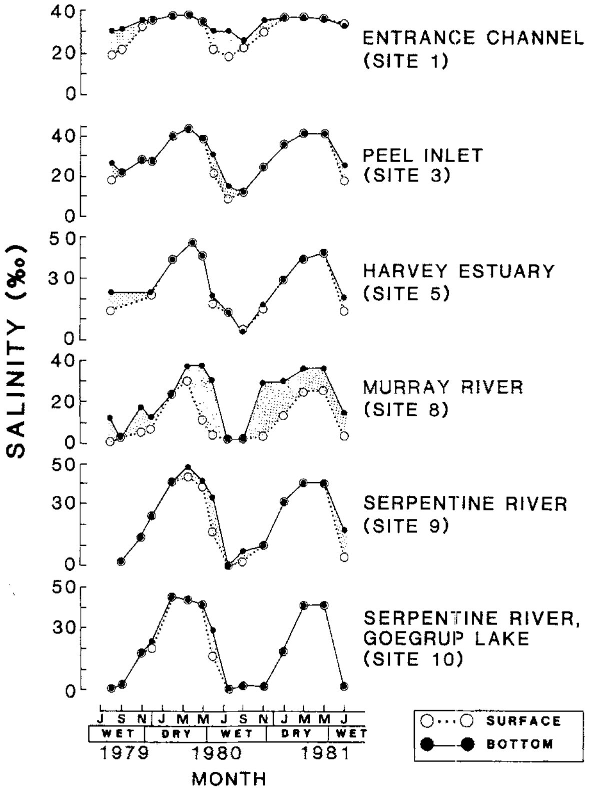


Fig. 2. Surface and bottom salinities at the six gill-net sampling sites in Peel-Harvey Estuary

Both surface and bottom salinity differed significantly among sites and between wet and dry periods (Table 1, Fig. 3). There was also a significant site × period interaction (Table 1). The SNK test showed that during the wet periods the overall mean surface salinity of 23.3‰ at Site 1 in the Entrance Channel was significantly higher than the means of 2.9 to 19.3‰ at Sites 3, 5, 8, 9 and 10. The overall mean surface salinity at Site 8 in the Murray River (2.9‰) was significantly lower than those at Sites 1, 3 and 5 (13.0 to 23.3‰) in the wet periods. However, in the dry periods, the overall mean surface salinity of 19.4‰ at Site 8 was significantly lower than those at all other sites which ranged from 36.2 to 38.0‰. The overall mean bottom salinity in the wet periods at Site 1 (31.0‰) was significantly higher than at Sites 5, 8, 9 and 10, where the overall means ranged from 8.1 to 16.0‰. By contrast, the overall mean bottom-salinities in the dry periods did not differ significantly among sites, ranging from 30.7‰ at Site 8 in the Muray River to 38.6‰ at Site 9 in the Serpentine River. Mean surface and bottom salinities at each site were significantly higher in the dry than wet periods (Fig. 3).

The coefficient of variation (CV) of surface salinity, which reflects the size of fluctuations in surface salinity over the study period, was lowest in the Entrance Channel (24.8%) and greatest in the rivers, where it ranged from 74.9% at Site 9

Table 1. *F*-values and levels of significance for the three-way ANOVAs of surface and bottom salinity and temperature. Degrees of freedom for residual mean squares are also shown

Sources of variation	df	Salinity		Temperature	
		Surface	Bottom	Surface	Bottom
Site	5	11.79***	3.28*	0.77	0.93
Period	1	171.30***	82.99***	49.47***	55.81***
Year	1	0.60	0.04	0.03	1.04
Site × period	5	2.93*	2.93*	0.43	0.56
Site × year	5	0.18	0.39	0.20	0.09
Period × year	1	0.49	0.05	0.57	0.33
Site × period × year	5	0.18	0.31	0.35	0.36
Residuals	57				

