Temporal Changes in a Tropical Nekton Assemblage and Performance of a Prawn Selective Gear

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Introduction

Certain aspects of the ecology of many trawlable nekton assemblages or communities in the warmer Indo-West Pacific subregions have been published in detail. Geographically, most of these associations are in habitats situated in the vicinity of either the often heavily urbanized or fished centers (Chua, 1973; Richards and Wu, 1985; Quinn and Kojis, 1986; Pinto, 1988; Weng, 1988; Shaw et al., 1990) or the ecologically alterable areas in connection with industrial or fishery development (Blaber, 1980; Quinn, 1980; Rainer and Munro, 1982; Rainer, 1984; Salini et al., 1994). The results of some of these and allied studies are often used to test the hypotheses of latitude gradients in species diversity and stability-time-disturbance features of benthic marine communities (Pianka, 1966; Sanders, 1969; Slobodkin and Sanders, 1969; Dayton and Hessler, 1972), with various degrees of success as illustrated by Richards and Wu (1985) and Quinn and Kojis (1986).

Situated well in the center of the Indo-Pacific, Papua New Guinea (PNG) has a very poor freshwater fish fauna (Munro, 1972; Berra et al., 1975; Roberts, 1978; Allen and Coates, 1990), but is extremely rich in the marine counterpart. Kailola (1987) recently revised the number of New Guinean (fish) species to nearly twice the 1,096 species recorded in the monumental work of Munro (1967). Meanwhile, except for a relatively few localities under current large-scale mining effects (Pernetta, 1988; Hughes, 1989), the aquatic environment in PNG is pristine (Apte et al., 1991). These biological features have motivated this study. On the component characteristics and perhaps species diversity, our attention is focused on the assemblage-oriented approach on fishes of Tyler (1971).

The primary goal of this study was to demonstrate our concern with trawl bycatch in general (Saila, 1983; Alverson et al., 1994) and prawn bycatch in particular (FAO-IDRC, 1982). Up to 50,000 t of finfish are trawled and then dumped as bycatch by prawn trawlers in the Gulf of Papua and Torres Strait annually (Watson, 1984; Pender and Willing, 1989; Harris and Poiner, 1990). These practices can affect wise resource use, sound prawning economics, or both (FAO-IDRC, 1982; Somers, 1990). Unfortunately the bioeconomic benefits of a variety of prawn selective gears tested for bycatch reduction elsewhere over 25+ years (Seidel, 1975) have been ignored by many, except Indonesian (Sujastani, 1984), fisheries-concerned personnel in the Indo-West Pacific. For example, in a 1990 special issue on “the effect of fishing,” mainly prawning (Aust. J. Mar. Freshwater Res. 41 (1): 1–197), no mention is made of the positive effect of several important types of selective gears intensively developed in the North Sea and, especially, the Gulf of Mexico from the early 1970’s. De-

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ABSTRACT—The temporal variation of components of a moderately diverse (H=*1.46*) *tropical estuarine fish assemblage (long. 146°30'E, lat. 8°45'S) was directed by salinities that had been determined by local oceanographic and probably topographic conditions. For this assemblage, two types of intrayear component profiles are predicted. Pooled data (1988–91) reveal a large component of regular/resident species (43%) in an assemblage which has been under a narrow temperature regime (<5°C). These results facilitate a discussion on the relevance and usefulness of three hypotheses often cited in studies concerning species diversity and component characteristics of the subtropical/tropical coastal nonreef fish assemblages.*

Manifestations of the assemblage are reflected in catch composition and weights of 39 trials conducted for a selective prawning gear whose performance in bycatch reduction, mainly for finfishes, is judged by an index, E, *we have previously proposed. This gear is capable of harvesting the prawn while conserving the demersal fish. Behavioral responses to netting of the prawns and the finfishes, especially the nearshore surface schoolers such as leiognathids, are discussed from several points of view. An adaptation in terms of group selection for leiognathids of their locking mechanism of median fin spines has been interpreted. For the purpose of bycatch reduction or* E *enhancement, suggestions for improvements in net design and trawl configuration by considering the behavioral features of fish are made. Our original formula of* E *is modified for general use.*

Bycatch problems in the regional prawn fisheries and their possible impacts on fishery planning and development in Papua New Guinea as a developing country are discussed. The gear tested may offer enormous ecological and economic benefits. The gear is multipurpose, extremely simple, and can also be used as a biological sampler.

velopment in the latter region from the mid-1970's, led by J. W. Watson, Jr. (1989), was instrumental, we believe, in the eventual ruling of the U.S. Government in June 1987 to require prawn trawlers to use conservation measures, e.g. selective gears, while trawling in southern and southeastern U.S. waters.

This paper first deals with the bycatch, composed primarily of finfish, in nets trawled by a prawn-selective gear under paired conditions in 39 trials made near Yule Island in the Gulf of Papua in November 1988 and April 1989–91. Information derived from the bycatch is used to analyze a nekton assemblage and performance of the gear tested. Finally, attempts are made to apply the results to several aspects on temporal changes in the tropical and subtropical demersal fish assemblages and on reduction and utilization of bycatch in the regional prawn fisheries.

Materials and Methods

Yule Island (long. 146°30'E, lat. 8°45'S) is about 150 km northwest of Port Moresby and 300 km southeast of major commercial prawn grounds (Fig. 1). Sea work was conducted once a year from 1988 to 1991 aboard the *Scomber* (5 GT, 12 m long), concurrent with an annual week-long practical cruise for students in fisheries (Kan et al., 1989; Matsuoka et al., 1991).

The study area is about 5 km northwest of Yule Island and open seaward to the west. Two tributaries of the Angabunga River system enter from north with their plumes visible up to 5 km from shore. The total study area in this open estuary is about 10 km^2. The general area is known as a traditional prawn ground but has been off limits to all vessels in the commercial prawn fleet. Ecologically, it is mostly undisturbed.

The structure of the trial net was described in detail by Kan et al. (1989) and Matsuoka and Kan (1991). The net was designed to hold a device which was expected to perform a similar function to the "Trawling Efficiency Device" or TED in several prawn gears tested intensively in the Gulf of Mexico (Watson et al., 1986; Watson and Taylor, 1986; Watson, 1989).

Our TED (Kan et al., 1989; Matsuoka and Kan, 1991) had two side windows which were closed with small net pieces in about half of the trawls conducted. When closed, the net would behave the same as a typical bottom trawl net. Therefore, there were a pair of trawling conditions: "TED-open" and "TED-closed." This enabled us to compare catches hauled under opposite circumstances, i.e. with and without the TED, using one gear. The TED was 165 × 85 × 85 cm in length, breadth, and height, respectively.

The net was dragged for 30 minutes at 1.5–2 knots (2.8–3.9 km/hour) during daytime. Hauled fishes and prawns were sorted immediately into taxonomic groups, often to the family level, and then weighed. Sample specimens were preserved in ice for later laboratory studies. Except for the prawns and larger edible finfishes, all other fishes hauled were eventually discarded. However, two 1991 TED-closed hauls were fully retained for a complete analysis of bycatch species composition.

Oceanographic data were taken before, during, and after a trawl on most occasions. The instruments used for in situ measurements were a 1 liter Van Dorn Sampler[1] (Yugosha) for water samples, a refractometer (ATAGO S/Mill 0–100‰) and Cole-Parmer Water Instrument (#5946) for salinities, a bottom sampler (Yugosha) for sediments, a current meter (Toho-Denton CM-1A) for currents 1 m below surface, and a vessel-fixed echo sounder (Furuno FE600) for depth. The direction of currents was determined by reading the degree of compass bearing.

Identification of the prawns and fishes was aided by Grey et al. (1983), Munro (1967), Masuda et al. (1984), and Kailola (1987). The species diversity index, H (Shannon and Weaver, 1963), was calculated from

$$H = -\sum\left(\frac{n_i}{N}\right)\ln\left(\frac{n_i}{N}\right) \qquad (1)$$

the dominance index, c (Simpson, 1949; Peet, 1974), from

$$c = \sum\left(\frac{n_i}{N}\right)^2 \qquad (2)$$

and the evenness index, e (Pielou, 1966), from

$$e = \frac{H}{\ln S} \qquad (3)$$

where n_i is the number of individuals of the ith species, N is the number of total individuals of all species, and S, is the total number of species observed.

