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THE DYNAMICS OF LEIOGNATHIDAE IN A TROPICAL DEMERSAL ICHTHYOFAUNAL COMMUNITY

Thesis submitted by

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for the degree of Doctor of Philosophy in
the Department of Marine Biology at
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DECLARATION

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma to any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

A S Cabanban
27 September 1991

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ABSTRACT

Cleveland Bay (Townsville), on the tropical northeastern shoreline of Australia, is a small bay (225 km^2) that historically has not been subjected to commercial trawling. However, the unexploited environment of Cleveland Bay is characterized by frequent disturbance by natural processes such as resuspension of sediments on the bottom due to currents generated by wind-waves and monsoonal trade winds, high terrigenous sedimentary input from riverine systems along the coast, and lowering of salinity due to increased flooding. This presents a rare opportunity to gain necessary biological and ecological information on the demersal ichthyofauna that may be typical of the unexploited bays in the Indo-Pacific region. The species composition and structure of the ichthyofauna of Cleveland Bay were studied using a strict sampling regime to provide a general view of the community. In addition, the distribution and abundance of leiognathids (Pisces: Leiognathidae) and their biology (growth, reproduction) were investigated. The extent of predation by synodontids (Pisces: Family Synodontidae) on leiognathids was estimated also. The ichthyofaunal community of Cleveland Bay was multispecific but consisted of only one assemblage at the scale of the whole bay (which is <20 m deep). Total biomass, leiognathid biomass, and leiognathid densities were highly variable at very small spatial and temporal scales (<20 m range of depth, < 1,000 m; daily) and these patterns persist through time (over years) in the frequently disturbed sedimentary regime of Cleveland Bay. The abundance of leiognathids persists despite high predation levels on recruits. This maintenance of high abundance may be explained by their fast growth and iteroparous reproduction. In addition, the leiognathids feed on zoobenthos and zooplankton that can respond rapidly to changes in the primary production of Cleveland Bay (due to resuspension of nutrients and recycling of nutrients by epibenthic biota). The strategy taken in studying this community (a combination of the **top-down** and **bottom-up** approaches) provided ecological bases for assessing the state of the ichthyofauna of Cleveland Bay and essential data for modelling multispecific, tropical demersal ichthyofauna and multispecies fisheries.

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CHAPTER I

RATIONALE AND OBJECTIVES OF THE PROJECT AND OVERVIEW OF THE TROPICAL DEMERSAL ICHTHYOFAUNA

Rationale

Demersal ichthyofaunal communities in the tropics are diverse assemblages (Pauly, 1979; Longhurst and Pauly, 1987) and are the bases of fisheries that contribute a significant proportion of the marine fisheries production from the Indo-Pacific and Australian regions (10 to 30 million tonnes; Suda, 1973; Liu, 1976; Liu *et al.*, 1978; Sinoda *et al.*, 1978; FAO, 1977 in Pauly, 1979; Silvestre *et al.*, 1987; Harris and Poiner, 1990). Twenty to 65 % of this catch is edible (*e.g.*, Suda, 1973; Sinoda *et al.*, 1978; Chan and Liew, 1986) but this percentage may vary among locations (*e. g.*, *Leiognathus equulus* is commercially important in Singapore and other Asian countries but is not considered as such in Australia). The remainder of the fishes trawled are processed for fish oil or fish-meal or thrown overboard as discards (Suda, 1973). Saila (1983) estimated that 1.4 m t y^{-1} of demersal fishes were discarded worldwide, usually associated with shrimp fisheries. The by-catch that floats is consumed by birds and other predators and that which sinks (about 70 % by weight) is consumed by mid-water and demersal predators and scavengers (Harris and Poiner, 1990). Trawling targetting such groups as carcharinids, rajids, carangids, lutjanids, and lethrinids, in demersal communities often imposes fishing mortality on many other species that do not have any commercial value (the so-called by-catch problem).

The demersal ichthyofauna in shallow (< 30 m), soft-bottom, continental shelf waters of the tropics is a distinctive but neglected assemblage (Longhurst and Pauly, 1987). In particular, there is a paucity of information on the structure of tropical demersal ichthyofaunas, patterns of distribution and abundance, biology of the species, and biological interactions of species within the communities (Sainsbury, 1982, 1984). Most demersal ichthyofaunas are exploited before proper investigation of the composition and the magnitude of the resource can be made (Longhurst and Pauly, 1987).

There are various reasons why there is a paucity of information on communities and populations of demersal ichthyofauna. The high monetary cost of investigating the species composition, variability in distribution and abundance, and trophic interactions within the demersal community has in many circumstances prohibited scientific investigation or has at least compromised scientific objectives [*see* Appendix 1, pp. 767-768, in Rainer and Munro (1982) for discussion of these issues; Ramm *et al.*, 1990]. Few surveys of the demersal ichthyofauna have been conducted before the commencement of commercial trawling and, for those that were, the results often were reported or analysed improperly (Longhurst and Pauly, 1987). In addition, there has been such a rapid development of demersal fisheries in the tropics that scientific investigations of the demersal ichthyofauna were overlooked or omitted (Longhurst and Pauly, 1987).

Furthermore, the best strategy to assess the status of these multispecific, demersal ichthyofaunal systems is unresolved. Two strategies for studying ecological systems are 1) to study component populations of species individually and generate generalizations from the sum of these studies ("bottom-up" approach) and 2) to study the community as a whole and then its parts ("top-down" approach; Gulland and Garcia, 1984). Few studies of tropical demersal ichthyofauna use the "top-down" approach (*e. g.*, Pauly, 1979; Rainer and Munro, 1982) but many isolated studies of demersal fish populations allow "bottom-up" analysis of these communities (*e. g.*, Balan, 1967; Krishnamoorthi, 1973; Liu and Yeh, 1974; Dan, 1980; Jayabalan, 1988; Wright, 1988; Wright, 1989a, b; Ramm *et al.*, 1990). Either of these approaches has limitations. In both, it is necessary to incorporate estimation of spatial and temporal variability at various scales and the investigation of interspecific interactions (*e. g.*, competition, predation; Sainsbury, 1982, 1984). A comprehensive knowledge of the demersal ichthyofauna from an unexploited environment is useful for several reasons. Firstly, it is important to have baseline information on the natural state of the demersal ichthyofauna to be in a position in the future to assess whether changes have occured. Changes in the community of fishes have occured in exploited systems (Pauly, 1979). The changes caused (*e. g.*, in relative abundance of species and decline in overall catches; *sensu* Pauly, 1979) by commercial trawling of demersal ichthyofaunal communities can only be assessed properly by access to good baseline data and an understanding of the community which is currently being exploited. Most tropical demersal ecosystems have already been subjected to commercial trawling and this trawling is believed to be a major agent of ecological change (Longhurst and Pauly, 1987). Thus, it is imperative that information from any remaining unexploited ecosystems is gathered.

Secondly, most surveys conducted to date present a somewhat superficial picture of the community. Lists of species (*e. g.*, Druzhinin and Phone Hlaing, 1972; Sinoda *et al.*, 1978) are not as useful in impact-assessment as estimates of biomass per trophic group in detecting ecological change (Kulbicki and Wantiez, 1990). Studies of individual populations of species (*see* overview) are also incapable of providing important information on interspecific interactions (Sainsbury, 1982, 1984).

Thirdly, the demersal ichthyofauna has been studied rarely as a unit. General knowledge of demersal ichthyofauna is based on studies of species or families of demersal fishes from different localities where the state of communities may differ substantially. Some of the common families of fishes studied are Synodontidae [in Japan (Hayashi *et al.*, 1960; Hayashi, 1983), Australia (Sainsbury and Whitelaw, MS); the Mediterranean (Bograd-Zismann, 1965; Ben-Ruvia, 1973; Ben-yami and Glaser, 1974); China Sea (Liu and Yeh, 1974)], Gerreidae [in Australia (Dolar, 1986), in Kiribati (Yeeting, 1990)], Nemipteridae [in India (*e. g.*, Krishnamoorthi, 1978; Dan, 1980)], and Leiognahtidae [in Indonesia (Pauly, 1977; 1978), Philippines (Tiews *et al.*, 1968), Kuwait (Wright, 1988; 1989b)]. A series of studies within a demersal environment will possibly provide a better understanding of demersal communities.

Fourthly, there is a need to gain knowledge of the structure of the community, of patterns of abundance of component species and variability thereof, and of trophic interactions. Such information may provide biological realism to management strategies for this resource (Sainsbury, 1982, 1984). Few estimates of the variability in abundance of species are available. The necessity for knowledge of interactions between species (*e. g.*, predator-prey interactions), especially in multispecific, tropical demersal communities is now viewed as an important component in the conservation and management of demersal fisheries (Sainsbury, 1982; Sissenwine, 1984). The stability of diverse tropical demersal ichthyofauna is hypothesized to depend on these interactions (Beddington, 1984; Paine, 1984). Such interactions have been found to contribute significantly to fluctuations in abundance of species [*e. g.*, synodontid-lutjanid interaction (Sainsbury and Whitelaw, MS); Sissenwine, 1984)].

Fifthly, ecological studies of demersal fishes in the tropics have rarely been carried out in unexploited systems [in the Gulf of Carpentaria, Australia - Rainer and Munro (1982), Rainer (1984), Ramm *et al.*, 1990; in the Central Great Barrier Reef, Australia - Watson and Goeden (1989); in New Caledonia - Kulbicki and Wantiez (1990)]. Most demersal ecosystems in the Indo-Pacific have been exploited or currently are being exploited [*e. g.*, in Thailand (Pauly, 1979), Philippines (Pauly, (1979); Aprieto and Villoso (1977); Pauly (1982); McManus (1986); Indonesia (Pauly, 1977; 1978); and Malaysia (Chan and Liew, 1986)].

Lastly, it is imperative to gain knowledge of a small (<20 m deep), relatively unexploited system using a rigorous sampling design capable of detecting any local variation. Spatial and temporal variations of this kind affect variability in fisheries (Steele, 1984).

Overview of tropical demersal ichthyofaunas

The spatial scale of sampling can determine the result of studies of the structure of demersal fish communities. Community structure includes such attributes as species composition, the relative abundance of species within the community and trophic composition. Several large-scale studies (defined as those that sampled a depth range >30 m over a period of 3 months or more) found that the structure of the community of fishes is composed of 2 subcommunities that are separated at the 30 m bathymetric mark [in the Philippines (McManus, 1986); Australia - Gulf of Carpentaria (Ramm *et al.*, 1990) and Central Great Barrier Reef (Watson and Goeden, 1989)] while a medium-scale study (depth range sampled < 30 m) found a community of fishes that is composed of inshore and offshore assemblages (Rainer and Munro, 1982). In both these studies, spatial and chemo-physical factors that were related to the structure of the community were distance from shore, depth, sediment type, temperature, and salinity (Rainer and Munro, 1982; McManus, 1986; Watson and Goeden, 1989; Ramm *et al.*, 1990). Spatial factors appear to have a more pronounced effect than temporal ones on the structure of the community of demersal fishes in the Central Great Barrier Reef region of northeastern Australia (Watson and Goeden, 1989).

Almost half of the total stock of most demersal fish communities in the Indo-Pacific region is composed of small prey-species belonging to the families Leiognathidae, Gerreidae, and Mullidae (Pauly, 1979; Chan and Liew, 1986;

Kulbicki and Wantiez, 1990). These prey-fishes are zooplankton-feeders (Chan and Liew, 1986) or carnivores on micro- and macro-zoobenthos (Kulbicki and Wantiez, 1990). Only a small percentage of the total biomass are intermediate predators, *e. g.*, species of the families Synodontidae, Lethrinidae, Lutjanidae, Ariidae, and Serranidae [Pauly, 1979; Chan and Liew, 1986; Kulbicki and Wantiez, 1990; 2.1 % of the total numbers in New Caledonia, Kulbicki and Wantiez (1990)]. In terms of number of species, piscivores account for about 20 % of the ichthyofauna (in Malaysia: Chan and Liew, 1986; in New Caledonia: Kulbicki and Wantiez, 1990). Large predators such as sharks, groupers, and conger-eels compose the majority of the remaining biomass.