$* = p < 0.05$; $*** = p < 0.001$

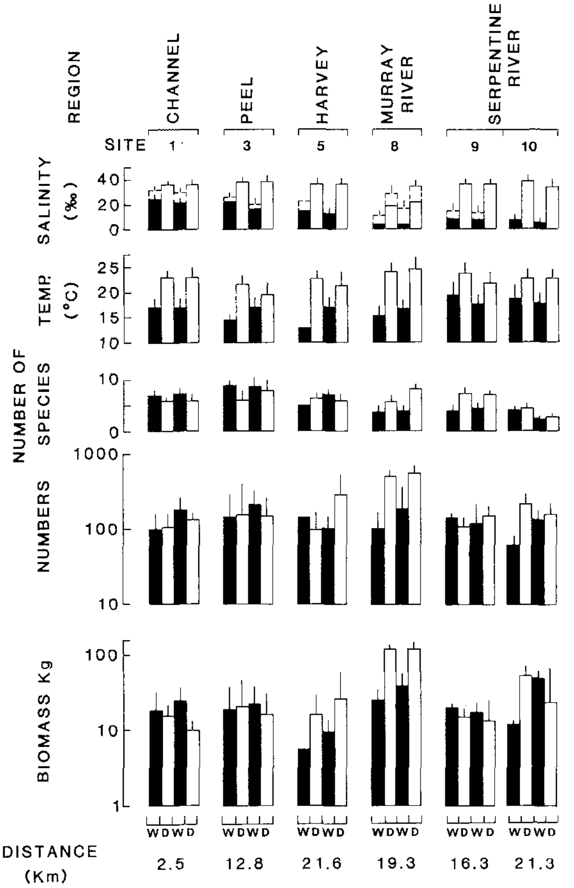


Fig. 3. Means (+1 standard error) for surface salinity and temperature, and number of species, numbers and biomass of fish in sequential wet (W) and dry (D) periods for years between mid-1979 and mid-1981. First two histograms represent data at each site for 1979/1980, last two represent 1980/1981. Mean salinities for bottom waters (– – –) are also shown where they differed by more than 5‰ from those of the surface waters. Abscissa shows distance from estuary mouth

in the Serpentine River to 96.3% at Site 8 in the Murray River (Table 2). Intermediate values of 40.7 and 54.1% were recorded in Peel Inlet and Harvey Estuary, respectively. Although the CV for the salinity at each site was lower in the bottom than surface waters, the pattern of change in the CV of bottom salinity through the system paralleled quite closely that shown by the surface waters (Table 2).

The temperature of the surface and bottom waters did not differ significantly at any site in the wet or dry periods ($p > 0.05$). Mean surface and bottom temperatures differed only between periods of the year (Table 1). The mean surface temperatures ranged from 19.7° to 24.6 °C during the dry periods and from 12.8° to 19.4 °C in the wet periods (Fig. 3). The CVs for the temperature of the surface waters were similar to those for the bottom waters, ranging from 21.3% at Site 10 in Goegrup Lake to 28.2% at Site 8 in the Murray River (Table 2).

Composition of the fauna

A total of 18 508 fish, representing 26 species and 18 families of teleost and one species of elasmobranch, were caught in gill nets. Twenty species accounted for 99.5% of the total catch (Table 3). It must be recognized, however, that as a result of the selectivity of gill nets, some species were probably under-represented in these samples. The mullets *Mugil cephalus* and *Aldrichetta forsteri* were the most abundant species, followed by *Nematalosa vlaminghi*, *Gerres subfasciatus* and *Cnidoglanis macrocephalus* (Table 3). Species such as *M. cephalus* and *A. forsteri* were widely distributed throughout the system, whereas others such as *Trachurus mccullochi* and *Contusus brevicaudus* had a far more restricted distribution (Table 3).

Number of species, abundance and biomass of fish

The mean number of species differed among sites and there was a significant site × period interaction (Fig. 3, Table 4). During the wet periods, the overall mean number of species at Sites 1, 3 and 5 (range = 6.8 to 8.9) were shown by the SNK test to be significantly higher than those at Sites 8, 9 and 10 in the rivers (range = 3.3 to 4.3). During the dry periods, however, the overall means at Sites 3, 8 and 9 (range = 6.9 to 7.4) were higher than at Site 10 (3.7). The mean number of species was higher at Sites 8, 9 and 10 in the rivers in the dry periods than in the preceding wet period, whereas the reverse trend was evident at Site 1 in the Entrance Channel and Site 3 in

Table 2. Coefficient of variation of surface and bottom salinity and temperature at the six gill net sampling sites between August 1979 and July 1981

	Region and Site No.					
	Channel	Peel Inlet	Harvey Estuary	Murray River	Serpentine River	
	1	3	5	8	9	10
Surface salinity	24.8	40.7	54.1	96.3	74.9	90.1
Bottom salinity	10.7	32.5	46.6	62.2	64.7	86.6
Surface temperature	22.1	22.3	24.9	28.2	22.0	21.3
Bottom temperature	20.1	21.6	24.6	26.7	19.9	21.7

Table 3. Percentage frequency of occurrence of the 20 species representing 18 413 fish used for classification and ordination. Number of samples taken at each site is in parentheses. Dash indicates species not caught

