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Trawl-Caught Fish in Moreton Bay, Australia: Value, Dominance, Diversity and Faunal Zonation

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Abstract

Fish in the semi-enclosed Moreton Bay in southern Queensland, Australia, were sampled at nine sites using an otter trawl monthly during daylight. Of 112 recorded species 20 (17.8%) were recognized food species. They were, however, of little commercial value because of their small size. Six species (5% of total species) were most abundant, and accounted for 76% of the catch; 91 species (81%) were very rare making up only 8% of the catch. Shannon-Wiener diversity indices ranged from 1.1 to 2.5, with estuarine sites showing higher diversity than oceanic sites. Similarity analysis (Kendall's coefficient of association) showed that the fish fauna at oceanic sites was different to that of inner, estuarine sites. Four faunal zonations in Moreton Bay are proposed: two oceanic, a central and an estuarine zone.

Introduction

Otter trawls were first introduced to Moreton Bay, Queensland (Fig. 1), in the 1950s (Maclean 1973) for catching shrimp. The shrimp fishery has developed to the extent that trawling is the dominant commercial fishing method in the Bay (Williams 1980). The by-catch of crabs and fish by trawlers has caused concern among both professional and recreational fishermen in the Bay (Pashen and Quinn 1984), which is semi-enclosed by four sand islands with three main openings to the Pacific Ocean.

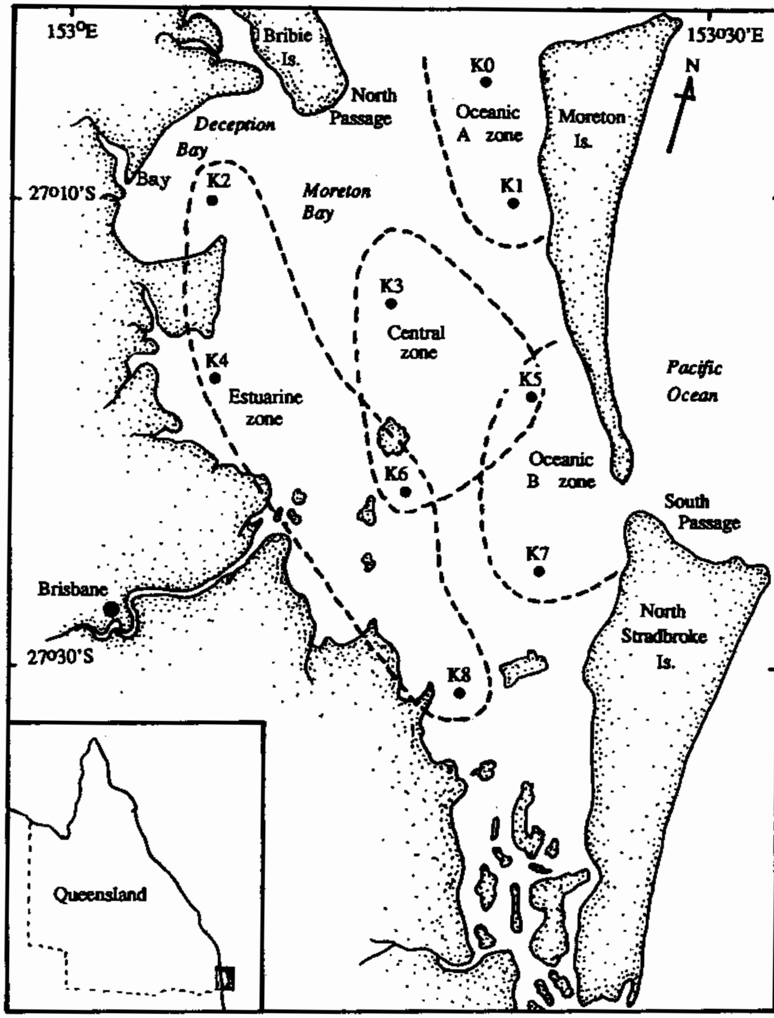


Fig. 1. Trawling sites of K0 to K8, and the proposed four zonations of fish fauna in Moreton Bay, Queensland.