In the analysis of catch composition, all statistical tests were applied at the 95% significance level unless stated otherwise. An index of gear performance in bycatch reduction, E (Kan et al., 1989; Matsuoka and Kan, 1991), was calculated from

$$E(\%) = \frac{F_c - F_o}{F_c} \times \frac{P_o}{P_c} \times 100 \qquad (4)$$

where F stands for the catch weight of finfishes, P for that of prawns, c for a TED-closed condition, and o for a TED-open condition.

Results

Oceanographic Parameters

Trawls were made to transect a portion of a plume about 1.5 km from shore. The sea surface in the trawling area was green to light green and brown. Water temperatures ranged from 27°C to 30°C and salinities from 7‰ to 28‰ (mean 12.1‰) during 1988–90 (Table 1). The area was shallow, 8–12 m, with a soft deposit type of bottom.

Bottom salinities, measured in 1991 only, were high, ranging from 34.8‰ to 35.7‰. Surface salinities of the year were relatively high (mean 25.2‰). Mean current speed was 0.25 m/sec (5.12 n.mi./day). The current directions were mainly southeastward (295°–325°) (Table 1).

Trawled Animals in General

The trawled animals consisted of a target catch of four penaeids (*Penaeus merguiensis*, *P. monodon*, *Metapenaeus endeavouri*, and *M. ensis*) and a bycatch

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[1] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1.—Oceanographic parameters recorded near Yule Island in northeastern Gulf of Papua. Note: Data were collected in mid-November 1988, early to mid-April 1989–90, and on 9 April 1991.

Item	No. of records	Range 1988–89	Range 1990	Range 1991	Mean
Temperature (˚C)					
Air	39	26–35	26–35		30.84
Surface	43	27–30	27–30	29–30	28.85
Bottom	4			29 (all)	29.00
Salinity (‰)					
Surface	43	7–28	7–21	22–27	18.71
Bottom	4			35–36	35.40
Current	4				
Speed (m/sec)				0.15–0.35	0.25
Direction (compass 4 degrees)				295–325	310

Table 2.—Finfishes caught by TED-open and TED-closed trawls northwest of Yule Island in the northeastern Gulf of Papua.

Family and species caught, 1988–91	TED-closed catch (1991) Notation[1]	No. of fish	Percent of fish
Carcharhinidae			
Carcharhinus macloti	R	1	0.02
Sphyrnidae			
Sphyrna lewini	P		
Dasyatidae			
Dasyatis bennetti	P, NR		
Himantura uarnak	P		
Gymnuidae			
Aetoplatea tentaculata	P		
Clupeidae			
Anodontostoma chacunda	P		
Herklotsichthys sp.	P		
Sardinella albella	R, ON	1	0.02
Sardinella melanura	O	3	0.05
Engraulidae			
Setipinna tenuifilis	P		
Thryssa aestuaria	R	3	0.05
Thryssa hamiltonii	R	4	0.07
Thryssa sp.	R	1	0.02
Synodontidae			
Saurida tumbil	O, ON	1	0.02
Synodus variegatus	P		
Ariidae			
Arius armiger	R	151	2.52
Plotostidae			
Plotosus canius	P		
Antennaridae			
Kuiterichthys furcipilis	P, NR		
Fistularidae			
Fistularia petimba	P		
Platycephalidae			
Platycephalus indicus	P		
Pegasidae			
Pegasus volitans	O, ON	3	0.05
Teraponidae			
Terapon jarbua	R	12	0.20
Terapon theraps	R	44	0.73
Priacanthidae			
Priacanthus macracanthus	R	3	0.05
Apogonidae			
Archamia lineolata	P		
Sillaginidae			
Sillago sihama	R	3	0.05
Lactariidae			
Lactarius lactarius	R	19	0.32
Carangidae			
Alectis indicus	P		
Carangoides chrysophrys	O, ON	2	0.03
Caranx para	R	1	0.02
Caranx sexfasciatus	R	8	0.13
Megalaspis cordyla	R	1	0.02
Parastromateus niger	P		
Scomberoides commersonianus	R	2	0.03
Scomberoides lysan	P		
Scomberoides tol	P		
Selar boops	O, ON	3	0.05
Selaroides leptalepis	O, ON	3	0.05
Ulua mentalis	P		
Menidae			
Mena maculata	P		
Leiognathidae			
Gazza minuta	R	304	5.07
Gazza sp.	P		
Leiognathus rapsoni	R	147	2.45
Leiognathus splendens	R	3,760	62.70
Secutor ruconius	R	622	10.37
Lutjanidae			
Lutjanus erythopterus	P		
Lutjanus johnii	P		
Lutjanus semicinctus	P		
Nemipteridae			
Nemipterus marginatus	P		
Nemipterus sp.	P		
Gerreidae			
Gerres filamentosus	P		
Pomadasyidae			
Pomadasys argenteus	P		
Pomadasys argyreus	R	584	9.74
Pomadasys maculatum	P		
Sciaenidae			
Johnius (Johnieops) goldmani	R	25	0.42
Johnius (Johnieops) amblycephala	P		
Johnius (Johnieops) belangerii	R	20	0.33
Johnius (Johnieops) macropterus	P		
Nibea soldado	P		
Otolithes ruber	R	84	1.40
Protonibea diacanthus	P		
Mullidae			
Upeneus sulphureus	R	94	1.65
Upeneus tragula	P		
Drepanidae			
Drepane longimana	P, NR		
Drepane punctata	R	43	0.72
Cirrhitidae			
Cirrhitichathys falco	P		
Sphyraenidae			
Sphyraenells flavicauda	P		
Polynemidae			
Polydacttylus microstoma	R	2	0.03
Polydactylus sealei	R	6	0.10
Trichiuridae			
Trichiurus lepturus	R	15	0.25
Sombridae			
Scomber japonicus	O, ON	4	0.07
Bothidae			
Pseudorhombus elevatus	R	3	0.05
Cynoglossidae			
Cynoglossus bilineata	R	3	0.05
Triacanthidae			
Triacanthus indicus	R	4	0.07
Tetradontidae			
Arothron nigropunctatus	R, ON	2	0.03
Arothron sp.	R	6	0.10
Sphoeroides spadiceus	R		
Total 37 families and 77 species/forms		5,997	ca. 100

[1] Note: "NR" indicates a species new to Papua New Guinea, "ON" denotes a species only occurred in 1991, "O" is an occasional species, "P" is a periodic species, and "R" is a regular/resident species.

of many finfishes along with a few jellyfishes, gastropods, mantis shrimps, crabs, starfishes, and reptiles (one sea turtle and two sea snakes). Numerous silvery and mucous leiognathids were conspicuously on top of the bulk of hauled animals in each of the catches. Three dasyatid stingrays were trawled on different occasions during 1989–90; they were excluded from the comparison of finfish catches due to their anomalously large size (each >20 kg), which would bias the results. On many occasions, seabirds and sharks were observed scavenging the bycatch soon after it had been discarded.

Trawled Fishes

A total of 77 species in 37 families were identified (Table 2). Three were new records for PNG: stingray, *Dasyatis bennetti* (specimen disc width 650 mm); frogfish, *Kuiterichthys furcipilis* (specimen TL 53 mm); and batfish, *Drepane longimana* (specimen TL 168 mm). *Cirrhitichthys falco* appears to be new to the record of fishes from the Papuan Gulf. One form in each of the five genera, *Herklotsichthys*, *Thryssa*, *Gazza*, *Nemipterus*, and *Arothron*, was of uncertain taxon.

Among the 37 families, Carangidae had more than 10 species, Sciaenidae had seven species, Clupeidae, Engraulidae, and Leiognathidae each had four species, and Lutjanidae and Pomadasyidae each had two species. The remaining 30 families were all monospecific.

Eight species were found only in 1991: *Sardinella alebella*, *Saurida tumbil*, *Pegasus volitans*, *Carangoides chrysophrys*, *Selar boops*, *Selaroides leptalepis*, *Scomber japonicus*, and *Arothron nigropunctatus*.