Rank	Species	% of total fauna (≥ 1%)	Region and Site No.					
			Channel	Peel	Harvey	Murray River	Serpentine River	
			1 (15)	3 (15)	5 (13)	8 (15)	9 (14)	10 (15)
1	*Mugil cephalus*	31.0	46.7	60.0	69.2	100.0	100.0	100.0
2	*Aldrichetta forsteri*	26.1	100.0	100.0	92.3	86.7	92.8	93.3
3	*Nematalosa vlaminghi*	13.1	20.0	20.0	38.0	66.7	57.1	33.3
4	*Gerres subfasciatus*	10.3	40.0	66.7	92.3	13.3	35.7	–
5	*Cnidoglanis macrocephalus*	6.5	93.3	86.7	61.5	26.7	50.0	6.7
6	*Pelates sexlineatus*	4.6	53.3	73.3	61.5	33.3	57.1	20.0
7	*Amniataba caudavittatus*	3.2	33.3	6.7	–	80.0	78.6	53.3
8	*Sillago schomburgkii*	1.3	66.7	33.3	46.1	6.7	42.9	–
9	*Argyrosomus hololepidotus*	1.0	60.0	26.7	30.8	13.3	14.3	13.3
10	*Pomatomus saltator*	1.0	20.0	80.0	30.8	20.0	14.3	–
11	*Engraulis australis*		13.3	33.3	53.8	33.3	21.4	13.3
12	*Trachurus mccullochi*		33.3	–	–	–	–	–
13	*Rhabdosargus sarba*		13.3	26.7	–	13.3	7.1	6.7
14	*Hyporhamphus melanochir*		–	53.3	23.1	6.7	–	–
15	*Pseudorhombus jenynsii*		26.7	26.7	–	–	7.1	–
16	*Pseudocaranx wrighti*		13.3	13.3	7.7	–	–	–
17	*Contusus brevicaudus*		13.3	13.3	–	–	–	–
18	*Gymnapistes marmoratus*		–	13.3	7.7	–	–	–
19	*Acanthopagrus butcheri*		–	6.7	–	6.7	–	6.7
20	*Sillaginodes punctatus*		–	20.0	15.4	–	–	–

Peel Inlet (Fig. 3). This factor probably accounts for the significant site × period interaction.

Despite the fact that the mean number of fish ranged from 60 at Site 10 during the wet period of 1979 to 561 at Site 8 during the dry period of 1980/1981 (Fig. 3), it did not differ significantly among sites, or between periods and years (Table 4). While mean biomass also did not differ significantly between either periods or years, it did differ significantly among sites (Table 4, Fig. 3). The overall mean biomass of fish caught at Site 8 (61.7 kg) was significantly greater than at Sites 1, 3, 5 and 9 (range = 13.8 to 20.0 kg).

Correlations between environmental and biotic variables

The temperatures of the surface and bottom waters were significantly correlated with the surface and bottom salinity, respectively (Table 5). There was a significant inverse correlation between both surface and bottom salinity and the distance from the estuary mouth (Table 5). By contrast, neither surface nor bottom temperature were correlated with distance from the estuary mouth (Table 5).

In simple-regression equations, neither the number of species, nor total abundance nor biomass of fish in the collective data for the Entrance Channel, Peel Inlet and Harvey Estuary (Sites 1, 3 and 5) were correlated significantly with salinity, temperature or distance from the estuary mouth (Table 6). However, significant positive correlations were found between the number of species and the abundance of fish in the rivers (Sites 8, 9 and 10) and both the salinity and temperature of the surface and bottom waters (Table 6). The number of species in the rivers was also inversely correlated with distance from the estuary mouth. Biomass in the rivers was significantly correlated only with bottom salinity and distance from the estuary mouth. The highest correlation coefficients between the environmental and biotic variables in the rivers were obtained between the number of species and the abundance of fish and the bottom salinity

Table 4. *F*-values and levels of significance for the three-way ANOVAs of number of species (*S*), numbers (*N*) and biomass (*B*). Degrees of freedom for the residual mean squares are also shown

Source of variation	df	S	Log_{10} $(N+1)$	Log_{10} $(B+1)$
Site	5	7.97***	1.83	5.21***
Period	1	1.16	3.08	1.46
Year	1	0.15	2.43	0.28
Site × period	5	4.00**	1.50	2.04
Site × year	5	1.07	0.12	0.21
Period × year	1	0.08	0.24	2.64
Site × period × year	5	0.62	0.72	0.60
Residuals	57			

** $=p<0.01$; *** $=p<0.001$

Table 5. Correlation coefficients between environmental variables of surface and bottom salinity and temperature and distance from estuary mouth, for Peel-Harvey Estuary (Sites 1, 3, 5, 8, 9, 10). No of samples = 87