Detailed predator-prey interactions in the community are documented in a few studies. The diet of predatory species, *Megalaspis cordyla* (Sreenivasan, 1974), *Psettodes erumei* (Devadoss and Pillai, 1973), *Saurida undosquamis* (Hayashi *et al.*, 1960; Bograd-Zismann, 1965; Sainsbury and Whitelaw, MS) and *S. elongata* (Hayashi *et al.*, 1960), have been studied. The consumption rate of prey species by *S. undosquamis* is high [in Japan; Hayashi *et al.* (1960)] and could potentially subject a higher rate of mortality on small prey fishes than could fishing (*e. g.*, in the Northwest Shelf, Australia; Sainsbury and Whitelaw (MS)].

Little is known about changes in species composition through time or variability in abundances of species in tropical demersal fish communities. Species composition was found to be variable with little seasonal component in the Gulf of Carpentaria and in New Caledonia (Rainer, 1984; Kulbicki and Wantiez, 1990). The abundance of many species varies substantially among months (Watson and Goeden, 1989), with season, and probably also over a longer periods

(Rainer, 1984; Kulbicki and Wantiez, 1990). Some numerically abundant species (*e. g.*, *Leiognathus* sp. nr. *blochi*, *Nemipterus tolu*, *Pomadasys maculatus*) were seasonally abundant (Rainer, 1984).

Objectives of the Project

This project focuses on these aspects of the biology and ecology of the demersal ichthyofaunal community of fishes in Cleveland Bay, tropical Australia. The study has employed a statistically sound sampling design which allowed the estimation of variability in space and time.

The objectives of the project, conducted in Cleveland Bay, Australia, were:

1. to define the species composition of the ichthyofaunal community and to describe the patterns of distribution and abundance of dominant species;
2. to identify the most abundant family of fishes and to describe the patterns of distribution and abundance of the most abundant species belonging to the family;
3. to describe the reproduction and recruitment of some dominant species and to estimate parameters of growth of some dominant species that could be used in fisheries models; and,
4. to identify the major predatory species and estimate the rate of natural mortality they impose upon the most abundant family of fishes in the community.

CHAPTER II describes Cleveland Bay as a small and relatively unexploited tropical demersal ecosystem and outlines the sampling procedure employed.

CHAPTER III presents results of a survey of the total trawlable ichthyofauna in Cleveland Bay and compares variation in the structure of the community in space (Inshore, Offshore, and at the level of individual Sites) based on classification analysis. Patterns of distribution and abundance of several species are presented. In addition, the contribution of the most abundant family of fishes to the total biomass of fishes in the Bay is estimated. The results are discussed in terms of the scale of sampling and the importance of small prey-species.

CHAPTER IV presents data on the distribution and abundance of leiognathids. The patterns of distribution and abundance of 4 dominant species are described in detail. The results are discussed in terms of the behaviour, biology, and environment of leiognathids.

CHAPTER V summarizes data on the growth, reproduction, and recruitment of the 4 abundant species of leiognathids. The results are discussed in terms of possible explanations of the abundance of leiognathids.

CHAPTER VI quantifies the level of predation on leioganthids by the dominant piscivore in the community and estimates the natural mortality imposed on the prey by the predator. The estimate of natural mortality was compared with an estimate of fishing mortality (imposed by research surveys). The implications of the findings to management of demersal fisheries are discussed.

CHAPTER VII summarizes and synthesizes the results of these studies (Chapters III to VI) and discusses the state of Cleveland Bay in relation to the physical environment and the implications of the results to modelling demersal fisheries. In addition, some directions for research in the future are presented.

CHAPTER II

GENERAL MATERIALS AND METHODS

Description of Cleveland Bay

Cleveland Bay is located at 19°13'S, 146°55'E on the eastern coast of Queenland, Australia (Figure 1). Cleveland Bay is part of the "Three Bays" system; the other two bodies of water that compose this system are Halifax Bay and Bowling Green Bay. [This system has been the subject of a multidisciplinary scientific study in 1974 (Stark *et al.*, 1975, James and Stark, 1982).] Cleveland Bay, with an area of ~225 km^2, is the smallest of the three bays. Magnetic Island, with fringing coral reefs, and Cape Cleveland separates Cleveland Bay from Halifax Bay to the north and Bowling Green Bay to the south, respectively. The port city of Townsville (North Queensland, Australia), the largest city in the region, is built along its shoreline.

Cleveland Bay was formed recently by the postglacial rise in sea level about 12,000-9,500 y BP (Carter and Johnson, 1987). The base of Cleveland Bay is Holocene sediment fill that was formed 6,500 y BP and lies 15 m below the sea floor (Carter and Johnson, 1987). During the mid-Holocene high, Cape Cleveland was probably an island 2-3,000 y BP (Carter and Johnson, 1987).

Cleveland Bay received high terrigenous sedimentation during the Holocene period and this applies also at present (Carter and Johnson, 1987; Belperio, 1983). The longshore drift and advection resulting from Cape Cleveland being an island would have delivered substantial terrigenous sediment from the Burdekin River during the mid-Holocene high (Carter and Johnson, 1987). At present, the Burdekin River still contributes about 1.1 x 10^6 metric tonnes of silt and clay to the Townsville and adjacent areas (Wolanski and Jones, 1981; Belperio, 1983; Carter and Johnson, 1987). However, the main source of terrigenous material is Ross River which deposits 0.333 x 10^6 tonnes of sediments into Cleveland Bay per year (Belperio, 1983). The construction of Ross River Dam in 1972 has reduced this sedimentation rate. The Bohle River and other creeks that drain directly into Cleveland Bay are other sources of sediments (Walker, 1981a; Belperio, 1983). As a result of this sedimentation, Cleveland Bay is shallow; the range in depth is from 1 m to 17 m.

Resuspension and resettling of this bottom sediment cause a wide transparency range to occur, but the mean Secchi disk depth recordings increase linearly with water depth across the shallow regions (such as Cleveland Bay) of the lagoon of the Great Barrier Reef (Walker, 1981a). Wave-induced currents, especially during winter months, generate coastal turbidity (Belperio, 1978). Salinity in Cleveland Bay is 36 parts per thousand (ppt) but can be variable, depending on the discharge of small rivers along Cleveland Bay and from the Burdekin River (Walker, 1981b; Cabanban, unpublished data). Differences in surface and bottom salinities are minimal (Walker, 1981c). The range of water temperature (at 10 m) is from 19.3 to 30.9°C with a mean monthly minimum of

20.9°C in July and mean monthly maximum of 30.0°C in January (Walker, 1981a).

Run-off during the rainy season enriches Cleveland Bay with silica, nitrate, and phosphate. These nutrients are resuspended from the sediment to the water column by wave-turbulence from local winds, tidal resuspension, and as ocean swell is dissipated on the barrier reefs (Walker, 1981b; Walker and O'Donnell, 1981; Belperio, 1983; Dight, 1985). The intermittent release of nitrogen and phosphorus has important effects on the magnitude of primary production within this Bay (Walker and O'Donnell, 1981). Concentrations of phytoplankton chlorophyll are dependent upon intermittent resuspension of bottom sediment (Walker, 1981b).

Tides within Cleveland Bay are dominantly semi-diurnal and tidal currents are greater than 0.70 m sec^{-1} during spring tides (Belperio, 1978). Waves are generally wind-generated and are usually slight to moderate because of the protection from oceanic swells by coral reefs on the outer continental shelf (Belperio, 1978).

The climate in the region is characterized by wet and dry seasons. The wet season, from late December to late March, corresponds to the influence of monsoonal lows. Eighty five percent of the average rainfall (1,130 mm/year) falls between December and April (Burdekin Project Committee, 1977 in Belperio, 1983). Northeasterlies and northwesterlies prevail during the wet season. Cyclonic winds are experienced at least once every 1.36 years (Oliver, 1978) during the wet season. The prevailing winds during the dry season, from April to November, come from the east or from the southeast.

There is a strong variation in the intensity of wet seasons among years (Isdale, 1984). The rainfall patterns influence the rate of sedimentation, levels of nutrients, turbidity, and salinity of Cleveland Bay strongly (Walker, 1981a, 1981b, 1981c; Walker and O'Donnell, 1981).

The soft-bottom epifauna of Cleveland Bay is composed of echinoderms, molluscs, crustaceans, bryozoans, algae, and demersal fishes (Stark *et al.*, 1975). Jones and Derbyshire (1988) and Watson *et al.* (1990) reported that the 'inshore' zone of the Great Barrier Reef Lagoon (< 40 m) has a uniform composition of benthic fish and invertebrates and is different from 'midshelf' and 'inter-reef' zones. Birtles and Arnold (1983, 1988) found that a sampling site (2c along the central Great Barrier Reef transect) closest to, and presumably characteristically the same as, Cleveland Bay, had poor epifaunal species diversity. Echinoderm and molluscan diversity and abundance in the zone near Cleveland Bay were lower than that of the offshore sites (Birtles and Arnold, 1983, 1988). Stark *et al.* (1975) reported 175 species of demersal fishes, with new records for the region and possibly some new species.

Sampling Gear

Sampling was done with the use of twin otter trawls fitted on the 19 m *RV James Kirby* (James Cook University research vessel). These otter trawls are the standard trawls used in commercial trawling in the region (D. Duncan, pers. comm.). The length of the trawl headrope was 12 m and the effective width of the net 8 m. The mesh size was 4 cm throughout.

The otter trawls were size-selective, based on a mesh-selection experiment.

This experiment was conducted on 10 April, 1990 when recruitment to leiognathid populations had been completed. The experiment was conducted by covering the starboard cod-end with another net (= cover) with a much smaller mesh size (1.2 cm). There was no change in the sampling regime (*see* below). The catch of the trawl and the cover were preserved separately. In the laboratory, length-frequency measurements of 5 mm intervals were collected for the catches in the codend and cover. The probability of capture, which is the proportion of individuals in the cod-end of the total individuals of a length-class captured, was calculated. A smooth curve (logistic) was fitted to estimate the probabilities of capture by size class (computer software FB 29 in Pauly, 1984).

For *Leiognathus splendens*, the most abundant species captured, individuals below 50 mm (SL - standard length) have less than a 50 % probability of capture (Figure 2). For *L. bindus*, a smaller species, individuals below 45 mm SL have less than a 50 % probability of capture (Figure 2). *Secutor ruconius*, a smaller but deep-bodied species, has 50 % probability of capture around 46 mm SL (Figure 2). Thus, small, immature fish of the populations of different leiognathid species were undersampled by the trawl with known probability of retention once exposed to the gear. Consequently, the length-frequency data was adjusted according to the probabilities of capture of length-classes due to the selectivity of the gear.

A pilot study was attempted to determine the optimum duration of trawling time to provide a reasonable representation of species (10, 15, 20 minutes; unpub. data). Due to high variability in catch, this study was inconclusive. However, 10 minutes was decided upon as a qualitatively suitable duration of trawling, providing sufficient samples when a school of leiognathids was hit. In addition, trawling for 10 minutes allowed more replicated trawls to be done in one sampling day.

The speed of trawling was 2.3 knots. The area trawled at this speed and duration of 10 minutes was calculated using the formula:

$a = t.\ V.\ h.\ x_2$

where t is the time spent trawling

V - speed of trawler over ground (2.3 knots)

h - length of trawl's headrope (12 m)

x_2 - effective width of the net (= width of net divided by length of headrope; 8 m divided by 12 = 0.67)

The area trawled by one net was 6,000 m^2 per 10 minutes (= 0.034 km^2 per hour).