Previous studies in Moreton Bay using trawls were concerned with fish assemblages (Bradbury 1978; Burgess 1980), catch variation (Stephenson et al. 1982a, 1982b), and the biology/ecology of particular fish species (Maclean 1969; Weng 1986). Little mention was made of commercially valued species of fish in the catch with the exception of Maclean (1973) who analyzed night trawl catches over a period of three months. Penn (1977), in Cockburn Sound, Western Australia, provided a comparison of day and night trawl catches.

The present study, based on daytime trawl samples, examines the catch of commercially-valued fish, their size range and the seasonal occurrence of dominant species, species diversity and faunal similarity among nine sites. Four zonations of fish fauna within Moreton Bay are proposed.

Materials and Methods

Sampling was carried out at nine sites in Moreton Bay (Fig. 1) from a 21-m shrimp trawler during daylight hours, using an otter trawl net of 5.2-m headlength with 30-mm mesh. The net had a 1-m long 10-mm mesh codend lining. Each trawl was at a speed of 3 to 4 knots (5.5-7 $km \cdot hr^{-1}$) for 15 minutes. Samples were collected monthly from June 1974 to April 1975. Each fish was identified and the length to caudal fork measured to the nearest millimeter.

The main characteristics of each site are presented in Table 1. The identification of fish is primarily based on Marshall (1964). The decision as to what were commercially valued species was subjective, based upon fishermen's opinions and the author's observations in fish markets. In some cases their opinions differed.

Table 1. The main characteristics of the nine sampling sites (K0 to K8) in Moreton Bay.

	K2	K4	K8	K6	K3	K7	K5	K1	K0
Estuarine/Oceanic Prevalence*	E	E	E	E	EO	O	O	O	O
Weak/Strong Currents*	W	W	W	W	(W)S	S	S	S	S
Bare/partly Seagrass +	B	B	B	B	B	B	S	B	B
Muddy/Sandy Substrate +	MS	MS	M(S)	M(S)	MS	S	S	S	S
Depth (m)	4-5	4-5	5-10	5-10	10-15	10-20	10-20	10-30	10-30

Notes: * from Milford and Church (1977).
+ from Maxwell (1970).

Criteria for five levels of abundance of species were developed as follows, being a new approach to assess fish species from Moreton Bay:

Very rare species — Those represented by a number of individuals less than the total number of samples (N_1), i.e., < 1 fish per sample.

Rare species	- Those represented by a number of individuals ranging from $N_1 + 1$ to N_2 (note: $N_2 = N_1 \cdot a$).
Common species	- Those represented by a number of individuals ranging from $N_2 + 1$ to N_3 (note: $N_3 = N_2 \cdot a$).
Abundant species	- Those represented by a number of individuals ranging from $N_3 + 1$ to N_4 (note: $N_4 = N_3 \cdot a$).
Very abundant species	- Those represented by a number of individuals more than $N_4 + 1$.

where a is a constant. The latter is determined upon the proportion in which it multiplies the total number of samples (N_1) by repeating itself to the situation when N_4 ($N_3 \cdot a$) is not larger than the number of individuals of the most abundant species. For example, a = 2 was best fit in this study, in which the whole range from the minimum to the maximum number of individuals of each species was included within the five levels of abundance.

Many diversity indices for such communities have been developed and critically tested (Edgar 1983). The Shannon-Wiener index (H) was used in this study to indicate the species diversity at each site:

$$H = -\sum_{i=1}^{n} p_i \cdot \ln p_i$$

where p_i is the proportion of individuals in the i^{th} species (i.e., $p_i = n_i \cdot N^{-1}$);

N is the number of total individuals of all species at the site;

n is the number of individuals of the i^{th} species.

The similarity of fish faunal groups between sites was compared using Kendall's coefficient of association T_{ab} (Kendall 1970), which is based on presence/absence rather than abundance of species. It has been satisfactorily applied in a benthic infauna study (Orth 1973).

$$T_{ab} = (CW - XY) \cdot (AU \cdot BV)^{-0.5}$$

$$T_e = (X^2_{0.05} \cdot S^{-1})^{0.5}$$

where A is the number of species at site a;

B is the number of species at site b;

C is the number of species common to sites a and b;

S is the total number of species at all sites;

U = S – A, species not occurring at site a;

V = S – B, species not occurring at site b;

X = A – C, species found at site a but not at site b;

Y = B – C, species found at site b but not at site a;

W = U - Y = V - X, species not found at either site.