	Surface salinity	Bottom salinity	Surface temperature	Bottom temperature
Bottom salinity	0.90***			
Surface temperature	0.45***	0.37***		
Bottom temperature	0.46***	0.37***	0.98***	
Distance from estuary mouth	−0.27*	−0.28**	0.03	0.02

* $=p<0.05$; ** $=p<0.01$; *** $=p<0.001$

Table 6. Correlation coefficients between number of species and log-numbers and log-biomass and salinity, temperature and distance from estuary mouth. Significance of the regression coefficients for the significant variables in the multiple regression equation and the multiple correlation coefficients are shown in parentheses

Variable	Region of estuary		
	Basins (Sites 1, 3, 5)	Rivers (Sites 8, 9, 10)	Whole system (Sites 1, 3, 5, 8, 9, 10)
No. of species			
Surface salinity	−0.21	0.39**	0.29**
Bottom salinity	−0.28	0.53*** (***)	0.34** (**)
Surface temperature	−0.23	0.42**	0.06
Bottom temperature	−0.22	0.39**	0.04
Distance	−0.03	−0.40** (**)	−0.31** (*)
(Multiple R)	(NS)	(0.63)	(0.41)
Log (numbers + 1)			
Surface salinity	−0.06	0.30*	0.14
Bottom salinity	−0.09	0.47** (**)	0.25* (*)
Surface temperature	−0.01	0.36*	0.20
Bottom temperature	0.01	0.34*	0.19
Distance	0.01	0.12	0.04
(Multiple R)	(NS)	(0.47)	(0.25)
Log (biomass + 1)			
Surface salinity	0.06	0.17 (*)	0.02
Bottom salinity	0.04	0.33* (**)	0.13
Surface temperature	0.01	0.20	0.15
Bottom temperature	0.04	0.18	0.15
Distance	−0.09	0.35* (**)	0.16
(Multiple R)	(NS)	(0.58)	(NS)
No. of samples	43	44	87

* $=p<0.05$; ** $=p<0.01$; *** $=p<0.001$

(Table 6). In the data for the whole system, significant positive correlations were present in simple regressions relating both the number of species and the abundance of fish with the bottom salinity. The number of species in the whole system was also positively correlated with surface salinity and inversely correlated with distance from the estuary mouth.

In multiple regressions, bottom salinity was significant in each of the equations relating separately the number of species, abundance and biomass in the rivers to the five environmental variables (Table 6). Distance from the estuary mouth was also significant in the multiple-regression equations for the number of species and biomass in the rivers. In the data for the whole system, bottom salinity was significant in the multiple-regression equations relating the number of species and abundance of fish to the environmental variables (Table 6). Distance from the estuary mouth showed a significant inverse correlation for the number of species in the whole system.

Classification

Classification of the 87 gill net samples based on the six abundance categories separated the fauna at sites in the Entrance Channel (Site 1), Peel Inlet (Site 3) and Harvey Estuary (Site 5) from those at Sites 8, 9 and 10 in the rivers (Fig. 4). The main indicators for the Entrance Channel and basins of Peel Inlet and Harvey Estuary were *Cnidoglanis macrocephalus, Hyporhamphus melanochir, Gerres subfasciatus* and *Pomatomus saltator,* whereas for the rivers they were *Mugil cephalus, Amniataba caudavittatus* and *Nematalosa vlaminghi* (Fig. 4). The abundance levels at which these species were indicators for their respective regions varied (Fig. 4).

At the second level of division, samples collected at Sites 8 and 9 during the dry periods (December to May) tended to group together, whereas those from the wet months (June to November) clustered with 14 samples from Site 10 (Fig. 4). The five samples from Sites 8 and 9 in the wet periods which grouped with those in the dry, were from either June or November, i.e., at times immediately following or preceding the dry periods. Indicator species at Sites 8 and 9 in the dry were *Nematalosa vlaminghi* and *Pelates sexlineatus,* while *Amniataba caudavittatus* and *Aldrichetta forsteri* were indicators for the wet periods and Site 10 (Fig. 4).

Classification of data for Sites 1, 3 and 5 separated five samples collected at Site 1 in the Entrance Channel from all the others (Fig. 4). These five samples were the only ones in which *Trachurus mccullochi* was caught. At the next level of division, 13 samples from Site 3 in Peel Inlet grouped with eight samples from Site 5 in Harvey Estuary and six from the Entrance Channel (Fig. 4). *Cnidoglanis macrocephalus, Pelates sexlineatus* and *Pomatomus saltator* were indicators for this group. The five samples from Site 5 which were separated from the above group were collected between July and September and characterised by high numbers of *Gerres subfasciatus* (Fig. 4).