Sampling Design

Cleveland Bay was divided into two locations: Inshore (1 - 6 m depth) and Offshore (9 - 17 m). There were three Sites per location (Figures 1, 3). Permanent Sites were chosen semi-arbitrarily from the preliminary surveys conducted throughout the Bay. Seagrass areas and a dredge dumpsite were eliminated from the design as untrawlable areas. The remaining areas of the trawlable Bay were then partitioned into Inshore and Offshore locations with 3 sites. The sites were separated by approximately 4,000 m. There were two trawls per site and these were approximately 1,000 m apart. Sampling was conducted approximately monthly from April 1988 to April 1990. In the study of the structure of the community (Ch. III), there were 4 sites per location (Figures 4, 5) which were sampled in 2 consecutive days in a single month. (Charts showing the location of the sites sampled are presented again in Chaptes III and IV for easy reference.) Locations (Inshore, Offshore) and months were considered fixed, orthogonal factors. Both sites and trawls were nested in combinations of location and months. Month, Location, and Site were considered fixed factors and Trawl as a random factor. The catches of each net were separated and considered replicates. There was no significant difference in the total catches (biomass) of the two nets (ANOVA; $F = 1.45$; $p > 0.05$). This indicated that the catches of each net were from the same population being trawled.

On board the research vessel, the catch of each net was sorted into leiognathids, other fishes, and invertebrates and then each group was weighed (wet weight) separately. The leiognathids and synodontids in the samples were preserved in alcohol (70 %) or formalin (10 %). The synodontids were the most abundant of the piscivorous fishes in Cleveland Bay (Chapter III).

Figure 1. Map of Cleveland Bay, Townsville showing Sites 1-6; Sites 1-3 in the Inshore Location and Sites 4-6 in the Offshore Location. Inset-map of Australia showing location of Townsville.

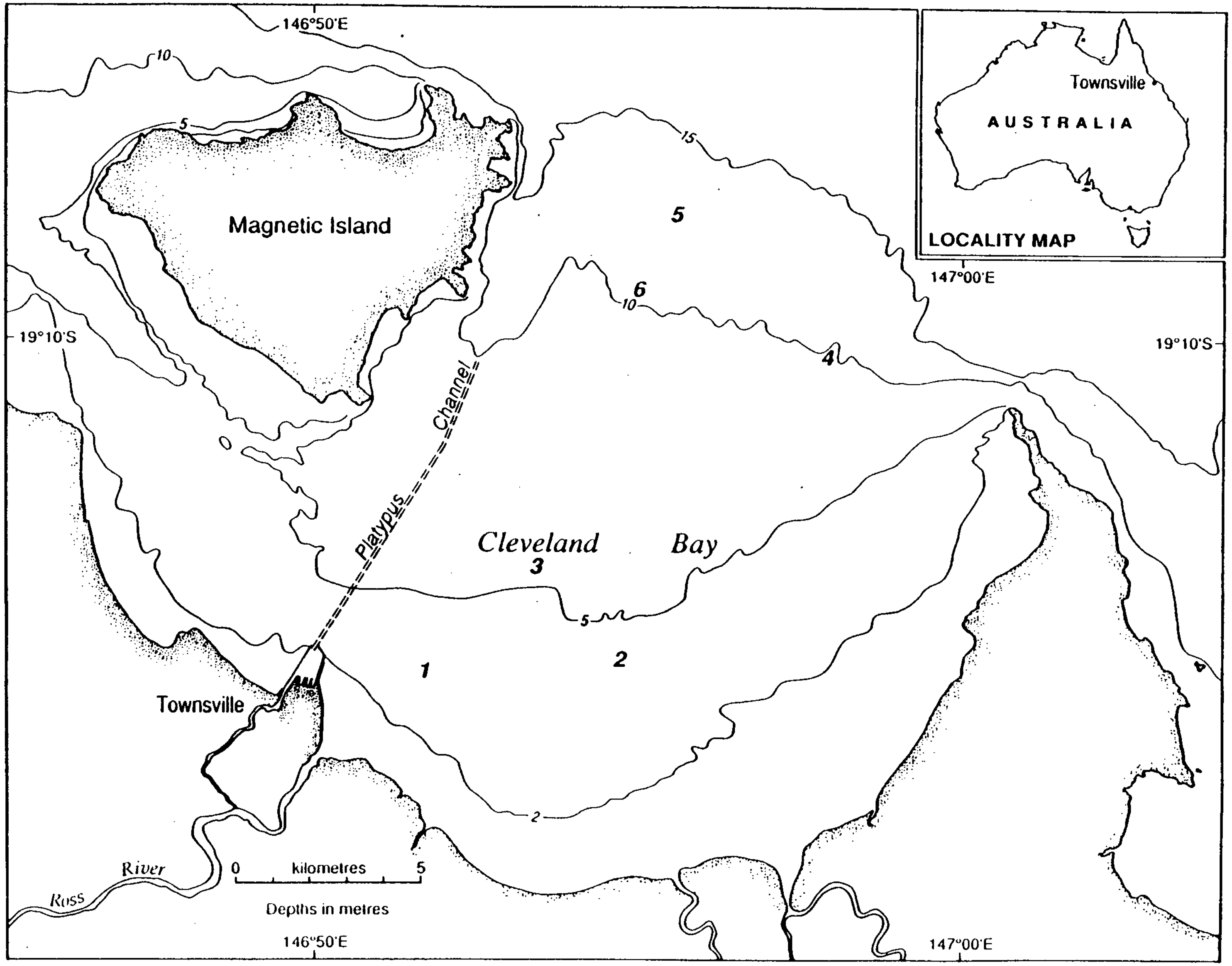

146°50'E
10
5
Magnetic Island
15
5
6
10
4
19°10'S
19°10'S
147°00'E
Platypus Channel
Cleveland Bay
3
5
1
2
2
Townsville
Ross River
0 kilometres 5
Depths in metres
146°50'E
147°00'E
Townsville
AUSTRALIA
LOCALITY MAP

Figure 2. Plots of probability of capture by length class (standard length) for *Leiognathus splendens* (top), *L. bindus* (centre) and *Secutor ruconius* (bottom). Results derived from a mesh selectivity experiment.

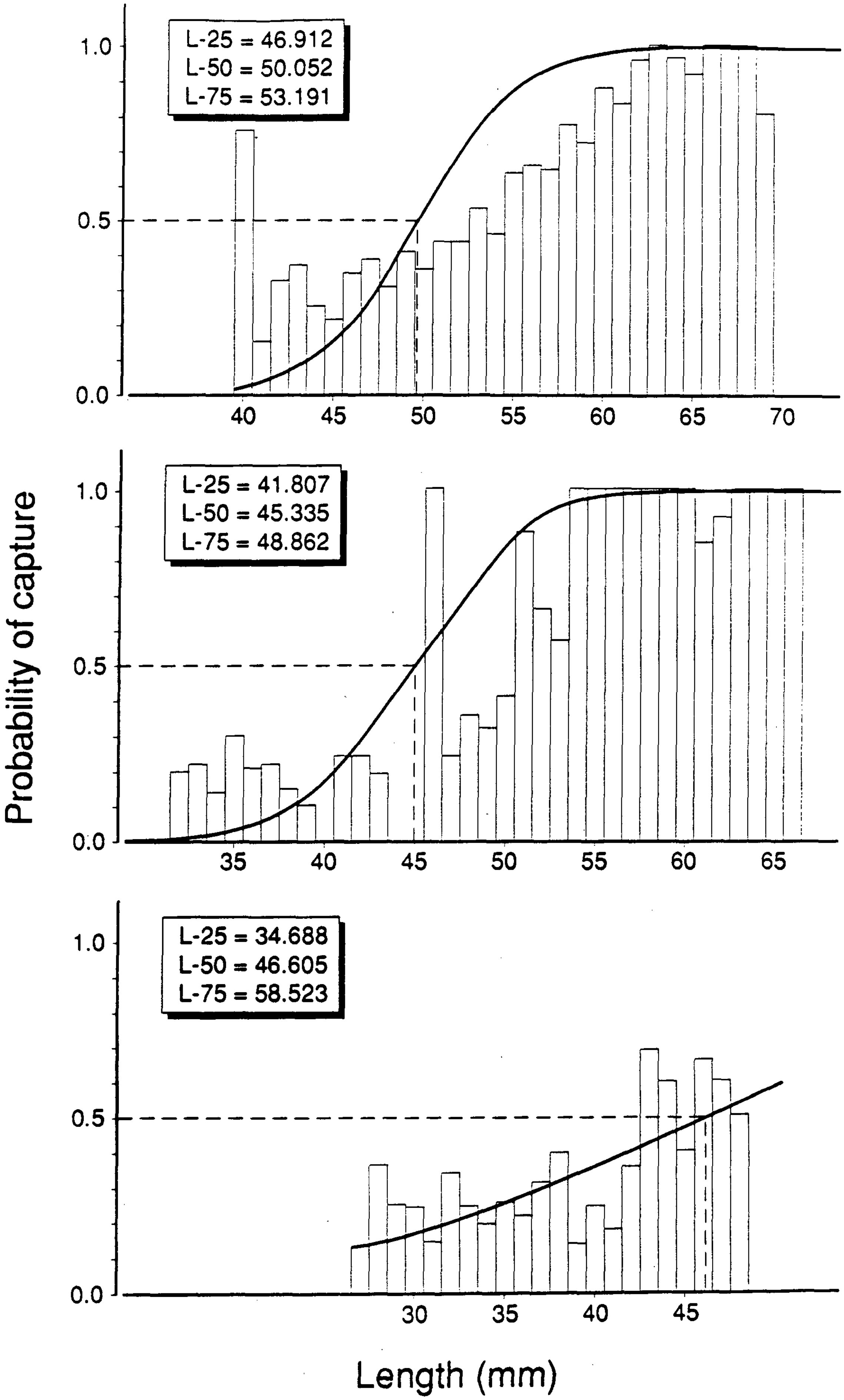
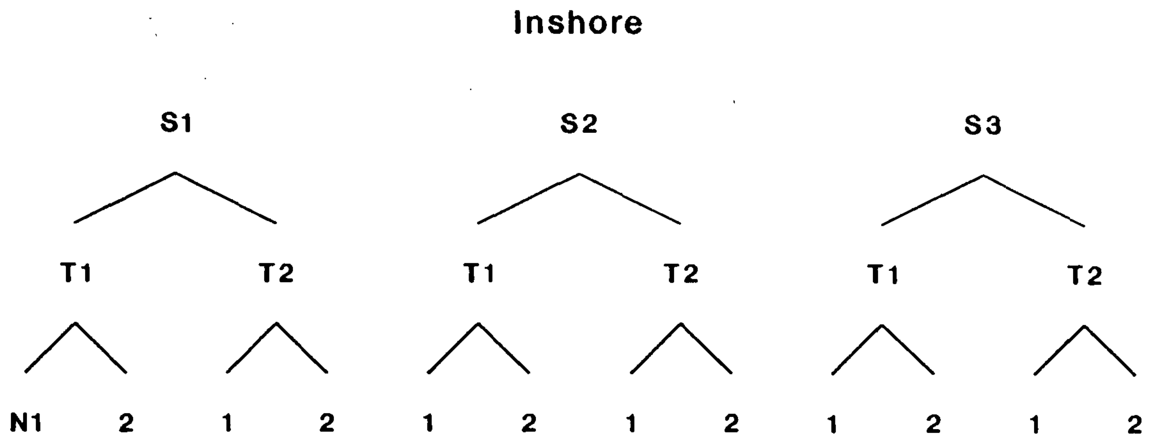

L-25 = 46.912
L-50 = 50.052
L-75 = 53.191
1.0
0.5
0.0
40
45
50
55
60
65
70
L-25 = 41.807
L-50 = 45.335
L-75 = 48.862
1.0
0.5
0.0
35
40
45
50
55
60
65
L-25 = 34.688
L-50 = 46.605
L-75 = 58.523
1.0
0.5
0.0
30
35
40
45
Probability of capture
Length (mm)

Figure 3. Sampling design for long-term studies of distribution and abundance of leiognathids in Cleveland Bay.

S = Site, T = Trawl, N = Net.