The significance of T_{ab} is determined by the chi-square test. The critical value for significant similarity at the 5% level (df = 1) is T_e as given above. There is significant similarity when $T_{ab} > T_e$.

Results

Commercially valued species

A total of 102 trawls was made, from which 112 fish species were identified from 21,034 individuals, including 11 species (represented by 37 individuals) of sharks and rays. Only 20 species (17.8%) with 3,267 individuals (15.5% of the catch) were of commercial value. Another 15 species (13.4%) with 531 individuals (2.5%) were accepted as food fish by some fishermen.

About half of the species with commercial value were each represented by only a few (<20) fish of small size. Seven commercial species were represented each by more than 100 fish (Table 2). Most individuals of these seven species (Table 3) were juveniles of little commercial value. The exceptions were some large (>18 cm) *Pseudorhombus jenynsii* (Bleeker), *Pseudorhombus arsius* (Buchanan) and *Sillago maculata* (Quoy & Gaimard). Only *S. maculata* was caught in significant numbers. It is usually regarded as a useful by-catch. Trawlers retain large *S. maculata* for sale to help defray expenses, particularly when shrimp catches are seasonally low (April to September). It occurs throughout the year, with larger individuals in the deeper waters (Weng 1986).

Two commercially valuable species (*S. maculata* and *P. arsius*) occurred throughout the year, but the remaining five were highly seasonal (Table 2). In particular, large numbers of juvenile *Chrysophrys auratus* (Bloch & Schneider) (Table 3) occurred during a short period from November to January, mostly in the vicinity of the South Passage (Fig. 1) where there is strong oceanic influence.

Dominance of species

According to the criteria described above, the five levels of abundance are listed in Table 4. There was a high percentage of the "very rare" species. The few "very abundant" species represented a high percentage of the total catch.

Four of the six "very abundant" species (Table 2) were by-catch species (called "trash" fish in Australia because they are discarded) which predominated in catches throughout the year. Length-frequency data of the six most common by-catch species are shown in Table 3. They were mostly small fish with varied spatial distributions and seasonal occurrences (Table 2).

Species diversity

The number of species and individuals, and the species diversity index at each sampling site are shown in Fig. 2. The number of species ranged from 19 at K0 to 66 at K6, and the number of individuals from 448 fish (29 species) at K8 to 7,196 fish (43 species) at K3.

Table 2. Numerical order, distribution, seasonal occurrence and abundance levels of the 21 species (excluding the species of the "very rare" level) caught by trawl in Moreton Bay. Note: '#' indicates species of commercially-valued fish.

	Species	Common name	K2	K4	K3	K6	K8	K7	K5	K1	K0	Season	Total fish	Abundance level
01	*Monacanthus oblongus*	Horse-face leatherjacket	20	16		770	4,335	43	342	1,492	198	Each month	7,716	
02	*Lovamia fasciata*	Common cardinal fish	255	89	216	2,236	587	206	233			Each month	3,824	
03	*Centropogon marmoratus*	Marbled fortescue		9		26	1,279	2	11	2		Jun-Oct	1,329	Very
04	*Chrysophrys auratus*	#Snapper	29		5	280		542	218	13		Nov-Jan	1,087	abundant
05	*Pelates quadrilineatus*	Trumpeter perch	260	578	9	169	2	44		4		Dec-Jul	1,066	
06	*Upeneus tragula*	#Mottled goatfish	20	47		129	76	378	269	6		Dec-Feb	928	
07	*Sillago maculata*	#Trumpeter whiting	105	39	23	51	44	203	35	2		Each month	532	Abundant
08	*Arnoglossus waitei*	#Waite's flounder	6		3		196	127	24	4		Jul-Oct	357	
09	*Gerres ovatus*	Common silverbelly	36	129	8	138						Each month	311	
10	*Spheroides squamicauda*	Scaly-tailed toadfish	270					4	8	15		Dec-Feb	297	
11	*Polynemus multiradiatus*	#Flat threadfin	50	132	11	10	22		11			Jan-Feb	236	Common
12	*Saurida undosquamis*	Spot-tailed grinner				66	106	5	42	6		Apr-Sep	225	
13	*Amblyrhynchotes hypselogeneion*	Bar-cheeked toadfish						2	5		210	April	217	
14	*Siphamia roseigaster*	Pink-breasted siphonfish	23	20	13	9	130					Jan-Feb	195	
15	*Equulites moretoniensis*	Black-banded ponyfish	24	9		31	113		4			Jun-Jul	181	
16	*Tragulichthys jaculiferus*	Green porcupine fish	1		9	21		87	44	1		Dec-Jan	163	
17	*Paratrigla papilio*	Butterfly gurnard					1			50	80	Apr-Jul	131	
18	*Pseudorhombus jenynsii*	#Small-toothed flounder	27	2	18	53	3	9	5	7	6	Sep-Feb	130	Rare
19	*Euristhmus lepturus*	Long-tailed catfish	1	79	16	23	6					Jan-Sep	125	
20	*Parapercis nebulosus*	Bar-faced weever	16			34	21	14	30	3	2	Each month	120	
21	*Pseudorhombus arsius*	#Large-toothed flounder	6	3	13	60	12	14	1	2		Each month	111	