Ordination

The first two axes of the ordination accounted for 74.7% of the variation on the first four axes available using DECORANA. Samples from the rivers (Sites 8, 9 and 10) had high ordination scores on Axis 1, while those from the Entrance Channel and basins (Sites 1, 3 and 5) had low scores (Fig. 5a). Species characteristic of samples in the rivers, i.e., species with high ordination scores on Axis 1 of Fig. 5b, included *Amniataba caudavittatus, Acanthopagrus butcheri, Nematalosa vlaminghi* and *Mugil cephalus.* Species characteristic of Sites 1, 3 and 5, i.e., species with low ordination scores on Axis 1 of Fig. 5b, were *Gymnapistes marmoratus, Gerres subfasciatus, Hyporhamphus melanochir* and *Sillago schomburgkii.*

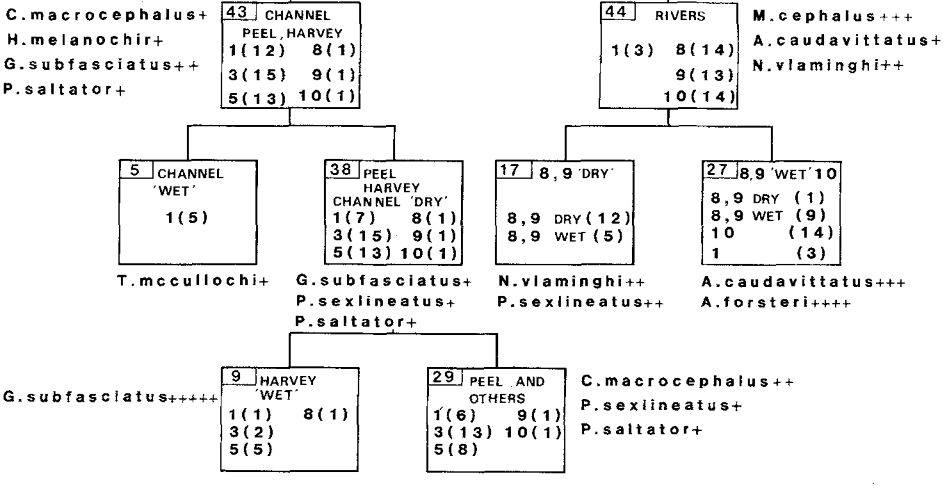
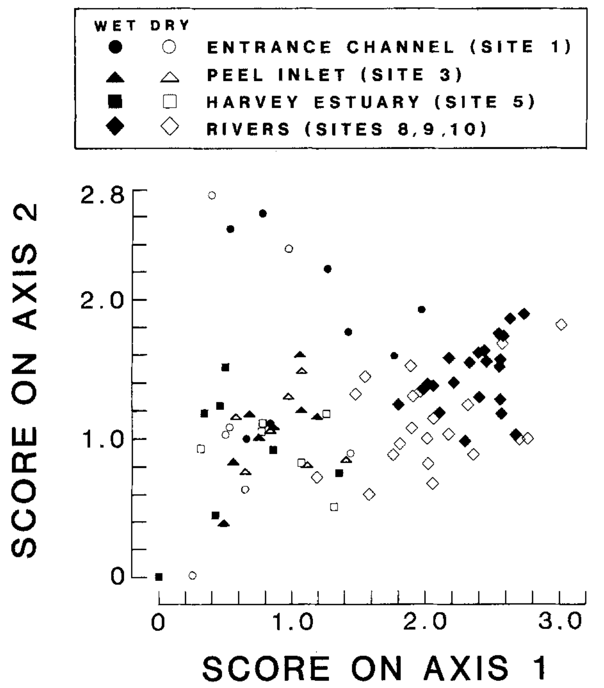


Fig. 4. Classification using TWINSPAN of species-abundance data for Peel-Harvey Estuary obtained from 87 samples from the six gill-net sampling sites. Abundance categories of 0, 1 to 4 (+), 5 to 9 (+ +), 10 to 49 (+ + +), 50 to 99 (+ + + +), >100 (+ + + + +) were employed. Heading in each box refers to region or "season" which included either all or majority of the samples in that grouping. Number of samples in each group is given in top left-hand corner of each box, and frequency of occurrence of each site is shown in parentheses. The indicator species are listed in order of importance; full specific names are given in Table 3