Inshore
S1
S2
S3
T1
T2
T1
T2
T1
T2
N1
2
1
2
1
2
1
2
1
2
1
2

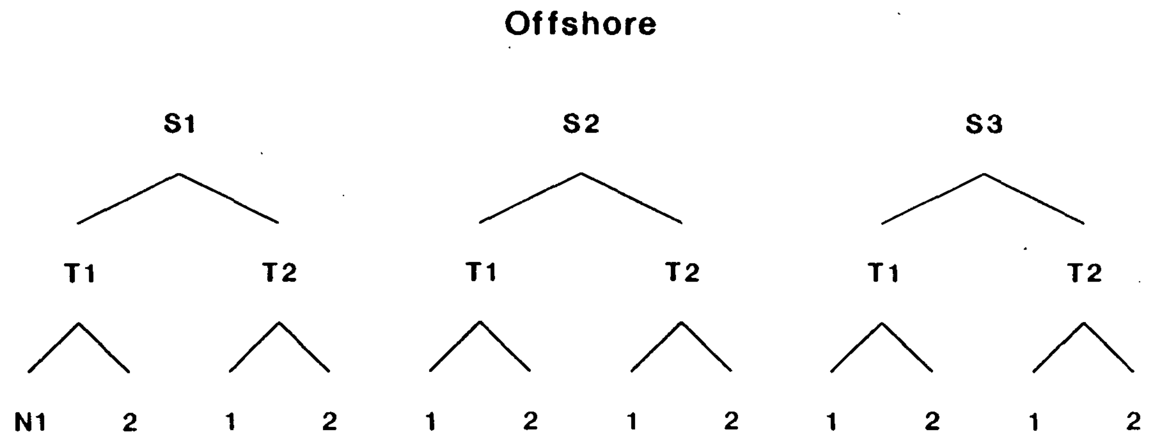

Offshore
S1
S2
S3
T1
T2
T1
T2
T1
T2
N1
2
1
2
1
2
1
2
1
2
1
2

Figure 4. Map of Cleveland Bay, Townsville showing Sites 1-8; Sites 1-4 in the Inshore Location and Sites 5-8 in the Offshore Location. Inset-map of Australia showing location of Townsville.

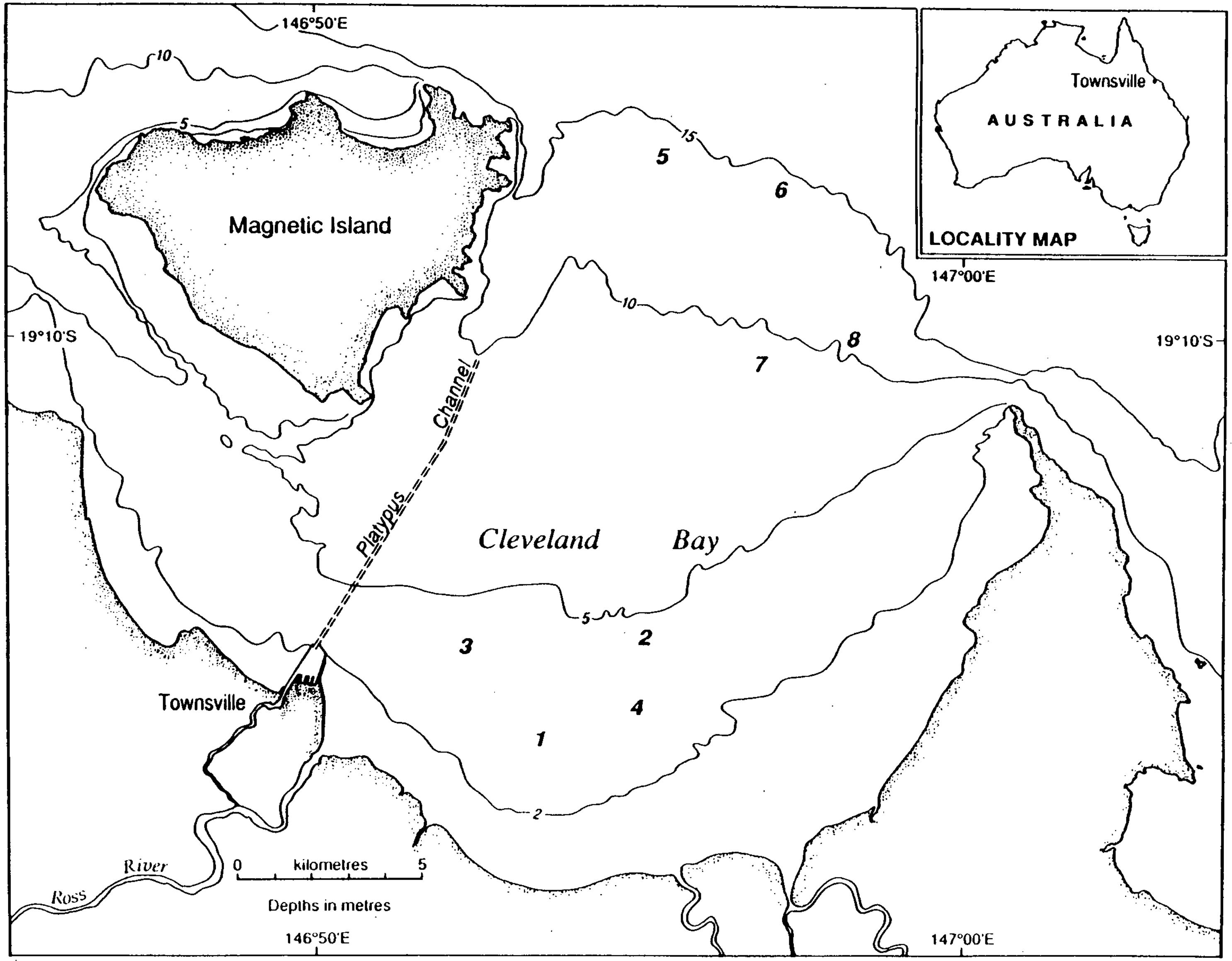
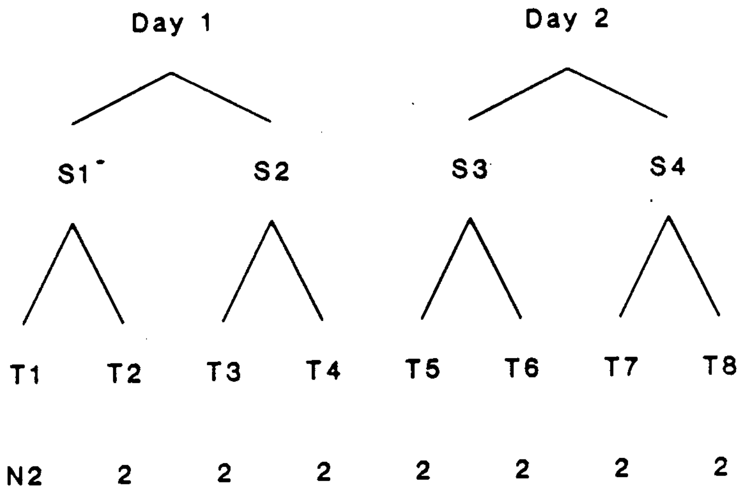

146°50'E
10
5
Magnetic Island
15
5
6
10
8
7
19°10'S
19°10'S
147°00'E
Platypus Channel
Cleveland Bay
5
3
2
4
1
2
Townsville
Ross River
0 kilometres 5
Depths in metres
146°50'E
147°00'E
Townsville
AUSTRALIA
LOCALITY MAP

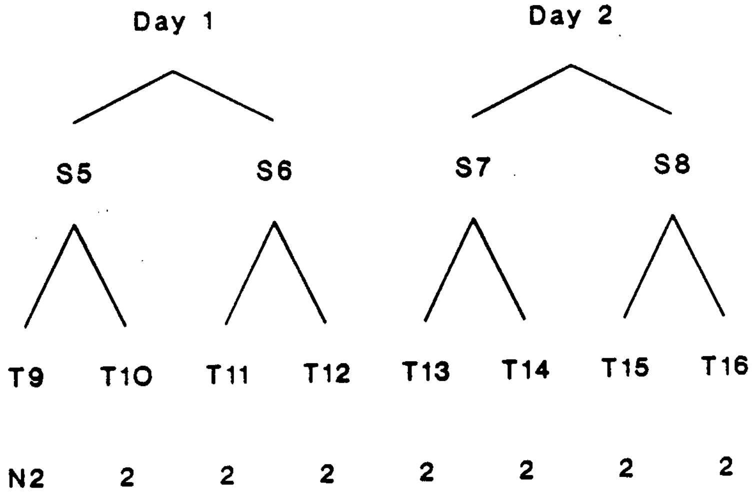
Figure 5. Sampling design for the study of community structure in Cleveland Bay.

S = Site, T = Trawl, N = Net.

Inshore



Offshore



CHAPTER III

THE ICHTHYOFAUNAL COMMUNITY ASSOCIATED WITH SOFT SUBSTRATA IN CLEVELAND BAY, TROPICAL AUSTRALIA

Introduction

There is a paucity of knowledge on (1) the structure of the ichthyofaunal community, (2) patterns of distribution and abundance of species, and (3) identification of the abundant family of fishes in many tropical demersal habitats. Furthermore, there is limited information on these aspects of ecology from small and relatively unexploited tropical demersal communities.

The structure of demersal communities of tropical fishes appears to differ according to the scale at which the community was studied (Ramm *et al.*, 1990). Large-scale surveys (over depth ranges > 30 m or from months to years) provide a general picture of 2 subcommunities separated by depth (McManus, 1986; Watson and Goeden, 1989; Ramm *et al.*, 1990) with seasonal and interannual variability in abundances of species that compose these communities (Rainer, 1984; Watson and Goeden, 1989; Kulbicki and Wantiez, 1990). Medium-scale surveys (over depth ranges <30 m) have sometimes described distinct inshore and offshore assemblages of fishes (Rainer and Munro, 1982). No small-scale surveys of demersal communities (over depth ranges < 20 m) have been carried out.

Few studies have investigated the individual patterns of distribution and abundance of species in tropical demersal communities of fishes. The large-scale studies of Rainer and Munro (1982), Rainer (1984), and Kulbicki and Wantiez (1990) have shown that the patterns of distribution and abundance of several species in New Caledonia (Kulbicki and Wantiez, 1990) and 89 species in the Gulf of Carpentaria (Rainer and Munro, 1982; Rainer, 1984) are variable among seasons and between years. Many abundant species displayed a variety of spatial patterns but most species occured frequently only within a limited range of depths (Rainer and Munro, 1982). As well, many abundant species have different patterns of seasonal abundance (Rainer, 1984). Spatial patterns were related to water depth, size of sediment material, and distance from shore (Rainer and Munro, 1982; Rainer, 1984; McManus, 1986; Watson and Goeden, 1989; Watson et al., 1990). Temporal patterns were correlated with seasonal variations in salinity, water temperature, and migratory behaviour of species (Rainer, 1984; Kulbicki and Wantiez, 1990). Although the sampling in the latter studies was medium-scale (over three months and one year; <30 m), a description of the patterns of distribution and abundance of species in shallow-water and at intermediate depth (<20 m) was given by Rainer and Munro (1982) and Rainer (1984). It is unknown whether extensive sampling over two days in shallow-water (<20 m) will yield the same information on distribution and abundance.

The abundance of families of fishes in demersal communities has been estimated mainly in terms of gross tonnages from commercial fishing (*e. g.*, Liu *et al.*, 1978; FAO, 1977 in Pauly, 1979; Sinoda *et al.*, 1978; Silvestre *et al.*, 1987; Harris and Poiner, 1990; Hill and Wassenberg, 1990) and secondarily from ecological surveys (*e.g.*, Dredge, 1989a, b; Kulbicki and Wantiez, 1990). The Leiognathidae has been recorded as the most abundant family in catches of commercial trawling in the tropics (*e. g.*, Pauly, 1979; Kulbicki and Wantiez, 1990). It is further assumed that because this family is composed of small fishes, they are more numerically abundant than other common species (*e. g.*, Pomadasyidae, Mullidae). However, these suggestions are based on catches of trawls in large, deep, and exploited areas in the tropics. It is unknown whether the leiognathids are also abundant components of the demersal ichthyofauna in small, shallow, and relatively unexploited demersal habitats.