From the 1991 TED-closed catch data, the abundance of individual species in each family was assessed (Table 2). Leiognathids were the most abundant group (about 80% of 5,997 fish trawled), followed distantly by pomadasyids (9.7%), ariids (2.5%), mullids (1.7%), and 18 other groups (about 6% combined). This profile yielded a diversity index (*H*) of 1.46, a dominance index (*c*) of 0.42, and an evenness index (*e*) of 0.28 for the assemblage in April 1991.

Finfish Catch vs. Trawling Condition

In addition to the four penaeids, most listed finfishes (Table 2) were found in the majority of hauls in 1988–89. Minor fishes (Group 7 below) occurred less in 1990. In the 1991 TED-closed hauls, only one-half of the 77 species, in 22 of the 37 families, occurred (Table 2).

In terms of catch weight, the penaeid prawn and six finfish groups were distinguished in nearly all 1988–90 catches:

1) Penaeids (penaeid prawns),
2) Leiognathids (ponyfishes),
3) Pomadasyids (javelinfishes or grunts),
4) Polynemids (threadfins),
5) Sciaenids (jawfishes or drums),
6) Lactariid—*Lactarius lactarius* (milk trevally), and
7) All other finfish families.

This taxocene was tabulated for an analysis of catches from 13 pairs (TED-closed vs. TED-open) and 13 sets of weight data obtained, respectively, from the 1988–89 and 1990 trawls (Table 3).

As expected, the total and mean weights of the 13 TED-closed catches were considerably greater than those of the 13 TED-open ones (855 kg vs. 548 kg and 66 kg vs. 42 kg, respectively). However, the mean weight of prawns in these two types of trawls in 1988–89 (6.3 kg and 5.6 kg) was not significantly different ($P<0.05$). Also, the prawn retention ratio percentage, mean (open) / mean (closed) × 100, was extremely high, up to 98%, in 1990. Conversely, the mean exclusion ratio percentages (1 – retention ratio) × 100, of all finfish in a TED-open trawl were only 38% and 54%, respectively, in 1988–89 and 1990.

Fish catch weights under the two trawling conditions during 1988–90 were compared (Table 4). Leiognathids, caught repeatedly in very large quantities, showed no difference among all catches ($P<0.05$). Difference between the TED-closed and TED-open catches was significant for pomadasyids ($P<0.05$), but only slightly significant for either sciaenids or polynemids ($P<0.1$). However, it was noted that the sciaenids were completely absent from five, and, polynemids from two, of the 13 TED-open catches (Table 3). Other fishes (Group 7), in 32 families, contributed to this difference between two trawl types. *L. lactarius* occurred much more in the TED-closed catches of 1990 than those of 1988–89 ($P<0.05$).

Gear Performance

Pooled data for 1988–90 (Table 3) gave the present dual-condition gear a performance in bycatch reduction, *E* of 43%. The gear performed better in 1990 (51%) than 1988–89 (34%). This difference was caused by a large increase of the biomass of *L. lactarius* in catches in 1990 (Table 3). This fish fluctuated again in its abundance, in the opposite direction, the following year (Table 2).

Discussion

Temporal Variation of the Assemblage

We could only trawl a site within a particular week each year between 1988 and 1991. The area and time selected for the trawling therefore were extremely crucial (Johnson and Nielsen, 1985). The ecosystem northwest of Yule Island is known to be relatively undisturbed as well as unexploited. Our trawling was timed to a transition in direction of two trade winds prevailing the Gulf of Papua (Wyrtki, 1960): the "Lahara," northwest from December to March and the "Laurabada," southeast from late March–early April to late October. As the pattern of both surface and bottom currents there has been known to be generally parallel to that of the trade winds (MacFarlane, 1980), we expected to collect a good deal of data by sampling an assemblage which we believed was in a process of change in composition.

Without critically considering an effect of time lag, data collected at a particular period apply only to the fish assemblage congregated at the time of collection (Fay et al., 1978), here mainly one week in mid-April. For this study of fish and prawn selective trawl gear, data were collected through a program conducted intensively at a selected time and site (Kan et al., 1989; Matsuoka et al., 1991) and, hence, were judged important to show certain aspects of the fish/nekton assemblage then converged, as reflected by its characteristics shown in the TED-open and TED-closed catches.

Temporal change in trawl fish assemblages in various habitats has been studied since the late 1960's when the concept of fish assemblage was advancing (Tyler, 1971). Only abiotic factors (Marais, 1988) are considered, by concept. Salinity has been observed as a causative factor in maintaining intrayear (within year) and /or interyear (between years) variations in several estuarine and coastal fish/macrobenthos assemblages in PNG and Queensland, Australia (Stephenson, 1980; Quinn, 1980; Stephenson et al., 1982; Rainer, 1984; Quinn and Kojis, 1986; Weng, 1988). In April 1991, only half of the total number of fish species recorded during the study period (1988–91) occurred in the TED-closed catches (Table 2). This change is believed to be a consequence of the more saline water in 1991 than in each of the two previous years (Table 1).

Higher salinity than usual in the estuary could be caused by one or more of the following conditions: drought at higher altitudes, greatly reduced local rainfall, higher rate of local evaporation, inflow of oceanic water, or heavy influx of salt ions from anthropogenic sources. For this estuary in April 1991, the latter condition was impossible. The first two conditions could not be verified due to lack of local meteorological data; however, the general weather pattern along the Papuan coast indicated an absence of both conditions during March–April 1991. Daily air temperature varied very little in our records during 1988–90. However, based on our in situ observations of the current direction, a delay of the "Laurabada" was occurring in mid-April 1991 and, consequently, the "Lahara" together with the currents it drove continued to persist southeastward. As a result, there was an influx of oceanic waters, driven by the southeastward winds, into this open estuary. Our salinity records of two earlier years in April indicate that no such delay has taken place for either year (Table 1). Nevertheless, Yule Island itself should topographically subdue any major northwestward currents from reaching the estuary (Fig. 1).

Structure and function in a system of fish assemblages or communities are dynamic. Information on temporal variation of the components are essential for ecological studies on such a system (Ross, 1986). Meanwhile, as pointed out by Tyler et al. (1982) and Caddy and Sharp (1986), present knowledge of the structure and function of fish/nekton associations should be consolidated and mapped for convenience in marine resource management (Munro, 1983; Butler et al., 1986).

Among the eight species that occurred only in 1991, seven are truly marine fishes: three carangids (Gunn, 1990) and one each, clupeid, scombrid, synodontid, and pegasid (Pietsch, 1978). They are designated as the occasional species of this assemblage; their occurrence has been coincident with an incursion of oceanic waters (34–35 ‰, "Type 3," Wolanski et al., 1984).

Our data are insufficient to shed further light on the remarkable interyear component change of this shallow water assemblage, as observed between 1988–89 and 1991. In our attempt to delineate the temporal component profile of the assemblage, two distributional records have been essential: a list of primarily estuarine fishes from two river deltas about 400 km northwest of Yule Island (Liem and Haines, 1977) and a record of trawlable teleosts from the Papuan Gulf in mainly offshore waters about 50 m deep (Kailola and Wilson, 1978). The data on the euryhaline elasmobranchs of Taniuchi et al. (1991) and the euryhaline teleosts of Roberts (1978), Collette (1983), and Quinn and Kojis (1986) from PNG are also helpful. By comparison, the status of temporal characteristics of nearly all present species in the assemblage can be inferred (Table 2).