a) SAMPLE ORDINATION SCORES



b) SPECIES ORDINATION SCORES

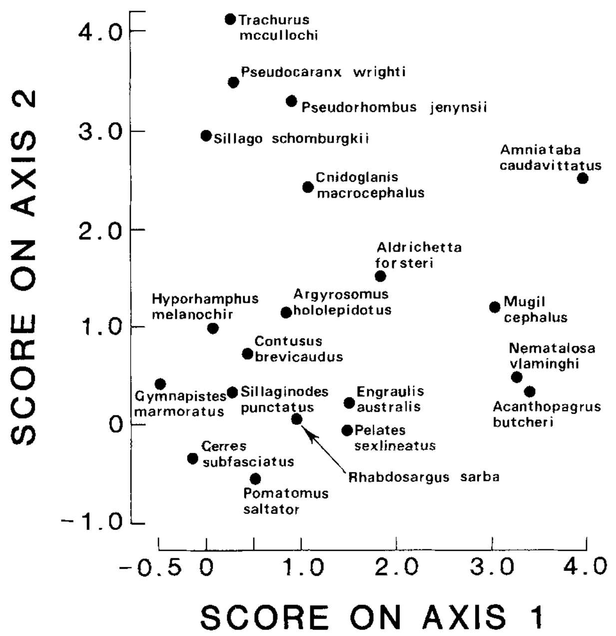


Fig. 5. Ordination scores for samples (a) and species (b) on Axes 1 and 2

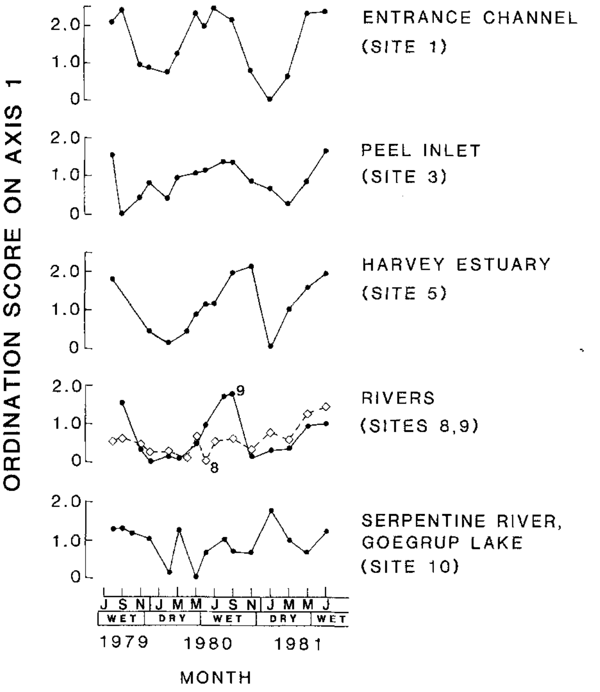


Fig. 6. Ordination scores on Axis 1 for data from each site on each sampling occasion

The five samples in the Entrance Channel, which were separated from other samples on Axis 2 of the ordination (Fig. 5a), were characterised by *Trachurus mccullochi, Pseudocaranx wrighti* and *Pseudorhombus jenynsii* (Fig. 5b). The ordination scores on Axis 2 for samples from Sites 8 and 9 in the rivers tended to be higher in the wet than dry periods.

Ordination scores on Axis 1 were inversely correlated with the salinity of the surface and bottom waters, and positively correlated with the distance from the estuary mouth (Table 7). Significant inverse correlations were also found for the relationships between ordination scores on Axis 2 and the temperature of the surface and bottom waters, as well as for the distance from the estuary mouth.

Table 7. Correlation coefficients of ordination scores on Axis 1 and Axis 2, obtained from ordinations of 87 samples (Fig. 5a), with environmental variables

Variable	Correlation coefficient	
	Axis 1	Axis 2
Surface salinity	−0.43***	−0.18
Bottom salinity	−0.37***	−0.19
Surface temperature	0.10	−0.29**
Bottom temperature	0.14	−0.25*
Distance	0.41***	−0.25*

* $=p<0.05$; ** $=p<0.01$; *** $=p<0.001$

Because the major proportion of the variation in the ordinations of the individual samples at each site was explained on Axis 1 (58 to 67% of the variation explained by the first four axes), only this axis was plotted against the time of year (Fig. 6). The trends shown by the ordination scores were similar in both years at Sites 1, 3, 5 and 9, with much higher ordination scores being recorded in the wet than dry periods (Fig. 6). No regular pattern of change in ordination scores was evident for the samples at Site 8 in the Murray River or Site 10 in Goegrup Lake (Fig. 6). Examination of both the species ordination scores for each site and the abundance data for the species in the individual samples helps explain the basis for the changes in faunal composition at Sites 1, 3, 5, and 9. For example, *Amniataba caudavittatus* was caught at

Sites 1, 3 and 5 only during the wet periods, particularly between June and September. In the wet periods, *Trachurus mccullochi* and *Pseudorhombus jenynsii* were also taken at Site 1, whereas *Engraulis australis* and *Sillaginodes punctatus* were caught at Sites 3 and 5. During the dry periods, *Pomatomus saltator* was found at Sites 1, 3 and 5, *Argyrosomus hololepidotus* at Sites 1 and 3 and *Pelates sexlineatus* at Site 5. *Argyrosomus hololepidotus*, *Sillago schomburgkii* and *Engraulis australis* were caught in the dry periods at Site 9 in the Serpentine River.