Despite the lack of baseline data from unexploited demersal ecosystems, the present knowledge of demersal ichthyofauna in the Indo-Pacific and Australian regions is based on several specific surveys. The community of fishes is rich in species and is of Indo-Pacific affinity (Liu, 1976; Aprieto and Villoso, 1977; Liu *et al.*, 1978; Chan and Liew, 1986; Rainer and Munro, 1982; Rainer, 1984; Dredge, 1989a, b; Ramm *et al.*, 1990). Physical and hydrographic factors appear to affect the distribution of species more strongly than biotic factors. Salinity, temperature, sediment-type (Rainer and Munro, 1982; Watson and Goeden, 1989; Watson *et al.*, 1990), depth (Rainer and

Munro, 1982; McManus, 1986; Ramm *et al.*, 1990), and distance from shore (Watson and Goeden, 1989; Watson *et al.*, 1990) have all been shown to affect distribution and abundance at medium- (depth range studied < 30 m deep) and large-scale (depth range studied > 40 m) studies. Species richness and abundance vary seasonally and interannually (Rainer, 1984; Kulbicki and Wantiez, 1990; Watson *et al.*, 1990). Species richness also declines as a result of exploitation (Chan and Liew, 1986) but this appears to be the least sensitive factor in detecting exploitation (Kulbicki and Wantiez, 1990). However, spatial effects were more important than temporal effects in the formation of clusters in the pattern analysis of a demersal community in Central Queensland waters (Dredge, 1989a,b; Watson and Goeden, 1989; Watson *et al.*, 1990).

Demersal fishes can be grouped conveniently into four trophic levels: small zoobenthic feeders, intermediate predators; zooplanktonic feeders; and large zoobenthic feeders (Chan and Liew, 1986). Zoobenthic-feeders (macro- and microcarnivores) dominate the trophic structure of the community (Pauly, 1979; Chan and Liew, 1986; Kulbicki and Wantiez, 1990).

Thus, the structure of the ichthyofaunal community, patterns of distribution and abundance of abundant species, and identification of the most abundant family were studied in Cleveland Bay, tropical Australia to provide a background for ecological and biological studies (Chapters IV, V, VI). The results of this study will also provide vital information on aspects of the ecology of demersal ichthyofauna that is currently limited. The small size (225 km^2) and shallow depth (<20 m) of Cleveland Bay allows sampling to be done more intensively than in larger areas. In addition, Cleveland Bay is a relatively unexploited environment (*see* Chapter II), particularly from a fisheries point of view (*see* Chapter I), which presents a rare opportunity to provide data on the natural state of demersal fishes. Furthermore, the results of this study are relevant in providing baseline information to assess ecological changes that may occur as a result of trawling, dredging, or pollution as a consequence of increased use of the port of Townsville. The aim of this chapter is to describe the community structure of the ichthyofauna in Cleveland Bay. A balanced design was used to sample the community at different spatial scales (Location, Site, Trawls) over a two-day period.

Materials and Methods

Study sites

For the purpose of this study, Cleveland Bay was divided into two locations: Inshore, from 0 to 6 m; and, Offshore, from 9 to 17 m (Figure 1). There were 4 sites per location: Sites 1 to 4 Inshore and Sites 5 to 8 Offshore. Sites within a Location were separated by approximately 4,000 m.

Sampling design

The sampling design was a balanced design with Trawls and Sites nested in combinations of Locations and Days (Figure 2). Samples were collected on 11 and 12 of March 1989 and data collection was limited to 2 days due to lack of funds. Sites 1 and 2 (Inshore) and Sites 5 and 6 (Offshore) were sampled on Day 1. Sites 3 and 4 (inshore) and Sites 7 and 8 (offshore) were sampled on Day 2. Two replicate Trawls were made at each Site. (Trawls within Sites were separated by approximately 1,000 m.) Thus, there were a total of 8 Sites and 16 Trawls in the study. Each net of the twin otter trawl was considered a replicate.

The catch of each net was considered a replicate because the distance of one net from the other is not wide, possibly only 10 m apart. As such they are sampling thesame population. In addition, the catches of the two nets are not statistically different.

Samples were collected using twin otter trawl gear (4 cm mesh net) fitted on the

James Cook University of North Queensland research vessel *RV James Kirby*. Trawling time was 10 minutes at a speed of around 2.3 knots. Each net was calculated to sweep 6,000 m^2 (Chapter II). The catch of each net was considered a replicate because the nets were about 10 m apart and sampling thesame population; there was no significant difference in the catches of each net.

The total wet-weight of fish and wet-weight of leiognathids were determined for each replicate immediately after capture. Catch of each net was preserved in 10 % formalin. All individuals in each replicate were identified to species level and counted in the laboratory.

Identification of species

Species were identified using the following taxonomic books: *Trawled fishes of Southern Indonesia and Northwestern Australia* (Gloerfelt-Tarp and Kailola, 1984); *Continental Shelf Fishes of Northern and Northwestern Australia* (Sainsbury *et al.*, 1984); and, *The fishes of New Guinea* (Munro, 1967). Representative specimens were lodged in the North Queensland Museum.

Analyses

Species richness was expressed as number of species per net. The Shannon-Weaver diversity index (Shannon and Weaver, 1949) (H') and *Hill's diversity number* (N1) (Hill, 1973) were computed using a computer package (Ludwig and Reynolds, 1988). An evenness ratio (*E4*, Modified Hill's ratio) was computed. Abundance was expressed as number of fish per net (= per 6,000 $m^{2)}$. Patterns of community structure were analyzed by an agglomerative, hierarchical classification strategy (PATN; Belbin, 1988). Sixty species of fish (those present in 6 or more replicates) were included in the analysis. The data were first transformed to $\log_{10}$ (X + 1) because of the presence of many zero values. Bray-Curtis similarity coefficients (Bray and Curtis, 1957) were calculated for pairs of samples and a flexible unpaired group mean average (UPGMA) sorting strategy with $B = 0$ was used to fuse groups. The Sandland and Young test (Sandland and Young, 1979) was used to detect significant differences between clusters in the resulting dendrogram. Cramer values (C) were calculated to show the contribution of individual species to any differences between clusters.

Four-factor analysis of variance (ANOVA) was used to detect differences in species richness and total standing stocks. In addition, the abundances of seventeen species, with numbers totalling more than 200 individuals were analyzed to determine differences in patterns of abundance. The factors in the analysis were Location (Inshore, Offshore), Day (1, 2), Site (nested in combinations of Location and Day) and Trawl (nested in Sites). Location and Day were considered as fixed factors, Site and Trawl as random factors (Underwood, 1981). Cochran's test was used to test for homogeneity of the variances. When samples did not pass Cochran's test, the data were transformed using $\log_{10}$ (X + 0.3, 0.5, or 1). Sum-of-squares in the analyses of variance were pooled when initial F-ratios were not significant for Site and Trawl at $p = 0.25$ (Underwood, 1981). The Student-Newman-Keuls (SNK) procedure was used to compare means (Winer, 1971). Results are presented graphically also.

To allow for comparisons between studies, a list of important species was prepared following the procedure of Rainer and Munro (1982). In this study, species that occured in 50 % or more of the replicates were defined as species that were important.

Results

Species composition and diversity

There were 127 species in 48 families of fishes identified in the samples (*see* Appendix 1). The most species-rich families in the samples were the Carangidae (15 spp) and Leiognathidae (8 spp). The latter family was also the most numerically abundant in the community (Figure 3). The top ten species, numerically, were *Leiognathus splendens*, *L. bindus*, *Pomadasys maculatum*, *Secutor ruconius*, *Pseudotriacanthus strigilifer*, *Pentaprion longimanus*, *Pseudorhombus arsius*, *Saurida micropectoralis*, *Gerres filamentosus*, and *Leiognathus moretoniensis*. Four of these species belong to the family Leiognathidae (genera *Leiognathus* and *Secutor*). The overall diversity of the ichthyofaunal community was $H' = 3.08$. There were 22 (Hill' *N1*) abundant species contributing to this diversity. In terms of evenness, the community was dominated slightly by several species ($E4 = 0.451$); about 30 species were ubiquitous (*i. e.*, sampled in all Sites). Species richness differed significantly only among Sites (Figure 4, Table 1), varying from a minimum of 16 at Site 5 and a maximum of 54 at Site 3 (Figure 4).

There were two major divisions in the pattern analysis (Figure 5) of the ichthyofaunal community. The first major division in the dendrogram split two of the four Inshore Sites [Site 1 (T1 and T2) and Site 3 (Trawl 5 and 6)] from the remaining two Inshore Sites and the four Offshore Sites. The second major set of divisions produced five groups at the level of 0.6 dissimilarity, these groups corresponding to 5 of the 6 remaining sites sampled. In general, catches of the two trawls at a particular site were similar. For example, Trawls 15 and 16 belonging to Site 8 were clustered together. The Sandland and Young Test (1979) showed that the following sites differed from each other at the 0.05 level of significance: Site 1 and 3; Site 2 and 4; Site 2 and 7; Site 5 and 6; Site 5 and 8; and Site 6 and 8. However, at the level of 1.42 dissimilarity, there were four major groups of Sites: Site-group 1 (Sites 1 and 3), Group 2 (Sites 2, 4, 7), Group 3 (Sites 6 and 8), and Group 4 (Site 5). The majority of the abundant species occurred frequently in all Site-groups (Table 2). The number of species shared within Site-groups was between 12 to 21. A small number of species were restricted to a Site-group [*e. g.*, *Terapon theraps*, Site Group 1 (C = 0.952), *C. talamparoides*, Site-group 3 (C = 0.604), *Epinephelus sexfasciatus*, Site-group 4 (C = 0.610)]. Site-group 3 had the most number of species that were restricted to this group (Table 2).

Patterns of distribution and abundance

At the level of species, various patterns of abundance were observed (Figures 6 - 9, Table 1). The patterns were categorized as those that were due solely to temporal (Day) variations, those due to spatial factors (Location, Site, Trawl), and those affected by interactions of temporal and spatial factors. *Sillago sihama* was an ubiquitous species but was significantly more abundant on Day 2 (Figure 6, Table 1). *S. sihama* was the only common species whose abundance was affected solely by Day. Patterns showing effects of spatial factors (*i. e.*, Location, Site, Trawl) were numerous. *Nemipterus* *peronii* was more abundant in offshore sites while *Gerres filamentosus* differed significantly between trawls (Figure 7, Table 1). The leiognathid *Secutor ruconius* was distributed mostly inshore but its abundance differed significantly only between sites while abundance of *Pomadasys maculatum* differed significantly only between trawls (Figure 7, Table 1). *Leiognathus splendens*, the most abundant species in the survey, was affected by all spatial factors; this species was more abundant inshore but displayed significant between Site and between Trawl differences in abundance (Figure 8, Table 1). *Saurida micropectoralis* was more abundant at Inshore than Offshore Sites (Figure 8, Table 1). In some species, temporal and spatial factors interacted to determine distribution and abundance (e.g. *Pseudotriacanthus striligifer* displayed a strong preference for the inshore location but this effect was much more pronounced on Day 1 than Day 2; Figure 9a, Table 1). Both *Torquigener whitleyi* and *Upeneus sulphureus* did not display significant differences in abundance at any spatial scale or between days (Figures 6b, 9b and Table 1) although the former species appeared to be more abundant offshore.

Contributions of families

Teleosts were collected in trawls in large quantities (from 2.0 to 15.5 kg/trawl). The total biomass of fishes varied significantly at the two smallest spatial scales - Sites and Trawls (Figure 10 and Table 1). Leiognathids were the dominant contributor to the abundance of fishes in the community (Figures 3, 10). They composed 0.009 % to 23 % of the biomass in the collections (Figure 10). The biomass of leiognathids was variable among Days, Sites, and Trawls (Table 1). A significantly greater biomass of leiognathids was caught on Day 2 (Figure 10, Table 1).