Table 3. Size range, mean size, standard deviations and life history stage (Juvenile (J)-Adult (A)) of the seven most common commercially valued (Nos. 1-7) and six by-catch (Nos. 8-13) fish species taken by trawl in Moreton Bay.

Species	No. of fish	Size range (cm)	Mean size ($\bar{X} \pm$ S.D.)	Life history stage
1 *Chrysophrys auratus*	1,087	7-14	10.3 ± 0.9	J
2 *Upeneus tragula*	928	4-15	9.2 ± 1.2	J
3 *Sillago maculata*	532	6-24	15.2 ± 3.2	J-A
4 *Arnoglossus waitei*	357	6-12	8.1 ± 0.9	J
5 *Polynemus multiradiatus*	236	3-19	9.2 ± 3.6	J
6 *Pseudorhombus jenynsii*	130	8-25	14.4 ± 2.2	J-A
7 *Pseudorhombus arsius*	111	8-25	15.8 ± 2.8	J-A
8 *Monacanthus oblongus*	7,716	4-13	8.2 ± 1.2	J-A
9 *Lovamia fasciata*	3,824	3-12	7.6 ± 0.9	J-A
10 *Centropogon marmoratus*	1,329	5-9	6.8 ± 0.5	J
11 *Pelates quadrilineatus*	1,066	7-16	10.4 ± 2.1	J-A
12 *Gerres ovatus*	311	9-16	12.2 ± 1.4	A
13 *Spheroides squamicauda*	297	5-12	7.8 ± 1.2	J-A

Table 4. The five levels of abundance of trawl-caught fish in Moreton Bay, based on the criteria of abundance described in this paper.

Category	Range of no. of fish	No. of fish per sample	Species No.	Species %	% of all individuals
Very rare	< 102	< 1	91	81.3	8.3
Rare	103-204	1-2	8	7.1	5.6
Common	205-408	2-4	6	5.4	7.8
Abundant	409-816	4-8	1	0.8	2.5
Very abundant	> 817	> 8	6	5.4	75.8

Site K3 (close to the center of the Bay) had an extremely high number of individuals (7,196 fish), which was due to the presence of the three most abundant by-catch fish (Table 2). Next in numerical order was K6. Although K8 appeared to be a similar type of habitat (Table 1) to K2 and K4, this site presented very different numbers of species (29) and individuals (448) (Fig. 2).

Species diversity indices ranged from 1.1 at K1 to 2.5 at K2 (Fig. 2). The estuarine sites (K2, K4 and K8) tended to show higher diversities than the oceanic or outer sites (K1, K3 and K5). The indices at K1 and K3 were lowest due to the presence of the most abundant species *(M. oblongus)* which represented the majority of the catch (Table 2) at these sites.