Discussion

Number of species, abundance and biomass

The data presented in this study provide very strong indications that bottom salinity has a marked influence on the number of species, abundance and biomass of teleosts in the deeper waters of the tributary rivers of the temperate Peel-Harvey estuarine system. This view is based on the presence in the riverine data of significant and positive correlation coefficients between bottom salinity and each of the above biotic variables and the significance of bottom salinity in each of the multiple regressions relating the environmental and biotic variables. Although significant correlations were also found between both the number of species and abundance of teleosts in the rivers and bottom temperature, the level of significance was always lower than for bottom salinity. Moreover, bottom temperature was not significant in any of the multiple-regression equations relating the environmental and biotic variables in the data for the rivers. The fact that temperature was significantly correlated with the biotic variables in the rivers, but was not significant in these multiple regressions, is almost certainly due to the correlation between this environmental variable and salinity. Hence, after salinity is taken into account, temperature is no longer important.

The fall in the number of species and abundance of teleosts in the rivers during the winter, when even the bottom salinity sometimes declined to less than 2‰, parallels the situation recorded in the Severn Estuary in the United Kingdom when, during the unusually wet winter of 1976/1977, the salinities fell below 5‰ (Claridge *et al.*, 1986). In contrast to the situation in the rivers, none of the environmental variables for the Entrance Channel and basins (Peel Inlet and Harvey Estuary) were either correlated with any of the three biotic variables or significant in the multiple-regression equations. The absence of an effect of salinity on the number of species, abundance and biomass of fish in the Entrance Channel and basins probably reflects the fact that salinities in these regions only occasionally fell below 10‰.

The multiple regressions clearly indicate that, in the deeper waters of the rivers, salinity influences the number of species, abundance and biomass of fish and that salinity is more important than distance from the estuary mouth in determining the first two biotic variables in the system as a whole. Since these findings are the converse of the situation in the shallow waters (Loneragan *et al.*, 1986), salinity apparently has a greater influence on the fish in the deeper waters of the Peel-Harvey Estuary. As in other estuarine and inshore waters (e.g. Gordon, 1977; Poxton *et al.*, 1983; Claridge *et al.*, 1986), the deeper waters of the Peel-Harvey system are characterised by fish that are larger and older than those found in the shallows (Potter *et al.*, 1983b; Lenanton *et al.*, 1984). The greater influence of distance from estuary mouth on biotic variables in the shallows is probably in part related to the fact that in many cases the fish in these regions have recently entered from the sea and, because of their small size, are less likely to be able to penetrate rapidly through the system. This view is consistent with the finding that, in contrast to the deeper waters, the number of species in the shallows was always greatest in the Entrance Channel (Loneragan *et al.*, 1986).

Although the correlation coefficients between bottom salinity and the number of species, abundance and biomass of fish were always significant and positive in the rivers, they were never significant and were sometimes negative in the basins and Entrance Channel (Table 6). These results suggest that fish move out of the rivers and into the basins when the salinity declines markedly. This would be consistent with the observation that the mean number of species in the rivers in each dry period was higher than in the preceding wet period, whereas the reverse trend occurred in the Entrance Channel and Peel Inlet (Fig. 3). Because salinity shows a close and inverse correlation with freshwater discharge (e.g. Claridge *et al.*, 1986), the reduced number of species, abundance and biomass of fish in the rivers at times of low salinities may also be partly due to the flushing effects of water movement. A similar decline in the abundance of fish following floods has been recorded in the relatively deep and narrow Sundays Estuary in the eastern Cape of South Africa (Marais, 1982).

From the above discussion it appears that fish move out of the saline reaches of the rivers into the basins when salinity decreases with increasing fresh-water discharge. However, the highly significant correlations between bottom salinity and the biotic variables in the rivers also indicates that the water below the halocline is important to at least some of those species which utilise the riverine waters. Since the bottom waters, particularly in the Murray River, often have a higher salinity than those near the surface, they offer a refuge to fish which have a preference for higher salinities, as well as providing an environment in which the physical effects of flushing are reduced.