Not surprisingly, none of the seven occasional species (9% of total number of species) is found in the above list of delta fishes, but all are in the record of Gulf fishes. About 33 (43%) species have occurred in catches throughout this study and hence designated as the resident or regular species of the assemblage. These are euryhaline species. Except *A. nigropunctatus*, caught only in 1991, all resident teleost species are found in the record of Gulf fishes. *Carcharhinus macloti* is the sole resident elasmobranch here. Its allied species, *C. carcharhinus* is highly riverine in PNG (Kan and Taniuchi, 1991). About 28 (85%) of the resident species or, in a few cases, their congenerics including the lutjanids, pomadasyids, and mullids, also occur in the Gulf deltas or similar habitats elsewhere in PNG. The remaining 37 (48% of the total number of species) species occurred intermittently during the study period and could be considered as the periodic species of this assemblage. These fishes should be more stenohaline and would move to less saline waters in the presence of oceanic water. About 22 (60%) of the periodic species are found in either the delta or the Gulf fish list mentioned above. There should be more periodic species in the delta list than in the Gulf record. However, the present figure (37) is acceptable because the latter list is considerably longer than the former (350+ species vs. 144 species), comprising only teleost species from a much greater zone covering many offshore and in particular nearshore/onshore subzones.

With valid data from four coastal or estuarine areas in the northwest Atlantic (lat. 38°N to lat. 45°N), Tyler (1971) hypothesized that a temperature range stabilizes the temporal components in fish assemblages. More regular or resident species would be expected to occur in an assemblage under a narrower temperature regime. Many studies of assemblages from several warmer temperate and subtropical coastal waters have supported this hypothesis to certain degrees, including Allen (1982) in southern California (lat. 34°N), Bennett (1989) in southwestern Cape, South Africa (lat. 34°S), Yoshiyama et al. (1982) in southern Texas (lat. 27°N), Quinn (1980) in southern Queensland (lat. 27°S), Jones and Chase (1975) in Guam (lat. 14°N), U.S.A., and Rainer and Munro (1982) in northwestern Queensland (lat. 17°S). Our assemblage (lat. 9°S), on an interyear basis during April 1989–91, was under a temperature regime less than 5°C wide, and had a very large component of resident species (43%). Quinn (1980) reported one tetradontid, *Spheroides pleurostictus*, as the only resident fish of an estuarine assemblage of 44 fishes (2.3%) with a 17°C wide annual temperature range. Richards and Wu (1985) listed 16 resident species in a bay assemblage immediately west of the island of Hong Kong (lat. 22°N) of 85 species (19%) with an annual temperature range of 12°C.

Bennett (1989) observed that the seasonal flooding and coastal topography impacted the annual component profile of three estuarine fish assemblages under a temperature range of 8°C. Quinn and Kojis (1986) related interyear component variation in an estuarine nekton assemblage in PNG where the temperatures ranged only 6°C due to local rainfall characteristics. Both rainfall and flooding affect local salinities (Stephenson, 1968; Lowe-McConnell, 1987). According to our study and Quinn and Kojis (1986), other weather-caused "anomalies" such as the intrusion of oceanic waters and local droughts may also affect salinities in the estuaries. Therefore, we suggest that in PNG the component characteristics of coastal nonreef fish assemblages are related to local salinities which in general are determined by a weather pattern that, in turn is controlled by the prevailing monsoons. Therefore, interyear variability, often unpredictable, may be superimposed upon predictable seasonality, in PNG and probably elsewhere in coastal areas of the tropics (Lowe-McConnell, 1987).

For the purpose of multispecies fisheries management, a holistic approach involving abiotic and biotic, including human, factors should be adopted in the study of temporal features of tropical demersal fish faunas for baseline information (Sainsbury, 1982; Gulland and Garcia, 1984; Longhurst and Pauly, 1987). Unfortunately, such studies from PNG are few. Dalzell (1987) reported a peaking in spawning intensity of two inlet engraulids associated with the monsoon seasonality in New Ireland. Recent relevant data on nearshore faunas in New Guinea include Erftemeijer and Allen (1990) and Nojima and Mukai (1990) on trophic relationships; Quinn and Kojis (1986) on indications of a mangrove-lined estuary as "safe site(s) (Frank and Leggett, 1983)"; Quinn and Kojis (1987) on some nekton behavioral responses to abiotic parameters; and Sundberg and Richards (1984), Wright and Richards (1985), and Lock (1986) on fishing activities and effects.

Although the applicability of the Shannon-Weaver diversity index (*H*) to such habitats as the often heterogeneous coastal bottoms has been questioned (Pielou, 1966; Caddy and Sharp, 1986), the index is frequently used by fisheries ecologists (Routledge, 1979; Washington, 1984). As diversity of a community or assemblage depends upon not only the number of species but also the evenness of distribution of individuals among the species, *H* should be measured along with additional ecological measures including the dominance index (*c*) (Simpson, 1949; Peet, 1974) and the evenness index (*e*) (Pielou, 1966). Our assemblage, in mid-April 1991, exhibited an *H* value (1.46) smaller than that in three other tropical assemblages, in Guam, southern Taiwan, R.O.C., and the Philippines: 3.05, 3.15, and 1.98 respectively (Jones and Chase, 1975; Lee, 1980; Pinto, 1988), and even of assemblages in the subtropical Hong Kong and Queensland (1.90–2.25) (Quinn, 1980; Richards and Wu, 1985; Weng, 1988). Both the dominance (*c*) and evenness (*e*) indices, here, were moderate, respectively, 0.42 and 0.28, reflecting the role *Leiognathus splendens* played in the former (*c*) and leiognathids as a whole in the latter (*e*).

Our smaller value of *H* may be due partially to the large mesh size (4.5 cm) of the net used. Mesh sizes used in other demersal fish surveys of tropical/subtropical waters, excluding those for larval/juvenile fish (Allen et al., 1983), ranging from 2.5 cm (Gibbs and Mathews, 1981–2; Pinto, 1988) to 5.5 cm (Watson et al., 1990). However, the *H* value (1.46) we observed is for an assemblage in waters under a strong oceanic influence ("Type 3" waters/salinities; Wolanski et al., 1984). Weng (1988) reported a decrease of diversity (*H*) in trawlable fish assemblages on a gradient from an estuarine zone (2.0–2.5) to a central (bay) zone (1.4–2.0) and two oceanic zones (1.9–2.0 and 1.1–2.0) in the subtropical Moreton Bay, Queensland. Nevertheless, providing that the sampler (4.5 cm mesh), sampling (daytime only), and local topography remain similar to those herein, we predict a typical *H* value around 1.5 for any assemblages congregated between December and March ("Lahara" type) and a typical *H* value up to 3.0 for those between April and November ("Laurabada" type) in the estuary presently studied. Assemblages of the "Lahara" type would have a larger component of resident species congregated in the oce-