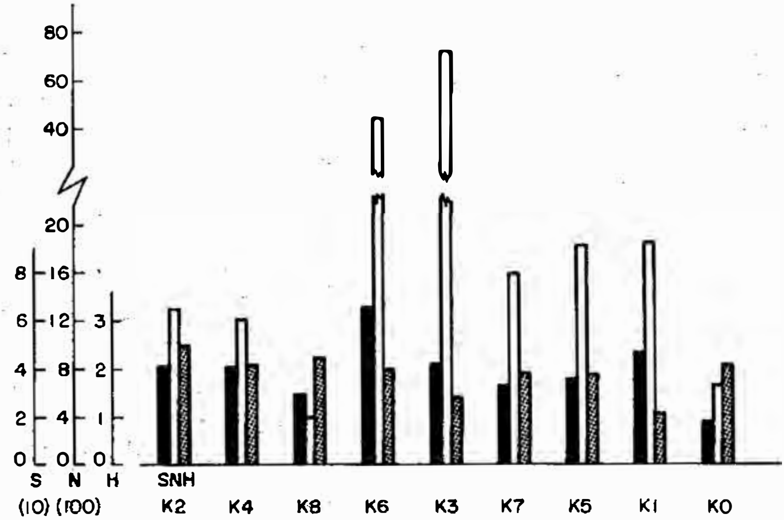


Fig. 2. Number of species (S, solid column), number of individuals (N, open column) and the species diversity index (H, shaded column) at each sampling site (K0 to K8) in Moreton Bay.

Faunal similarity

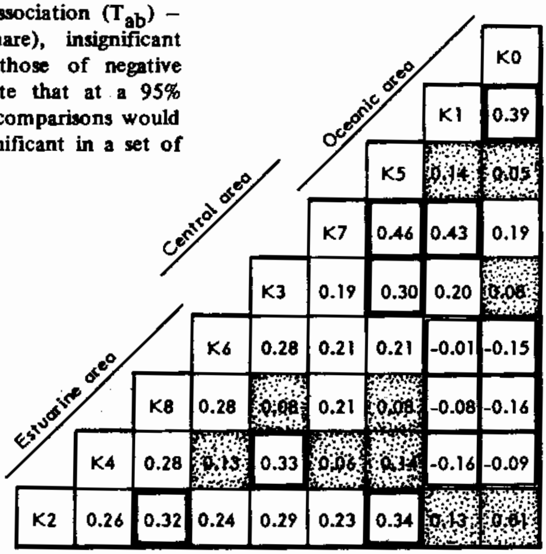
The number of common species (the species occurring at both sites) at any two neighboring sites varied from a minimum 7 out of 52 species (13.5%) between K0 and K2 to a maximum 20 out of 47 species (42.6%) between K5 and K7.

Kendall's coefficients of association between site pairs (Fig. 3) were of two groups, one from 0.01 to 0.46 and the other of negative values. These negative values indicated a high degree of faunistic dissimilarity between the estuarine sites (K4, K6 and K8) and the oceanic sites (K0 and K1).

Since the critical value of T_{ab} for significance (T_e) was 0.18, one-third of the association values (Fig. 3) were not statistically significant. The higher values ($T_{ab} > T_e$) related to adjacent sites. Values exceeding 0.30 inferred similar habitats except for two outstanding cases. One was a high T_{ab} (= 0.34) which occurred between two distant, dissimilar sites, K2 and K5; the other was a low T_{ab} (= 0.14) between two close sites, K1 and K5. Part of K5 was seagrass vegetation (Table 1) which might account for the outstanding results of these two cases.

Low significance of faunal similarity (T_{ab} = 0.19) between sites K0 and K7 indicates a significant difference between fish groups of the two main entrances of Moreton Bay to the Pacific Ocean (Fig. 1).

Fig. 3. Kendall's coefficient of association (T_{ab}) – high similarity (thick-lined square), insignificant similarity (dotted square) and those of negative values (double-lined square). Note that at a 95% significance level, two of the 36 comparisons would be expected to appear to be significant in a set of comparisons among random data.



Faunal zonation

Based on the faunal similarity as described above together with the consideration of species diversity and habitat characteristics, four faunal zonations (Fig. 1) in Moreton Bay are proposed: Oceanic A, Oceanic B, Central and Estuarine. The characteristics of the four zones are listed in Table 5.