Discussion

The ichthyofaunal community in the shallow (<20 m deep) tropical demersal environment of Cleveland Bay was composed of a diverse assemblage of fishes (Figure 4, Appendix 1). The numerous species that composed this community have varying patterns of distribution and abundance (Figures 6-9, Table 1). Among the small species which dominate this community were the leiognathids (Pisces: Family Leiognathidae), contributing up to 23 % of the biomass of fishes (Figure 10) or 47 % of the numerical abundance of all teleosts collected over the 2 days (Figure 3).

The tropical demersal ichthyofauna of Cleveland Bay, Townsville was studied systematically but at a comparatively small-scale (2 days, depth range studied < 20 m). The results of this study differed from studies where sampling was at medium- (depth range < 30 m) and large-scales (depth range >30 m).

Structure of the community of fishes

The ichthyofauna in the tropical demersal environment of Cleveland Bay, Northeastern Australia was composed of an assemblage of fishes that was similar both Inshore and Offshore (Figure 5). The two major groupings of Sites in the dendrogram did not coincide with Inshore and Offshore locations. Cleveland Bay is small (225 km^2) and the substratum of the Bay is homogeneous (muddy; no relief) throughout. These features partly explain the similarity of species composition at both locations.

The assemblage of fishes in Cleveland Bay is composed of groups of species that differed at the spatial scale of Sites. Behaviour (schooling and local migration) of the fishes possibly account largely for this finding. (This will be discussed further below.) Two types of evidence support this finding of variability at small spatial scales: the results of the multivariate analysis (dendrogram; Figure 5) and the univariate analyses of patterns of distribution and abundance of the numerically dominant species (Table 1, Figures 6-9).

In contrast, in a medium-scale study (< 30 m), the assemblage of fishes found inshore (<5 m deep) was different from offshore (<10 m deep; Rainer and Munro, 1982). In large-scale studies (>30 m depth range studied; months to years) 2 subcommunities of demersal fishes were found above and below the 30-m bathymetic mark in the Philippines (McManus, 1986) and in the Southeast Gulf of Carpentaria, Australia (Ramm *et al.*, 1990). The factors that were related to the structure of the community of fishes were distance from shore, depth, sediment type, temperature, and salinity (Rainer and Munro, 1982; McManus, 1986; Ramm *et al.*, 1990). Spatial factors were the primary determinants of the structure of the community of fishes in the Central Great Barrier Reef (Watson and Goeden, 1989).

Differences in scale of sampling in studies describing the structure of demersal ichthyofaunal communities contribute to the varying results (Ramm *et al.*, 1990). Small-scale (over depth range < 20 m; this study) and medium-scale (over depth range < 30 m; Rainer and Munro, 1982) sampling provide a more detailed picture of the structure of the community of fishes: small-scale sampling has shown species groupings at a spatial scale of kilometres (*e. g.* Sites) while medium-scale sampling indicates assemblages at spatial scales of tens of kilometres. Large-scale sampling in space (over depth ranges > 30 m) or time (to years), on the other hand, provide an overall picture of subcommunities which compose communities of demersal fishes (McManus, 1986; Watson and Goeden, 1989; Ramm *et al.*, 1990) and variability in abundances seasonally and interannually (Rainer, 1984; Watson and Goeden, 1989; Kulbicki and Wantiez, 1990). The systematic and small-scale sampling employed in this study allowed a more detailed description of the assemblage of fishes (Figure 4; Table 1) not detected in previous studies (Rainer, 1984; McManus, 1986; Ramm *et al.*, 1990).

Trophic structure

The trophic structure of the ichthyofauna in Cleveland Bay consisted of zoobenthic-feeders (*Leiognathus*, *Secutor*), carnivores, and scavengers (*e. g.*, Teraponidae, Pomadasyidae, Mullidae) and is typical of tropical demersal communities [Chan and Liew, 1986; Kulbicki and Wantiez, 1990]. Zoobenthic-feeders dominate the community; few piscivores were found in the Bay. Among the small species that dominate this community were the leiognathids (Pisces: Family Leiognathidae), contributing up to 23 % of the biomass of fishes (Figure 10) or 47 % of the numerical abundance of all teleosts collected over 2 days (Figure 3). The carnivores are represented by the piscivorous fishes, belonging to the genus *Gazza* (Family Leiognathidae) and the families Bothidae and Synodontidae, and the invertebrate-feeders, belonging to the families Triacanthidae, Gerreidae, Carangidae, Sillaginidae, Nemipteridae, and Tetraodontidae (Chan and Liew, 1986; Kulbicki and Wantiez, 1990; Cabanban, unpub. data). These carnivorous fishes feed on a wide range of prey and their feeding habits sometimes vary (*i.* e., piscivores feeding on invertebrates as well). The zoobenthic feeders compose > 46 % of the community by numbers (Figure 3), scavengers about 16 %, and the invertebrate-feeders 16 % of the ichthyofauna. At the apex of the food-pyramid are the piscivores, mostly synodontids, comprising 9 % of the abundance of fishes by numbers in Cleveland Bay. The trophic structure of the community is typical of demersal communities, particularly in having leiognathids as one of the abundant small zoobenthic feeders and planktivores and synodontids as one of the numerous piscivores (Pauly, 1979; Rainer and Munro, 1982; Chan and Liew, 1986; Dredge, 1989a, b; Kulbicki and Wantiez, 1990; Sainsbury and Whitelaw, MS).

Certain features of the trophic structure of communities may or may not be useful in detecting overall changes that result from trawling (Kulbicki and Wantiez, 1990). The density of fishes per trophic group is more sensitive to environmental changes than biomass per trophic group. The least sensitive feature is species richness of a trophic level. Thus, monitoring the density and biomass of fishes within each trophic group could be an integral part of a management scheme.

Species composition and richness

Surveys of teleosts in demersal communities have been conducted by trawls but differences in procedure, duration, and spatial scale occur among the studies. Most studies depended on commercial trawling so that systematic sampling, *i. e.*, standardized number of trawls and standardized duration of trawling, etc., was not feasible (see Rainer, 1984, pages 767 - 768; Ramm *et al.*, 1990). These studies covered a period of 1 month to 24 months (Table 3). The depth range sampled also differed from medium-scale (<30 m; Rainer and Munro, 1982) to large-scale (> 40 m; *e. g.*, McManus, 1986; Watson and Goeden, 1989; Ramm *et al.*, 1990). The differences among studies could result in different generalizations being reached. For example, more trawls will yield more species (Rainer and Munro, 1982) and investigation of different spatial scales may show more assemblages of teleosts (*e. g.*, Rainer and Munro, 1982; McManus, 1986; Ramm *et al.*, 1990).

The list of species (Appendix 1) of demersal fishes found in Cleveland Bay is not exhaustive because it was based on only two days of systematic sampling. Many species collected outside of these sampling days (later in sampling for leiognathids over two years) were not found in these collections. It is likely that greater sampling effort would record greater numbers of species (Rainer and Munro, 1982). For example, 175 species were recorded in Cleveland Bay and adjacent bays (Stark *et al.*, 1975). This included several new records for the region and several new species.

The ichthyofauna of Cleveland Bay is of the diverse Indo-Pacific biological province. The bay is species-rich and diverse, typical of the Indo-Pacific fauna [total species richness: range = 83 to 348; Table 3); diversity $H' = 1.83 - 2.37$, in the Gulf of Carpentaria (Rainer, 1984)]. In varying degrees, the ichthyofauna of Cleveland Bay is similar to that of many demersal communities in terms of number of shared-species (*see* below).

The species richness of fishes found in Cleveland Bay is comparable with Australian as well as other tropical demersal communities. Sainsbury *et al.* (1984) in an exhaustive taxonomic study included 732 species from extensive trawling surveys in the northwestern waters of Australia. This is the highest number of species recorded thus far for tropical demersal fish communities. The range of number of species from "non-taxonomic" studies (Table 3) in tropical demersal communities is 83 (Samar, Philippines; McManus, 1986) to about 330 (in the southeast Gulf of Carpentaria, Australia; Rainer, 1984) with the average around 170 species (Table 3). The number of species found in Cleveland Bay is not as high as in the northern waters of Australia [173 spp., 32 families (Rainer and Munro, 1982)]. However, it is richer than other areas such as Burma (Druzhinin and Phone Hlaing, 1972) and Singapore (Sinoda *et al.*, 1978). This may indicate that the demersal areas in Australia are still relatively undisturbed although Kulbicki and Wantiez (1990) reported that species richness was a relatively insensitive variate in detecting effects of environmental changes.

The ichthyofauna of Cleveland Bay was composed of species distributed widely throughout the Indo-Pacific. Thus, the community was similar to many tropical demersal communities. The fauna is the same in affinity (Indo-Pacific) as that of demersal communities in Australia [northern waters of Australia (Rainer and Munro, 1982; Rainer, 1984; Ramm *et al.*, 1990;) the coastal waters of the central Great Barrier Reef (Jones and Derbyshire, 1988; Dredge, 1989a, b), in Malaysia (Chan and Liew, 1986), in Burma (Druzhinin and Phone Hlaing, 1972), and the Philippines (Aprieto and Villoso, 1979; McManus, 1986; Villoso and Hermosa, 1982). The waters with the most similar fauna to Cleveland Bay are those in northern Australian waters (Ramm *et al.*, 1990), sharing 48% of the species present in Cleveland Bay. Although the trawling surveys of Dredge (1989a, b) and Jones and Derbyshire (1988) were in the same region as Cleveland Bay, only about 20 % of the 276 species they recorded were shared with Cleveland Bay. This is because the species lists of Dredge (1989a, b) and Jones and Derbyshire (1988) included fauna that are associated with reefs and fauna found in deeper waters. Similarly, the surveys of Kulbicki and Wantiez (1990) included reef species although there were species that were ubiquitous in both habitats. The least number of shared species between Cleveland Bay and other tropical Australian regions was that between the Southeast Gulf of Carpentaria (16.18 % of 173 species shared; Rainer and Munro, 1982). However, the ichthyofauna of Cleveland Bay is more closely related to that of the northern waters of Australia than that of the subtemperate waters of Moreton Bay, Australia with less than 10 % of species shared with Moreton Bay (Bradbury, 1978).

In contrast to comparisons of occurrence at the species level, most of the families of fishes (Appendix 1 and Figure 3) in Cleveland Bay are common to all tropical demersal ecosystems in the Indo-Pacific [*e. g.*, Philippines (Villoso and Hermosa, 1982; McManus, 1986), Malaysia (Chan and Liew, 1986), Thailand (Pauly, 1979) and Northern Australia (Rainer and Munro, 1982; Ramm *et al.*, 1990)]. Some of the families of fishes that are common to tropical demersal ecosystems are the Leiognathidae, Pomadasyidae, Gerreidae, Synodontidae, Carangidae, Teraponidae, and Bothidae. The species and relative abundance within each family differ slightly. For example, the Family Gerreidae is represented commonly in Cleveland Bay by 2 species, *Gerres filamentosus* and *Pentaprion longimanus* while 4 species, *P. longimanus*, *G. oyena*, *G. poeti*, and *G. macracanthus*, are common in the Gulf of Carpentaria (Rainer, 1984). Despite the small size of Cleveland Bay, the ichthyofauna is typical of the Indo-Pacific region.

Some of the species collected in Cleveland Bay are of commercial importance in Australia, *e. g.*, the scombrids, trichiurids, lutjanids, and sciaenids (*e. g.*, Rainer, 1984; Watson and Goeden, 1989) but many more species are considered commercially important in Asia, *e. g.*, leiognathids, carangids, nemipterids, pomadasyids, gerreids, mullids, engraulids, clupeids, ephippids [in Malaysia, Anon. in Chan and Liew (1986); in the Philippines, Villoso and Hermosa (1982), in Southern Burma, Druzhinin and Phone Hlaing (1972); in Singapore (Sinoda *et al.*, 1978); in Ceylon, Fernando (1972)].

Patterns of distribution and abundance

The assemblage of fishes in Cleveland Bay was characterized by a high number of dominant species [$E = 0.451$ or 27 species; range in several studies = 14 - 36 species (Druzhinin and Phone Hlaing, 1972; Fernando, 1972; Sinoda *et al.*, 1978; Pauly, 1979; Rainer and Munro, 1982; Villoso and Hermosa, 1982; McManus, 1986; Silvestre *et al.*, 1987; Kulbicki and Wantiez, 1990; Ramm *et al.*, 1990)]. The patterns of distribution and abundance of some of these dominant species differed from species to species (Table 1; Figures 6-9).