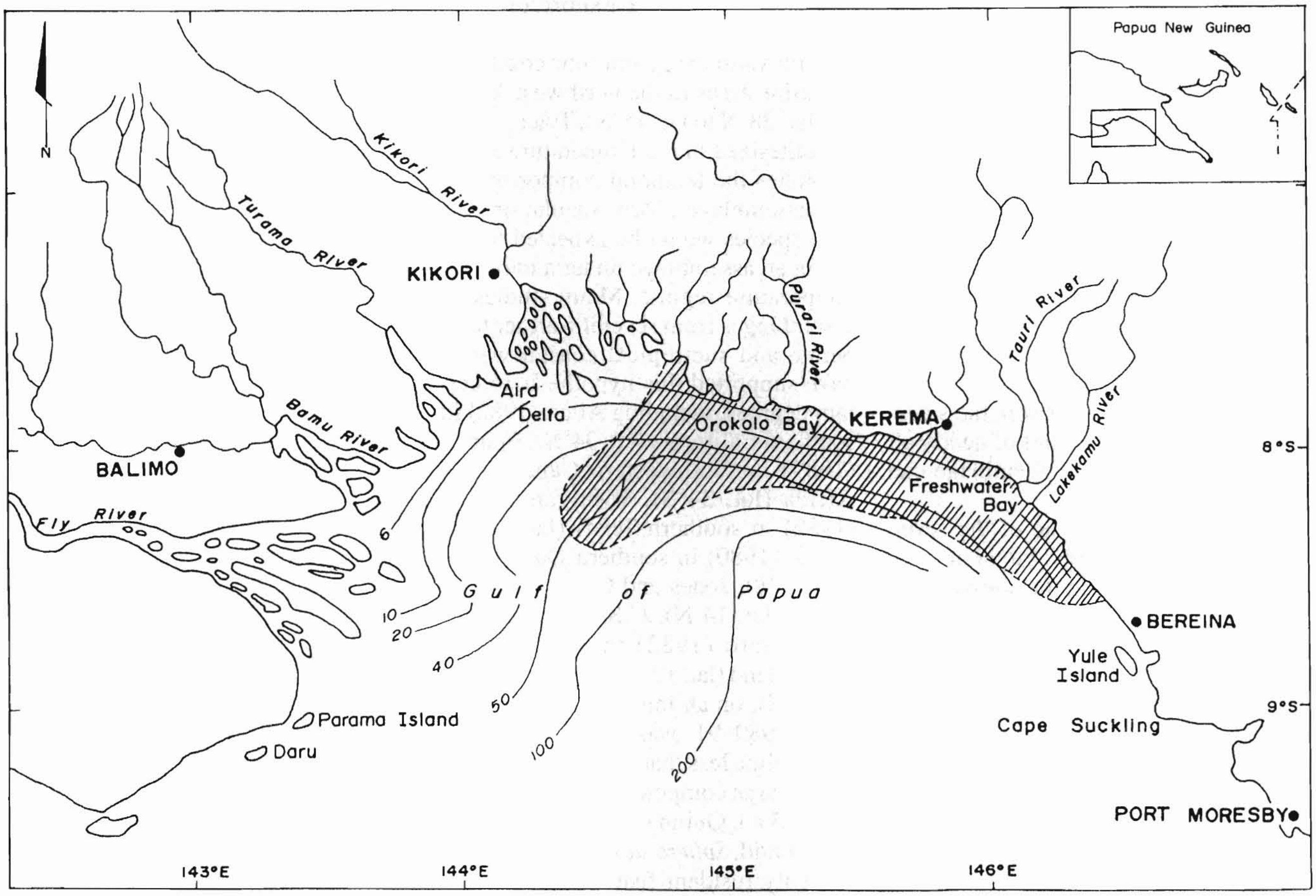

Figure 1A. — Commercial prawning grounds in the Gulf of Papua, PNG.

anic type waters while the "Laurabada" type would have a larger component of periodic species congregated in the estuarine-type waters.

In his interpretation and discussion of findings on the temporal profiles of several temperate and tropical demersal fish assemblages, Tyler (1971) made no reference at all to the then popular and seemingly relevant hypotheses of Pianka (1966) and Sanders (1969). Major works on the fish/macrobenthos associations in the southeast Asian and warmer Australian regions have similarly refrained (Chua, 1973; Blaber, 1980; Stephenson, 1980; Quinn, 1980; Rainer and Munro, 1982; Weng, 1988; Watson et al., 1990). This may be due to Pianka's (1966) use of the word "latitude," which is expressed for a totally artificial entity. It tends to be inconclusive and hence undesirable to test, with data derived from the spatially limited assemblages, those hypotheses that are of a general and mainly a faunal-region-scale manifestable nature.

For instance, in their attempts to present selected results either supporting or contradicting the hypothesis of Pianka (1966) and, perhaps, that of Sanders (1969) as well, Richards and Wu (1985) and Quinn and Kojis (1986) have conveniently used an entirely independent set of published data (see Fig. 8 in the former and Fig. 1 in the latter). The Tyler (1971) hypothesis on a manifestation of the effect of temperature regime is more prudent in elucidating the subject of component characteristics of fish assemblages.

As we have observed here, other causative factors such as salinity and topography should also be considered in drawing any conclusions on the component change and, perhaps, species diversity of coastal fish assemblages (Bennett, 1989), especially in the tropics. With reference to Quinn (1980), Quinn and Kojis (1986) discounted the effects of such factors existing in their study area for their comments apparently to contradict Pianka's (1966) concept. The two estuaries, Serpentine Creek in southern Queensland (lat. 17°S) and Labu lakes (lat. 7°S) in PNG, where Quinn sampled for those two publications, are different in salinity profile and especially topographic features. The latter, not described in Quinn and Kojis (1986), is unique in that those lakes are mostly separated from the sea by a narrow sandbar upon which several villages are situated, and the inflow of sea water to them is restricted to an opening less than 50 m in width (Apte et al., 1991). Fish assemblages in those two entirely and physically different habitats are hardly comparable in Pianka's (1966) context simply in terms of absolute number of species present.

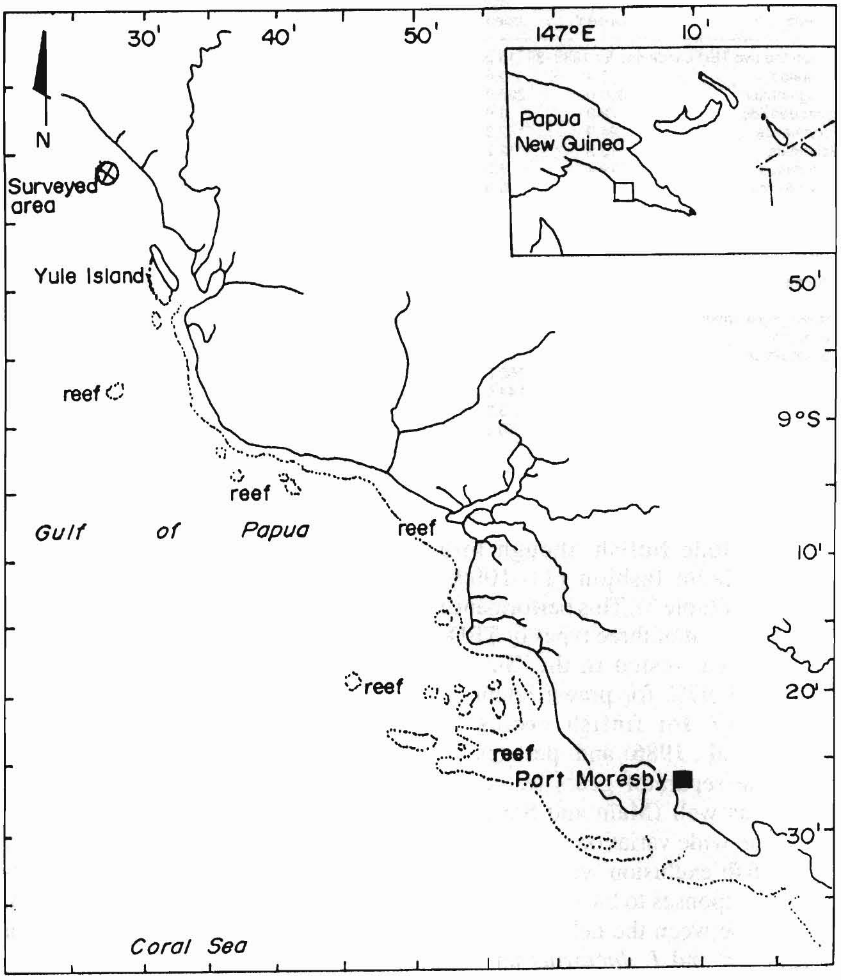

Figure 1B. — Study area in the Gulf of Papua, PNG.

Whether their analysis in the context of hypotheses on stability-time-disturbance of the benthic marine communities is desirable (Sanders, 1969; Slobodkin and Sanders, 1969; Dayton and Hessler, 1972; Connell, 1978), certain demersal fish assemblages in the seas adjacent to the South China Sea have been shown to be undergoing a significant temporal-spatial change in structure resulting from disruptions through overfishing (Pope, 1979; Pauly, 1979, 1982; Gulland, 1987; McKenna and Saila, 1991). Adjacent to the Gulf of Papua, Poiner and Harris (1986) also noted such a change due to the impact of commercial prawn trawling in the Gulf of Carpentaria, Australia. The demersal fish fauna of the Papuan Gulf is similar to those Indo-Pacific fish systems in structure (Harris and Poiner, 1990) and, perhaps, in function as well (Rainer, 1984), with the ubiquitous leiognathids plus carangids and sciaenids plus pomadasyids and mullids as, respectively, the major nektonobenthic and benthonektonic components. Therefore, its stability is expected to be vulnerable under any heavy exploitations that may result in a vastly declining fishery production (Pope, 1979; Pauly, 1979, 1982; Poiner and Harris, 1986; Lowe-McConnell, 1987).