Table 5. The characteristics of four proposed faunal zonations in Moreton Bay.

Zone	Sites included	Faunal similarity (T_{ab})	Species diversity (H)	Representative species
Oceanic A	K0 and K1	0.39	1.1-2.1, vary greatly, characterizing transitional area between the inner and outer Bay.	*Amblyrhynchotes hypselogeneion* *Paratrigla papilio* *Platycephalus longispinis*
Oceanic B	K5 and K7	0.46	1.9-2.0, represent the oceanic fish fauna. Number of fish abundant.	*Chrysophrys auratus* *Upeneus tragula* *Tragulichthys jaculiferus*
Central	K3 and adjacent parts of two close zones (K5 and K6)	0.28-0.3, high with a close range.	1.4-2.0, vary greatly, characterizing transitional area between oceanic and estuarine areas in the Bay. Greatest number of fish.	*Monacanthus oblongus* *Centropogon marmoratus* *Arnoglossus waitei* *Saurida undosquamis* *Equulites moretoniensis*
Estuarine	K2, K4, K6 and K8	0.26-0.32, high with a wider range.	2.0-2.5, high in general, which represents the diversified fish fauna of the estuarine portions of the Bay. Low number of fish.	*Pelates quadrilineatus* *Gerres ovatus* *Polynemus multiradiatus* *Euristhmus lepturus*

Discussion

Otter trawls are designed to catch demersal animals, but the effectiveness of this fishing gear in obtaining representative samples has long been questioned (Cleve et al. 1966; Fay et al. 1978; Uzmann et al. 1977). A number of workers hold the view that the variability in catch is unavoidable (Roessler 1965; Stephenson et al. 1982a, 1982b; Suzuki 1973; Taylor 1953), while others consider that the catch provides representative samples (Barnes and Bagenal 1951; Oviatt and Nixon 1973; Perret and Caillouet 1974). Fay et al. (1978) concluded that approximately 100 hauls, timed to include each season, were needed to obtain specimens of about 95% of catchable species of fish from an area of soft bottom in Santa Monica Bay, USA. Such an intensive sampling method had not been commonly practiced.

The trawl net used in this study caught predominantly small fish. Observations during this study on the fishermen's operation of gill nets and tunnel nets in Moreton Bay indicated that there were large fish of various species in the Bay. Whether these large fish could avoid the trawl by fast-swimming action or by swimming above the net has not been verified.

Sales from shrimp trawlers in Moreton Bay consist almost entirely of shrimp (*Penaeus* spp. and *Metapenaeus* spp.) and sand crab (*Portunus pelagicus* (L.)) (Williams 1980). Maclean (1973) and this study found that trawls in Moreton Bay caught mainly by-catch fish and very small quantities of some commercially important fish, apart from an important by-catch of *S. maculata*. The work by Penn (1977) off Western Australia recorded similar results; mainly small or juvenile fish were caught except for considerable numbers of large *Sciaena antarctica* Castlenau, which might be a species vulnerable to trawls.

The species abundance analysis showed that only six (5%) of the 112 species collected were dominant species. These species comprised 76% of the catch. Oviatt and Nixon (1973) found a similar pattern in the fish community of Narragansett Bay, USA. The six dominant species in Moreton Bay were found throughout most of the Bay. Of them, *M. oblongus* and *L. fasciata* were common throughout the year. The remainder appeared seasonally (Table 2). The majority (81%) of species of trawl-caught fish in Moreton Bay were considered to be very rare, together making up only 8% of the catch. The specimen records in the Queensland Museum and the comments of Marshall

(1964) agreed with this study in the abundance classification of those of "very rare" species.

Only 18 of the 112 species collected were found throughout the year. The remaining species were either highly seasonal or rare. Ten of the 112 species were widely distributed in Moreton Bay (Table 2) and the rest were mostly rare fish.