The patterns of distribution and abundance of several species reflected the variability of the ichthyofauna found in Cleveland Bay at small spatial and to a lesser extent temporal scales (<20 m, 2 days). The various patterns of distribution and abundance observed at this scale were: 1) those that were not different between Days and Locations (Inshore, Offshore, Site or Trawl) (*e. g.*, *Upeneus sulphureus* (Figure 9b); *Torquigener whitleyi*, Figure 6b); 2) those that were different between days [*e. g.*, *Sillago sihama* (Figure 6a); those that were different between Locations (*e. g.*, *Nemipterus peronii*, Figure 7a; *Saurida micropectoralis*, Figure 8b; *Terapon puta*), among Sites or Trawls (*Secutor ruconius*, Figure 7b; *Leiognathus bindus*; *L. moretoniensis*; *Pomadasys maculatum*, Figure 7b; *Pseudorhombus arsius*; *Gerres filamentosus*, Figure 7a; *Pentaprion longimanus*), or both (*e. g.*, *Leiognathus splendens*, Figure 8a); and 4) those that were different between Day and Location [(Location x Day interaction); *e. g.*, *Pseudotriacanthus strigilifer* (Figure 9a), *Anodostomata chacunda*). The possible explanations for these diverse patterns of distribution and abundance are the migratory and schooling behaviour of fishes. Local migration could explain the distribution and abundance of species between Days or Locations within the Bay as was observed by Rainer and Munro (1982) in the Gulf of Carpentaria. Schooling behaviour is the most likely explanation for the frequent occurence of significant differences in distribution and abundance at the level of Sites and Trawls (Table 1, Figures 6-9).

Contribution of leiognathids

Leiognathids, widely distributed in Indo-Pacific and Australian regions, are important contributors to the abundance and biomass of fishes in Cleveland Bay (Figures 3,10). Leiognathids, mostly *Leiognathus splendens*, *L. bindus*, *L. decorus*, and *Secutor ruconius*, contributed 0.009 to 23 % of the biomass of teleosts (Figure 10) or 47 % of the numbers of fishes in the samples (Figure 3). The biomass of leiognathids was highly variable (significant among Days, Sites, and Trawls) as was total biomass of fishes [among Sites and Trawls (Figure 10, Table 1)].

The enormous contribution of leiognathids to total fish biomass and the variability in abundance of this family in this small-scale study are corroborated by data on the biomass of leiognathids over a period of 17 months in Cleveland Bay (Chapter IV). The biomass of leiognathids was more than that of invertebrates (ANOVA - $p < 0.05$; SNK - other teleosts > leiognathids > invertebrates; $p < 0.05$). The contribution of leiognathids was 0.001 to 65 % of the biomass of the total fauna (of teleosts and invertebrates including penaeids, cephalopods, crustaceans; Chapter IV). In terms of fishes only, leiognathids composed an average biomass of 46 % (s. e. = 10.30) of the community in 1988, 20 % (s. e. = 5.415) in 1989; and 45 % (s. e. = 8.357) in 1990 (Chapter IV). Leiognathids thus compose a significant bulk of the biomass of fishes in Cleveland Bay.

The contribution of leiognathids to overall community biomass in Cleveland Bay was as important as in those of other demersal communities in the Indo-Pacific and Australian regions. In the survey of Dredge (1989a, b) in the central Great Barrier Reef region, *L. splendens* and *L. elongatus* ranked 23 and 46 in numerical abundance, respectively, among the 276 species of demersal and reef fishes sampled. In terms of biomass, leiognathids contributed significantly to the by-catch of demersal shrimp and fish fisheries in the Pacific Region and tropical Australia (1.0 % - 82 %; FAO 1977 in Pauly, 1979; Villoso and Hermosa, 1982; Rainer, 1984; McManus, 1986; Silvestre *et al.*, 1987; Harris and Poiner, 1990; Kulbicki and Wantiez, 1990). In the Gulf of Carpentaria, leiognathids accounted for the second highest catch-rate of any group (Rainer, 1984). In exploited demersal fish populations, leiognathids contributed from 3.5 % - 9 % of the total weight (Sinoda *et al.*, 1978). Despite the enormous biomass of leiognathids in tropical demersal communities, they appear to decline rapidly with increased exploitation (Pauly, 1979; Silvestre *et al.*, 1987).

The biomass of leiognathids may be an indicator of overexploitation or recovery from overexploitiation in demersal communities. In unexploited communities, leiognathids (and other small, prey-fishes such as Gerreidae, Mullidae) comprise almost half of the stock of demersal fishes [*e. g.*, in Thailand (Pauly, 1979; in Lingayen Gulf, Philippines (Villoso and Hermosa, 1982)] or rank highly in abundance (*e. g.*, Dredge, 1989a, b). In exploited communities [*e. g.*, in Indonesia (Rusmadji and Badrudin, 1987); Malaysia (Chan and Liew, 1986); in the Philippines (Aprieto and Villoso, 1979; Saeger, 1986) the biomass of leiognathids has declined and has contributed lesser to the total biomass. However, after a period of closure to fishing, demersal communities can recover with detectable increases in the biomass of leiognathids (Saeger, 1986; Rusmadji and Badrudin, 1987).

Status of Cleveland Bay

The results of this study, albeit limited to 2 days of sampling, show that Cleveland Bay is underexploited (see above discussion). The relatively underexploited status of Cleveland Bay provides an opportunity for the assessment of changes that may occur due to exploitation from trawling or pollution from the growing use of the Townsville port. For example, the biomass of dominant groups in the community can be used as indicators of changes occurring in the environment. In particular, the changes in biomass of leiognathids (and other small prey-species) were suggested to indicate overexploitation or recovery from overexploitation [in Samar Sea, Philippines (Saeger, 1986); in Malacca, Malaysia (Rusmadji and Badrudin, 1987)].

Cleveland Bay, in this relatively undisturbed state, is characteristically composed of a high abundance of leiognathids (one of the prey-species) and synodontids (one of the intermediate predators; Figures 10, 8). It has been suggested that in the unexploited state of tropical demersal fish communities, small-prey species (leiognathids, gerreids, mullids) are naturally abundant despite their being held at half of their potential biomasses by high rates of predation (Pauly, 1979). With exploitation, mortality is increased such that prey-populations decrease drastically and relatively more quickly than the predator-populations (Pauly, 1979). Furthermore, in the absence of predators, the biomass of leiognathids may increase in abundance after heavy exploitation (Saeger, 1986). Thus, in this relatively unexploited community, the relationship of prey- and predator-populations in demersal communities needs to be investigated and elucidated (*see* Chapter VI).

The effect of dumping of dredged materials was not investigated. However, the characteristics of the Sites close to the dump sites in Cleveland Bay were not consistent. For example, the Site 3, which is close to the inshore dump, had the highest diversity and also highest biomass and highest leiognathid biomass. On the other hand, Site 5 which is close to the offshore dump, had the lowest diversity and biomass. This appears to indicate that the dumps have no negative effect on species diversity and biomass.

However, the differences in Sites 3 and 5 could not be due to the proximity to the dump sites. The greater diversity and biomass recorded in Site 3 may be due to the nearness of this Site to the source of terrestrial input and nursery sites. Secondly, the spatial and temporal variation in abundance over 2 years was high (Chapter IV) such that Sites 3 and 5 do not consistently record extremes of diversity and biomass.

Nevertheless, this study has shown the status of Cleveland Bay. The repetition of this study (as part of a future monitoring scheme) during the dry months could improve the findings on the structure of the community. In addition, increase in the number of Sites per Location will ensure robustness of findings.

Conclusion

This systematic study of the structure of the community of fishes found in Cleveland Bay has shown that at this scale (2 days, < 20 m depth range):

1. the numerous species of fishes belong to one ichthyofaunal community;
2. the distribution and abundance of species of fishes were variable;
3. the leiognathids were the most abundant family of the demersal ichthyofauna.

Figure 1. Map of Cleveland Bay, Townsville showing Sites 1-8; Sites 1-4 in the Inshore Location and Sites 5-8 in the Offshore Location. Inset-map of Australia showing location of Townsville.

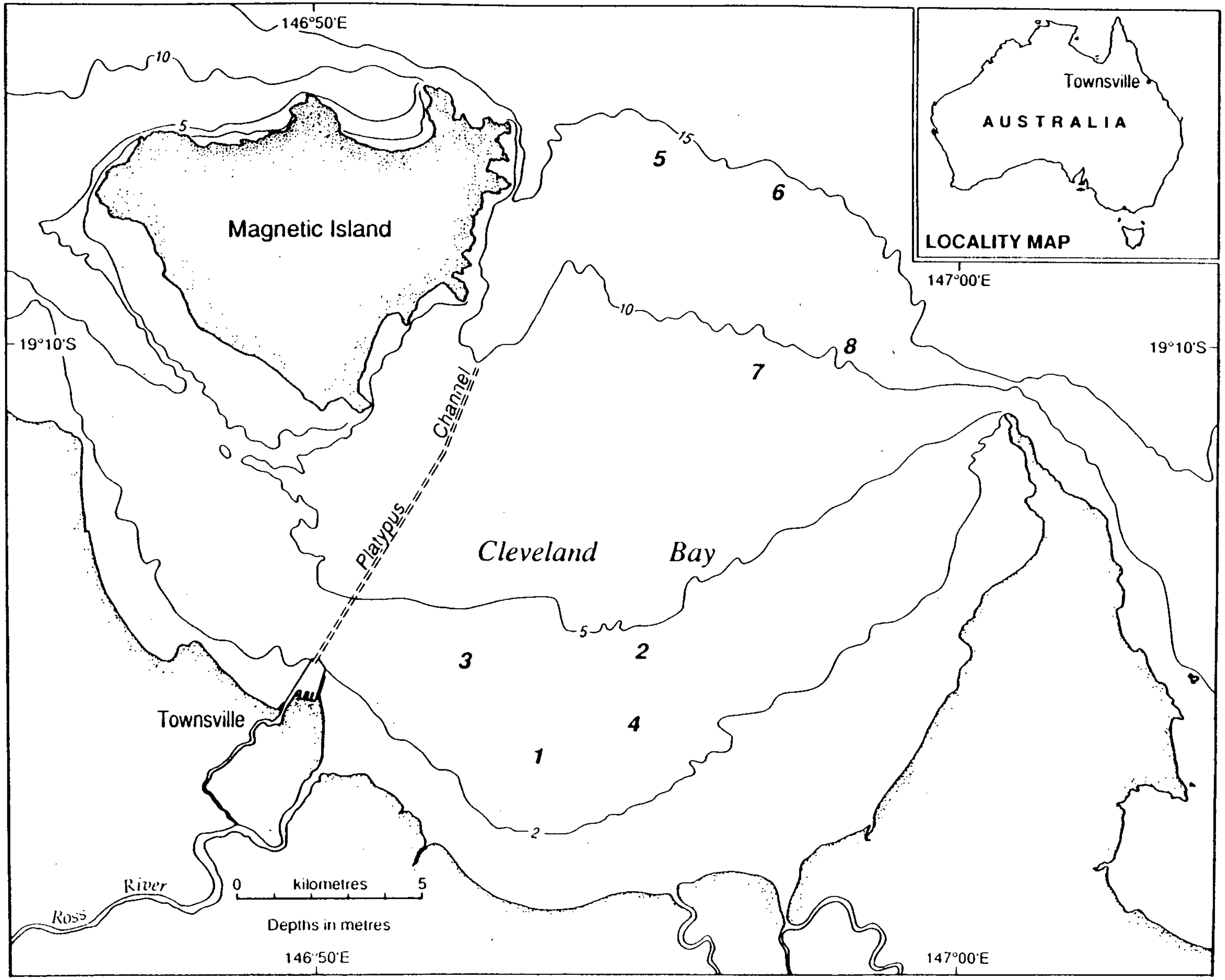
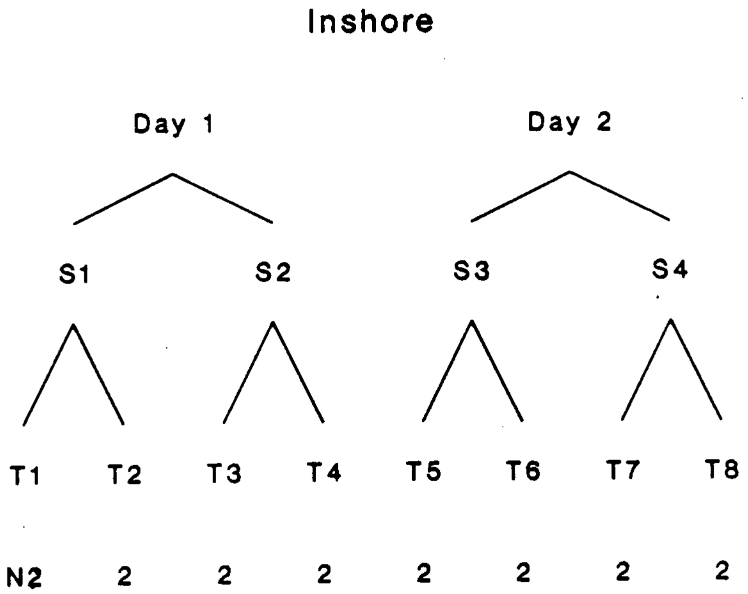