Current fishing intensity in the Gulf of Papua is considered moderate, if not low, being exerted mainly on the stocks of prawn and lobster (DFMR, 1989) and, occasionally, shark (Chapau and Opnai, 1986). However, fishing pressure on the Gulf demersal fish communities may grow considerably in view of a policy (DFMR, 1989; Agrodev, 1991) adopted recently by PNG to vigorously develop its fishery resources, aimed at a substitution of imports of the canned mackerels (up to US$50 million per year; Olson and Kan[2]). Previous relevant data only deal with the northwestern portions of the Gulf (Liem and Haines, 1977; Kailola and Wilson, 1978; Roberts, 1978; Watson, 1984). Along with the present findings from a northeastern Gulf fish assemblage, these data provide baseline information for the planning of fisheries development in the Gulf of Papua.

Table 3.—Comparison of catches (kg) under two TED trawling conditions.

		TED-closed/TED-open					
Year(s)	Taxocene	No. of trawls	Total weight	Range	Mean	S.D.	Retention ratio (%)[1]
1988–89	Penaeids	13/13	81.8/72.2	2.8–10.9/1.7–10.9	6.3/6.6	2.7/2.3	88.9
	Leiognathids	13/13	291.0/305.0	3.5–65.6/4.2–45.9	22.4/23.5	17.6/15.1	105.0
	Pomadasyids	13/13	247.0/59.5	2.1–32.4/1.0–12.8	19.0/4.6	8.5/3.2	24.2
	Polynemids	13/13	48.2/13.2	0.1–19.4/nil–5.0	3.7/1.0	5.0/1.4	27.0
	Sciaenids	13/13	43.1/14.4	nil–15.0/nil–5.0	3.3/1.1	4.4/1.5	33.3
	L. lactarius	13/13	37.4/28.0	0.1–16.9/nil–7.9	2.9/2.2	3.9/2.6	75.9
	Other fishes	13/13	107.0/55.9	3.8–12.5/1.0–12.9	8.3/4.3	3.0/2.9	51.8
	Mean		129.0/79.4	1.5–27.0/1.0–14.9	9.9/6.1	7.1/4.5	61.6
1990	Penaeids	7/6	38.3/32.2	3.5–7.5/2.8–10.2	5.5/5.4	2.1/2.7	98.2
	Leiognathids	7/6	229.0/118.0	10.4–68.8/8.5–39.9	32.8/19.7	21.8/19.7	60.1
	Pomadasyids	7/6	163.0/15.2	7.0–45.6/0.5–6.0	23.4/2.5	16.2/2.1	10.7
	Polynemids	7/6	113.0/12.6	3.8–40.8/0.5–4.4	16.2/2.1	12.0/1.3	13.0
	Sciaenids	7/6	43.0/18.6	2.1–9.4/0.5–5.5	6.1/3.1	2.3/1.9	50.8
	L. lactarius	7/6	143.0/102.0	10.0–30.0/3.8–36.5	20.7/17.0	7.5/11.5	82.1
	Other fishes	7/6	16.0/9.7	nil–3.0/nil–2.2	2.3/1.6	1.1/0.9	69.6
	Mean		118.0/46.0	5.6–32.9/2.3–15.8	16.9/7.7	10.2/5.0	45.6

[1] Note: Retention ratio is calculated from mean (open)/mean (closed) × 100.

Table 4.—Comparison of difference in catch weight (kg) under two TED trawling conditions. Note: F test of variance is at a 90% level of significance. Sign in the parentheses indicates a significant difference. The asterisk (*) indicates a significant difference at the 90% level.

	Variance			Mean		
Taxocene	TED closed	TED open	F-value	TED closed	TED open	t-value
Between the two TED conditions for 1988–89 (13 pairs)						
Penaeids	7.4	5.4	1.37(–)	6.3	5.6	0.72(–)
Leiognathids	309.0	228.0	1.35(–)	22.4	23.5	0.17(–)
Pomadasyids	72.9	9.9	7.35(+)	19.0	4.6	5.45(+)
Polynemids	24.9	2.3	12.28(+)	3.7	1.0	1.80(–)*
Sciaenids	15.2	2.2	6.79(+)	3.3	1.1	1.88(–)*
L. lactarius	19.4	7.0	2.78(+)	2.9	2.2	0.51(–)
Other fishes	9.9	8.6	1.04(–)	8.3	4.3	3.28(+)

	Variance			Mean		
Taxocene	1988–89	1990	F-value	1988–89	1990	t-value
Between years under the TED-closed condition (13 sets vs. 7 sets)						
Penaeids	7.4	4.4	1.73(–)	6.3	5.5	0.69(–)
Leiognathids	309.0	475.0	1.53(–)	22.4	32.8	1.16(–)
Pomadasyids	72.9	262.0	3.60(+)	19.0	23.4	0.81(–)
Polynemids	24.9	144.0	5.78(+)	3.7	16.2	3.31(+)
Sciaenids	15.2	5.3	3.60(–)	3.3	6.1	1.81(–)*
L. lactarius	19.4	56.3	3.66(+)	2.9	20.5	6.84(+)
Other fishes	9.9	1.2	7.76(+)	8.3	2.3	5.06(+)

Performance of Our TED Gear

Manifestation of this assemblage in the present catches is significant. As an estuarine species associated with low salinities (<5‰) in PNG (Quinn and Kojis, 1986), *L. lactarius* was very common in April during 1989–90 but was extremely rare in the same month in 1991 (Tables 2, 3). The reverse was true for *Arius armiger*, a marine fish, with 11 congenerics occurring in two river systems in the Papuan Gulf (Berra et al., 1975; Roberts, 1978) and the Sepik River in northern PNG (Allen and Coates, 1990). Both cases resulted from an inflow of oceanic waters, as we have observed. This is also reflected in catch composition and weights in our assessment of the TED-open gear in terms of its potential to reduce finfish bycatch (Tables 3, 4).

Our data indicate that, while being trawled, the TED-open net is able to retain prawns (retention ratio 89–98%) and to exclude finfish, though to a highly variable fashion (11–100%, mean 46%) (Table 3). This performance is similar to that of three types of TED-equipped gear tested in the Gulf of Mexico: 95–97% for prawn retention and 11–88% for finfish exclusion (Watson et al., 1986) and, perhaps, to that of the separator gears tested off Scotland as well (Main and Sangster, 1982). The wide variation observed by us in finfish exclusion was caused by different responses to the dual trawling condition between the nektonobenthic leiognathids and *L. lactarius* and the benthonektonic groups., e.g. pomadasyids, polynemids, and sciaenids. These results have demonstrated that the TED-open type of gear is capable of harvesting the prawn while conserving demersal fish. Also, as noted by Matsuoka and Kan (1991), this gear has only a moderate negative trawling impact on smaller demersal fish except perhaps the pomadasyids.

For general use, two variables, F_c and F_o, in the formula proposed for the measurement of the TED gear performance, *E* (Kan et al., 1989; Matsuoka and Kan, 1991), should be redefined to cover all trawlable nekton concerned including the *Loligo* cephalopods, a prominent

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[2] Olson, F. L., and T. T. Kan. 1989. The fishery resources of Papua New Guinea. Univ. PNG, Dep. Fish., Port Moresby, Unpubl. rep., 21 p.

component of several Indo-Pacific, often heavily exploited, bottom fish and prawn systems (Longhurst and Pauly, 1987; Gray, et al., 1990; Harris and Poiner, 1990; Shaw et al., 1990; McKenna and Saila, 1991). This measure is now proposed as follows:

$$E(\%) = \frac{N_c - N_o}{N_c} \times \frac{P_o}{P_c} \times 100 \qquad (5)$$

where N_c is the catch weight of all nekton other than prawn in the TED-closed or control net, N_o, the catch weight of all nonprawn nekton in the TED-open or test net, P_c, the catch weight of prawns in the TED-closed or control net, and, P_o, the catch weight of prawns in the TED-open or test net. Theoretical consideration of this measure, E (%), is that the performance of any TED or similarly equipped gears should be judged by the extent expressed in their dual function: to exclude all nonprawn nekton and to retain the prawns. Performance here varies from zero ($N_c = N_o$ and/or $P_o = 0$) to full ($N_o = 0$ and $P_c = P_o$) effectiveness.