Faunal composition

Classification and ordination gave essentially the same results in terms of the sites and "seasons" which grouped together and the species characteristic of these groups. The fauna at sites in the Entrance Channel, Peel Inlet and Harvey Estuary differed markedly from those in the Murray and Serpentine rivers. Since the ordination scores on Axis 1 were most highly correlated with salinity, the major difference between the species composition in the Entrance Channel and basins and those in the rivers is related to differences in the salinity regimes in these regions. These conclusions parallel those previously obtained for the shallows of the Peel-Harvey Estuary (Loneragan *et al.,* 1986) and are similar to the trends shown by fish faunas in other areas where salinity varies with region of the system (Warburton, 1978; Young and Wadley, 1979; Weinstein *et al.,* 1980; Yáñez-Arancibia *et al.,* 1980).

The indicator species for sites in the rivers include one species which is restricted to estuaries in south-western Australia (*Amniataba caudavittatus*), another which is semi-anadromous (*Nematalosa vlaminghi*) and a third (*Mugil cephalus*) which is marine and sometimes passes through the estuary into fresh water (Thomson, 1957; Chubb *et al.,* 1979, 1981; Chubb and Potter, 1984, 1986). By contrast, the indicator species for the Entrance Channel and basins (*Cnidoglanis macrocephalus, Hyporhamphus melanochir, Gerres subfasciatus* and *Pomatomus saltator*) were all marine species (Chubb *et al.,* 1979; Nel *et al.,* 1985). Although all the indicator species for the fauna in the deeper waters of the rivers were also indicators for the shallows (Loneragan *et al.,* 1986), this was not the case for the Entrance Channel and basins. The indicator species for the shallows in this latter region included three different marine teleosts (*Gymnapistes marmoratus, Contusus brevicaudus* and *Torquigener pleurogramma*) and a species (*Apogon rueppellii*) which can pass through the whole of its life cycle in the estuaries of south-western Australia (Chrystal *et al.,* 1985).

Classification and ordination also showed that the fauna at sites in the Murray (8) and Serpentine (9) rivers in the dry periods differed from those in the wet. The most important indicator species for the rivers in the dry periods was *Nematalosa vlaminghi,* a teleost which enters riverine areas during the summer to spawn (Chubb and Potter, 1984, 1986). The second indicator species for rivers in the dry periods (*Pelates sexlineatus*) is a marine species which penetrates the riverine regions as salinities increase (Potter *et al.,* 1983b). The presence of *Amniataba caudavittatus* as an indicator for the wet period in the rivers is consistent with the observation that this teleost is adapted to spend the whole of its life cycle in estuarine environments in south-western Australia (Chubb *et al.,* 1979). Although *A. caudavittatus* is restricted to estuaries in south-western Australia, it is found in the permanently high salinities present in coastal marine regions further north where there are no permanent estuaries (Chubb *et al.,* 1979).

The change in composition of the fauna at Sites 8 and 9 in the rivers is more marked with "season" than in the Entrance Channel and basins. However, some samples from the Entrance Channel in the wet months, which all contained *Trachurus mccullochi,* were separated from those in the dry and the basins. The five samples from the Harvey Estuary which were separated at the third level of classification from the other Harvey samples and from those in the Entrance Channel and most of those from the Peel Inlet, came from the wet period when the abundance of *Gerres subfasciatus* was high.

A seasonal change in the composition of the fauna at Sites 1, 3, 5 and 9 was shown by the relatively consistent pattern of change in ordination scores with time of year at these sites. The less clearly defined seasonal trends at Sites 8 and 10 are probably due to the effects on ordinations of catches which contain only a few species (generally less than four). The seasonal pattern of change within the Entrance Channel, basins and lower reaches of the Serpentine River can be largely attributed to movements in and out of the system of marine species such as *Pelates sexlineatus, Argyrosomus hololepidotus* and *Pomatomus saltator.*

In summary, this study emphasizes that salinity has a more pronounced influence on the number of species, abundance and biomass of fish found in the deeper waters of the rivers than it does on the smaller fish occurring in the shallows. Conversely, the distance from the estuary mouth did not influence the biotic variables in the whole system to the same extent in the deeper waters as in the shallows. However, as in the shallows, the composition of the fauna in the deeper waters in the saline river regions differed from those in the basins and Entrance Channel, and the salinity regime exerted a major influence on the composition of the fauna.

Acknowledgements. We thank P. Chrystal, R. J. G. Manning, P. Yewers, S. Bunn and all other colleagues and friends who helped with sampling. Dr. L. Beckley provided helpful discussion and R. J. G. Manning drew the figures. H. Gauch kindly provided the tape of the CEP programs and advice on their use, and R. Morales and P. Austin translated the programs to run on the Murdoch University computer. Financial assistance was provided by the Western Australian Department of Conservation and Environment, and the Western Australian Department of Fisheries.

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Date of final manuscript acceptance: November 28, 1986.
Communicated by G. F. Humphrey, Sydney