Interesting patterns of distribution were noted for the following species: *Centropogon marmoratus* was a characteristic species in K3 as it was found in high numbers in the area, but only from June to October (colder months of the year). *Chrysophrys auratus* and *Upeneus tragula* occurred mostly from November to January in areas (mainly in K5, K6 and K7) close to the entrance connected to the Pacific Ocean. These appearances inferred the recruitment season of the species, but whether Moreton Bay is their juvenile ground or is on their migration route is yet to be investigated. *Pelates quadrilineatus* and *Gerres ovatus* occurred mainly along the mangrove fringe (author's unpublished data).

Based on the night trawl data of Maclean (1973) and the present daytime trawls in Moreton Bay, *Lovamia fasciata* and *Chrysophrys auratus* are abundant on the bottom during both day and night; *Monacanthus oblongus* appears to descend during the day and rise by night; *Plotosus anguillaris* seems to show opposite diurnal movements. However, there may be other factors affecting the catchability of these species.

Edgar (1983) compared the nature of various diversity indices. He grouped the Shannon-Wiener index as one intermediate between those primarily influenced by (or sensitive to) dominance and those by number of species. Burgess (1980) found diversity values to be of limited value. In the present study, application of the Shannon-Wiener index is seen to be adequate to describe the differences between the samples collected.

A higher Shannon-Wiener index value means higher diversity, indicating a tendency for equal numbers of most species; low diversity implies marked dominance of a single species (Clifford and Stephenson 1975). Further examination of the prominent indices of this study, namely the lowest (1.1 at K1) and the highest values (2.5 at K2), agrees with the above statement. Station K2 had a codominance of three species (*Lovamia fasciata, Pelates quadrilineatus* and *Spheroides squamicauda*) represented by 255, 260 and 270 fish, respectively. In contrast, K1 had one extremely dominant species (*Monacanthus oblongus*).

The diversity index values of the estuarine sites were higher than those of the oceanic sites. Estuarine areas had approximately equal numbers of most fish species although some minor abundant species were also present. In contrast, the oceanic stations had a large number of fish represented by a few very abundant species.

Although Moreton Bay is small (approximately 1,400 km^2) and shallow (< 30 m), the large volume and tidal exchange in the Bay ensure that the salinity on the oceanic side of the Bay does not drop significantly even in flood conditions (Stephenson 1968). The estuarine side of the Bay is subjected to increased turbidity and reduced salinity (Blaber and Blaber 1980), particularly in times of heavy rainfall from November to March. The northern part of the Bay is wide and open; the southern part is narrow and scattered with islands. The physical differences (Maxwell 1970) between the north and the south do not result in large differences in fish fauna. Instead, a high degree of similarity ($0.32 < T_{ab} > 0.43$) was observed, i.e., K2 versus K8 ($T_{ab} = 0.32$) and K1 versus K7 ($T_{ab} = 0.43$). Hydrological differences (Milford and Church 1977) may account for dissimilarity between fish fauna of the eastern and the western regions, i.e., K0 and K1 versus K4, K6 and K8. Overall, 64 species were found in the eastern oceanic area and 75 species in the western estuarine area. However, only 27 of the 112 species sampled occurred in both areas.

Oviatt and Nixon (1973) found that depth, sediment, temperature and wind speed were significant in explaining distribution of fish. Hoff and Ibara (1977) regarded temperature and salinity to be the most important factors affecting the fish fauna diversity. The present study shows that the seasonal occurrence and habitat preference of most species, and the large numbers of rare species in Moreton Bay (Table 4) contribute notably to the varied catches of fish fauna. This is also reflected in the fish recorded by Bradbury (1978), Burgess (1980) and Stephenson et al. (1982a, 1982b).

Bradbury (1978) investigated a demersal fish community of a small, uniform area which was part of the central zone of this study, and stated that "the community is insensitive to difference in the scale of the environment". His conclusion cannot be applied to Moreton Bay as a whole because, as Weng (1986) and this study demonstrated, most fish species in Moreton Bay exhibit habitat preferences and seasonality. Stephenson et al. (1982a) in evaluating the effects of sampling alternatives found that the "site" factor was the most important sampling variable. They (Stephenson et al.

1982b) also stated that most of the species-in-sites showed significant annual cycles. More importantly, the taxa in the lists of the above studies as well as Maclean's (1973) conclusion agree with this study, that the trawl-caught species in Moreton Bay were mostly by-catch fish and of little commercial value.

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