Temporal-spatial variability of E should be great due to various abiotic, biotic, and human factors interacted in an assemblage of bottomfish ground. The value of E in this study was greater in 1990 (51%) than 1988–89 (34%) owing to an interyear fluctuation of abundance (biomass) of leiognathids and *L. lactarius* (Table 3). Compared to 1988–89, the relative abundance of this species was negligible in April 1991 when salinity was high (Table 1). Whether or not the abundance (biomass) of prawns affects E, it certainly does affect the weight of bycatch. Prawning fleets in the Gulf of Papua and Torres Strait expend effort differently over time and space (Kolkolo, 1983; Williams, 1986), apparently responding indirectly to the effect of higher salinities which are caused by the interactions of winds, currents, river runoffs and plumes, and topographic features (Wolanski et al., 1984). Unfortunately, our data on any links among salinity, prawn biomass, and finfish catch weights are inconclusive (Matsuoka et al., 1991). Further trials should be conducted for the typical "Lahara" and "Laurabada" types of fish/nekton assemblages.

Our TED-open net has shown an average E of 43%, calculated from the catch results between 1988 and 1990. Based on data of an earlier test of a variety of TED gears conducted off Mississippi-Louisiana (Seidel, 1975), their average E, calculated by us, was 27%. The E later advanced to 41% (Watson and McVea, 1977) and > 50% (Watson et al., 1986) with several improved versions of TED gears tested there. All of these results, including ours, have pointed out that most, if not all, TED/separator-equipped prawning gears are able to retain the prawn (target catch) effectively and to exclude the finfish (bycatch) ineffectively. Many fishes, e.g. ariids, stromateids, and sciaenids, were well excluded by two recent TED gears in the Gulf of Mexico (Watson et al., 1986). If only demersal fish were treated, the E during 1988–90 in our study could be as high as 65%. Apparently, the two 40 x 40 cm side windows of our TED have facilitated escapement for the demersal component of the present taxocene (pomadasyids, sciaenids, and polynemids).

Behavior of the Fish and Prawn in Relation to Escapement

The prawn component of the above formula for E, P_o/P_c, remains large in all relevant data available for calculation by us, ranging from 0.70 (Seidel, 1975), to 0.78 (Watson and McVea, 1977), 0.88 (Matsuoka and Kan, 1991), 0.92 in this study, and 0.95–0.97 (Watson et al., 1986). These results support a general observation that prawns are weak swimmers with little directional avoidance when stimulated either by the currents in natural water (Quinn and Kojis, 1987) or netting (Ko et al., 1970; Seidel, 1975; Watson, 1976; Valdemarsen, 1989). Prawn behavior thus directs the gear technologists away from paying attention to possible responses of the prawns in their design of high performance (E) separator/TED-equipped gears, except for a task of designing the gears on prawn size selectivity in terms of stock conservation.

Fish behavior and its use in capture fisheries has been recognized by biologists and gear technologists (Bardach et al., 1980; Wardle, 1983, 1986). Chen et al. (1989) reported an effect of mesh size on trawling and trawl fishes in relation to their escapement via different parts of an experimental gear. Watson (1989) presented an excellent discussion on the behavior of trawl fish and prawn in the Gulf of Mexico with proposals on modifications to prawn trawl design which may greatly reduce the finfish bycatch associated with a penaeid prawn fishery.

One of the TED gears of the J. W. Watson team, with a device which acts as a mechanical stimulus for fish avoidance and escapement, has achieved a finfish separation rate up to 80% with no significant loss of prawn in catches (Watson et al., 1986). This level of effectiveness is the minimum deemed acceptable by the PNG prawn industry in terms of TED gear feasibility in commercial prawning (Matsuoka and Kan, 1991). Our results only yield an effectiveness (E) about 51%. Here, the biological difference has been small among the component of benthonektonic fish whether it is observed from the Gulf of Papua, the Gulf of Mexico, or the North Sea (Main and Sangster, 1982).

Three highly TED-excludable fishes in our study, pomadasyids, polynemids, and sciaenids, are swift carangiform or subcarangiform type swimmers (Webb, 1975). Their body and tail shapes would give them the typical caudal fin aspect ratio (A) (Pauly, 1989a) of demersal fish of around 1.5 (Pauly, 1989b; Sambilay, 1990) and, while swimming, moderate Reynolds numbers, from $R_e > 5\times10^3$ to $R_e > 5\times10^5$ (Aleyev, 1977). These figures indicate their "burst" rather than "sustained" swimming mode. The functional morphology of the soft rays in these fish and many of their counterparts in the Gulf of Mexico and North Sea also signals their capacity for thrusting and maneuvering (Arita, 1971). Both the swimbladder and lateral line system are well developed, especially in the sciaenids. Specialized sensory structures for probing and tasting are frequently featured in the form of mandibular barbels (sciaenids and pomadasyids), pores on snout and lower jaw (sciaenids), and gustatory buds on free rays (polynemids) (Atema, 1980). It is considered that these benthonekton are sensitive and versatile and, therefore, highly adaptive as well as adjustable to any environmental changes either natural or caused by humans. They should be able to avoid an approaching net or escape from it via any exits available, e.g. a TED.

In night trawls off Mississippi and Alabama during mid-August to late September 1984, a collapsible fiberglass TED gear achieved very high reduction rates of 69–100% for three schooling neritic/epipelagic fishes: *Brevoortia patronus*, *Harengula jaguana*, *Scomberzomorus maculatus* (Watson et al., 1986). Our selective gear was extremely poor in excluding several carangiform swimmers including *L. lactarius* and especially leiognathids (Tables 2, 3, 4). This contrast may be due to certain faunal differences in test grounds between the Gulf of Mexico (lat. 30°N) and the Gulf of Papua (lat. 9°S). However, the above TED gear, while being tested, appeared to have disengaged any dense fish schools. Schoolers, especially the small pelagic/neritic clupeiformes and probably carangiformes, tend to break up from the compact schools at night (Hara, 1985; Thomas and Schulein, 1988). Kemmerer (1980) gave evidence of a disintegration at night of *B. partonus* schools in the northern Gulf of Mexico. Major schools of *S. maculatus* off Alabama and Mississippi might have already migrated eastward to the Florida coasts or westward along the Mexican coasts before mid-August (Collette and Nauen, 1983; Longhurst and Pauly, 1987). We are unaware of any valid data on the diel variation among schooling species in prawn bycatches observed in PNG or Queensland waters (Gray et al., 1990). However, calculated by us from R. A. Watson's (1984) data, the diel variation of average bycatch weights of the leiognathids in PNG commercial trawls is great indeed: 130 kg/day-trawl vs. 17 kg/night-trawl. Therefore, as is also true in sampling a nonreef demersal fish/nekton assemblage (Allen and DeMartini, 1983; DeMartini and Allen, 1984; Quinn and Kojis, 1987), any tests on the effectiveness of selective gears should be compared between day and night, especially if a component of schooling species is known to be large in an assemblage or a bottom fish ground concerned.

Ubiquity of the leiognathids has been well appreciated in several Indo-Pacific fish assemblages, in Singapore, Hong Kong, and PNG (Chua, 1973; Richards and Wu, 1985; Quinn and Kojis, 1986), and numerous prawn trawls in the Papuan Gulf and Torres Strait (Watson, 1984; Harris and Poiner, 1990). In probably every single haul in the present study, *L. splendens* and *Secutor ruconius* occurred the most in both weight and number (Tables 2, 3; Matsuoka and Kan, 1991). Meanwhile, Pinto (1988) noted for *L. brevirostris* and *S. ruconius* the two highest in total mortality, *Z*, among many fishes in a bay community in the Philippines.

Some aspects of reproduction of the leiognathids have been observed in the seas around southern India (Arora, 1951; Balan, 1963; James, 1975; James and Badrudeen, 1975; Murty, 1983). In general, these schooling silverbellied fish live neritic/nektonobenthic lives of <3 years, attain maturity around age 0–1 at 60–70 mm (a size similar to the peak length class we here observed; Matsuoka and Kan, 1991), and spawn more than once per year as either regular or opportunistic spawners with a high absolute fecundity, relative to their body size, of between 8,000 and 12,000 eggs. Their *Caranx*-like body shape should give an aspect ratio (*A*) about 4 (Palomares and Pauly, 1989; Pauly, 1989b) and a Reynolds number, $R_e>10^5$ (Aleyev, 1977), rendering them of a swimming mode more "sustained" than "burst," as favored in the maintenance of compact schools as "operational structures" (Breder, 1976).

Seigel (1982) described a locking mechanism of median fin spines in leiognathids, suggesting functions in defense and metabolic advantage via fin erection and, possibly, sound production. These functions would primarily benefit nonschooling and/or bottom fishes. We therefore interpret this mechanism as being adaptive to the schooling and surface/subsurface leiognathids in that, when simultaneously locked by all members in a school, it would help reduce the energy required to maintain uniformity and fluidity of schools while cruising (Breder, 1976). This would be similar in functions to automatic "cruise (speed) controls" frequently used in modern airplanes in the open sky and even automobiles on the open expressways for precise and easy cruising. The leiognathids' secretion of the thick mucus layer over the skin is also significant in sustaining their schooling efficiency while cruising (Breder, 1976). This ability to secrete, along with a highly protrusible mouth to facilitate feeding (Schaffer and Rosen, 1961) and other features mentioned above, has adapted the 25 or so carnivorous and bacterially bioluminescent leiognathid species extremely well to coastal, bay, and estuarine (Chua, 1973) environments throughout the Indo-West Pacific (James, 1975; Dunlap and McFall-Ngai, 1984; Shen and Lin, 1985). Whether or not directly contributed by a schooling behavior alone, leiognathid abundance or success has been a consequence of interplay between adaptation and evolution of the fishes concerned (eventually, "r-strategist"; Pianka, 1978) since probably the Oligocene-Miocene (Romer, 1966). Ironically, as illustrated by Murphy (1980), modern time fishing operations nearly negate all adaptive advantages of fish schools (Breder, 1976; Patridge, 1982) including those of the present leiognathids.

Balan (1963) stated that the surface or subsurface *L. bindus* schools moved toward the top film of waters upon fishing. Chen et al. (1989) indicated that the schooling *L. brevirostris* and *Setipinna taty* tend to swim upward at netting. From the profile of caught animals in nets, we noted the leiognathids usually on top. Therefore, some selectivity may be possible by modifying the net design and trawl configuration. For example, a low and canopied net opening which is made mechanically to open only near or on the bottom should reduce the quantity of leiognathids and other ecologically similar fish entering the trawl. Also, configuration and length of the filter or funnel and main nets of a gear may be modified to reduce the escapement of underutilized demersal fish (Workman and Taylor, 1989) or to enhance, as suggested by Matsuoka and Kan (1991), that of the ubiquitous surface fish, or somewhat to achieve both (Chen et al., 1989). Further, night trawling may encounter fewer fish schools composed mainly of bycatch species in the Gulf of Papua.

Bycatch and Its Impacts on PNG Fisheries Development

Despite their small body size, the leiognathids support commercially important fisheries in southern India (James and Badrudeen, 1975). As bycatch or target catch from the multispecies fisheries, the leiognathids along with ecologically similar fish are processed and marketed extensively in the southeast Asian region (Suwanrangsi, 1986; Ng and Hooi, 1987; Jean and Kuo, 1988). By contrast, finfish bycatch is almost totally wasted in the PNG prawn fishery; Watson (1984) estimated that only 250 t of primarily large fish were retained for sale fresh in 1982, and Agrodev (1991) recorded such a weight of 450 t in 1989. Bycatch discard has the effect of transferring large quantities of biological material from the bottom to the surface (Hill and Wassenberg, 1990). Bycatch discards benefit a few opportunistic scavengers and predators at or below the surface, as we and Hill and Wassenberg (1990) have observed, and on the bottom. The ecological efficiency in this transfer process initiated by trawlers must be extremely low. In terms of economic considerations on operational costs (gear, vessel, fuel, crew time, etc.) and harvest quality/value (less damaged prawns), current prawning economics in the Gulf of Papua should be considered greatly improvable using selective gears such as one TED equipped. The TED gear used in this study needs to be further evaluated, along with a bioeconomic analysis to identify its potential ecological and operational benefits. Nevertheless, to deal with the bycatch problem in prawn fisheries in regions such as the Gulf of Papua and Torres Strait, a strategy of bycatch reduction is more prudent than that of bycatch utilization (Pender and Willing, 1989).

Suggestions for various uses of the prawn bycatch for farm animal (e.g. crocodile) feeds and human consumption in PNG have been made from biological (Watson, 1984; Dalzell, 1986) and some bioeconomic (Witcombe, 1978; Barratt, 1986; Rajeswaran[3]) points of view. These uses may be ecologically and technologically attainable at both appropriate technology (Reilly and Barlie, 1986; NRC, 1988) and institutional (Okada et al., 1988) scales. However, it is highly doubtful that these uses, suggested for human consumption via commodities (Barratt, 1986), are socioeconomically viable in view of the consumption pattern of fishery products prevailing in PNG. PNG determined in 1986 (Kan and Hill, 1988) to develop its tuna fishery and other marine resources that are extremely rich in size and variety and readily retrievable as well as marketable worldwide (Philipson, 1989). Ironically, this country has become a world leader in canned mackerel imports, on average 25,000 t at US$24 million per year between 1980 and 1986 (Olson and Kan[2]). From 1982 to 1989, while the market weight of prawn finfish bycatch increased from 250 t to only 450 t, the imports of canned mackerel had tripled from 10,900 t to 33,000 t (Agrodev, 1991). Massive influx of this single import item is creating a "tinpis"[4] phenomenon in PNG; it appears to have already been a major socioeconomic constraint to the planning and development of fisheries and aquaculture (Kan, 1986) in PNG as well as in several other developing countries in this region (Lawson, 1978).

FAO-IDRC (1982), Saila (1983), and Alverson et al. (1994) drew attention to the wasteful disposal of trawl bycatches worldwide. Watson (1989) summarized the development of separator-equipped gears in trials conducted in the North Pacific, the North Atlantic, and especially the Gulf of Mexico from the late 1960's. Unfortunately, the concept of this type of gear in finfish bycatch reduction for ecological and economic benefits has been given insufficient attention by fisheries managers and gear technologists in the entire Indo-West Pacific region except of those from Indonesia and Australia (Sujastani, 1984; Mounsey[5]). This may result from a difference in the use pattern of various fishes, e.g. the leiognathids, as bycatch in the Gulf of Papua but as catch or even target catch in the south and southeast Asian regions. Nevertheless, the gear we studied is effective in excluding the demersal fishes while retaining the prawns. It, or a modified version of it, could be tested on a large commercial or intermediate technology scale. It is inexpensive, simple, and foldable; hence, it could also be used at a small subsistence or appropriate technology level (Cook and Tenakanai, 1986; NRC, 1988). Meanwhile, it ought to be an ideal sampler in the study of fish behavior and gear selectivity, especially employed along with the general type (Gibbs and Matthews 1981–2) or special type (Chen et al., 1989; Workman and Taylor, 1989) of samplers. This multipurpose gear is also extremely simple.

A balance between ecological and economic benefits must be sought in the use of modern fishing gears. Unlike probably the drift net and, to a certain degree, the modern purse seine, these gears should be highly selective. The future of fisheries management is managing the fisherman (Larkin, 1988) and his gears, whether in a developed or developing country or region.

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[3] Rajeswaran, N. 1990. Small scale fish meal processing in Papua New Guinea. Dep. Fish. Mar. Resour., Resour. Develop. Enforce. Br., Port Moresby, Unpubl. rep., 15 p.

[4] "Tinpis" is the PNG Pidgin English word for any processed and merchandized fish, especially mackerel in cans.

[5] Richard Mounsey, Senior Fishing Gear Technologist, Department of Primary Industry and Fisheries, G.P.O. Box 990, Darwin, N. T. 0801, Australia. Personal commun., July 1993.

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