146°50'E
10
5
15
Magnetic Island
5
6
Townsville
AUSTRALIA
LOCALITY MAP
147°00'E
19°10'S
10
8
7
19°10'S
Platypus Channel
Cleveland Bay
5
3
2
Townsville
4
1
2
Ross River
0 kilometres 5
Depths in metres
146°50'E
147°00'E

Figure 2. Sampling design for the study of community structure in Cleveland Bay.

S = Site, T = Trawl, N = Net.


Inshore
Day 1
Day 2
S1
S2
S3
S4
T1
T2
T3
T4
T5
T6
T7
T8
N2
2
2
2
2
2
2
2

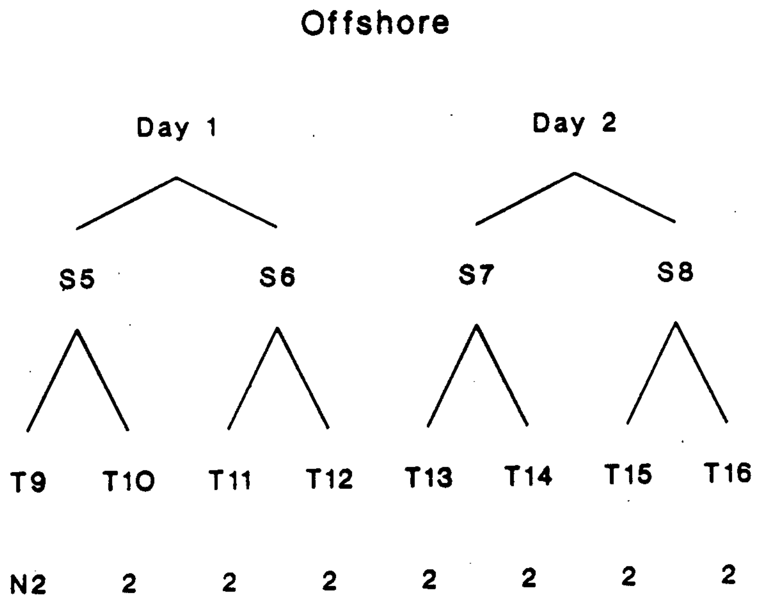

Offshore
Day 1
Day 2
S5
S6
S7
S8
T9
T10
T11
T12
T13
T14
T15
T16
N2
2
2
2
2
2
2
2

Figure 3. Relative numerical abundance of the major families sampled in Cleveland Bay.

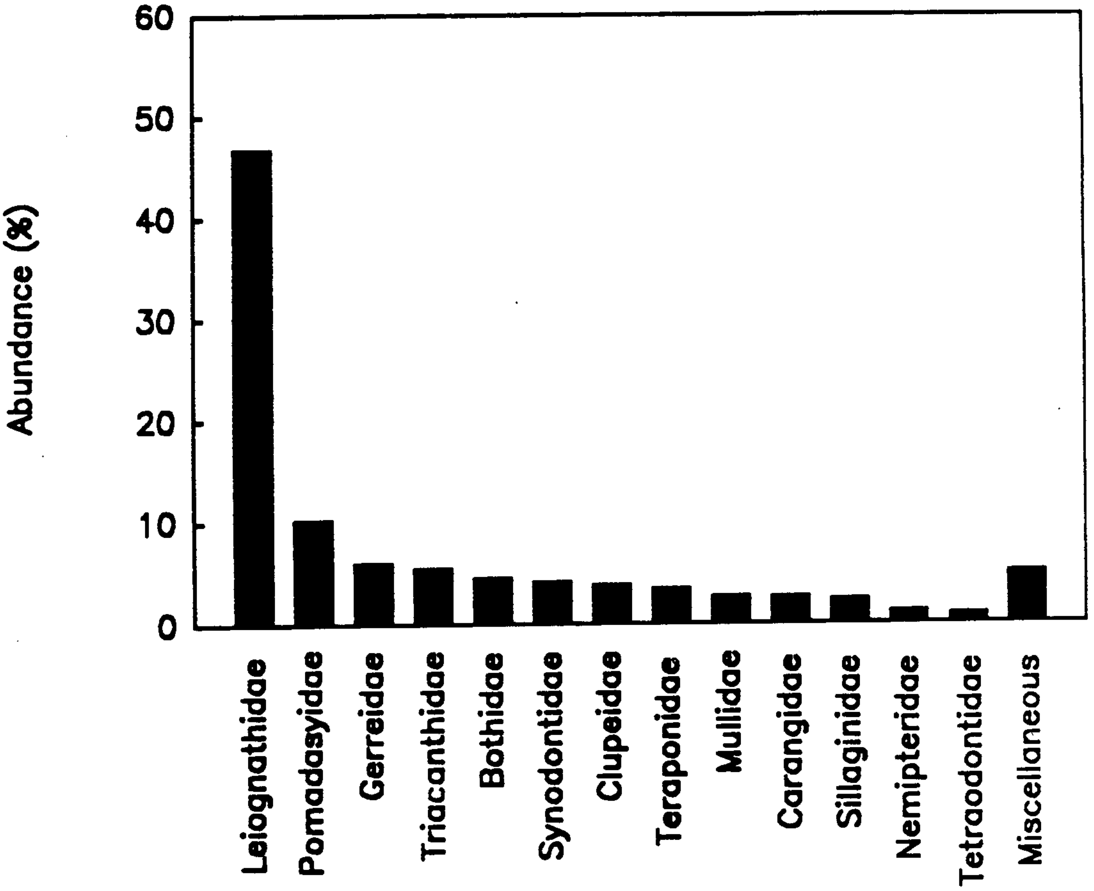
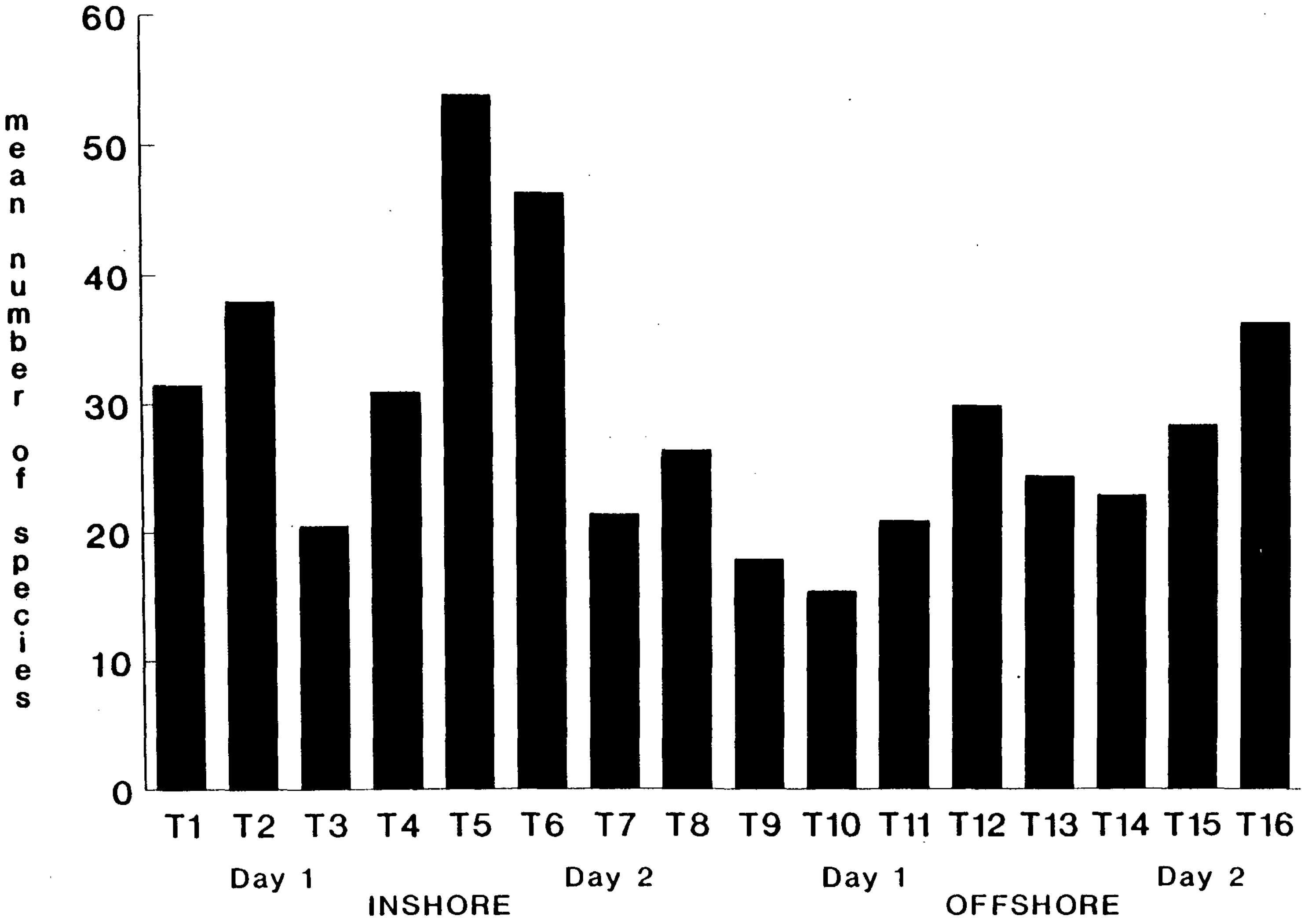

Abundance (%)
60
50
40
30
20
10
0
Leiognathidae
Pomadasyidae
Gerreidae
Triacanthidae
Bothidae
Synodontidae
Clupeidae
Teraponidae
Mullidae
Carangidae
Sillaginidae
Nemipteridae
Tetraodontidae
Miscellaneous

Figure 4. Pattern of species richness in Cleveland Bay.



mean number of species
60
50
40
30
20
10
0
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
T13
T14
T15
T16
Day 1
Day 2
INSHORE
Day 1
Day 2
OFFSHORE

Figure 5. Dendrogram of relationships among 8 sites from pattern analysis of the 60 most common species; the 4 Site-groups at a level of dissimilarity of 1.42 were Site 1 and 3, Site 2, 4, 7, Site 6 and 8, and Site 5; Trawl 1 and 2 belong to Site 1, 3 and 4 Site 2, 5 and 6 Site 3, 7 and 8 Site 4, 9 and 10 Site 5, 11 and 12 Site 6, and 13 and 14 Site 7, 15 and 16 Site 8.

(T - Trawl, N - Net; numbers 1-32 are cumulative number of nets).

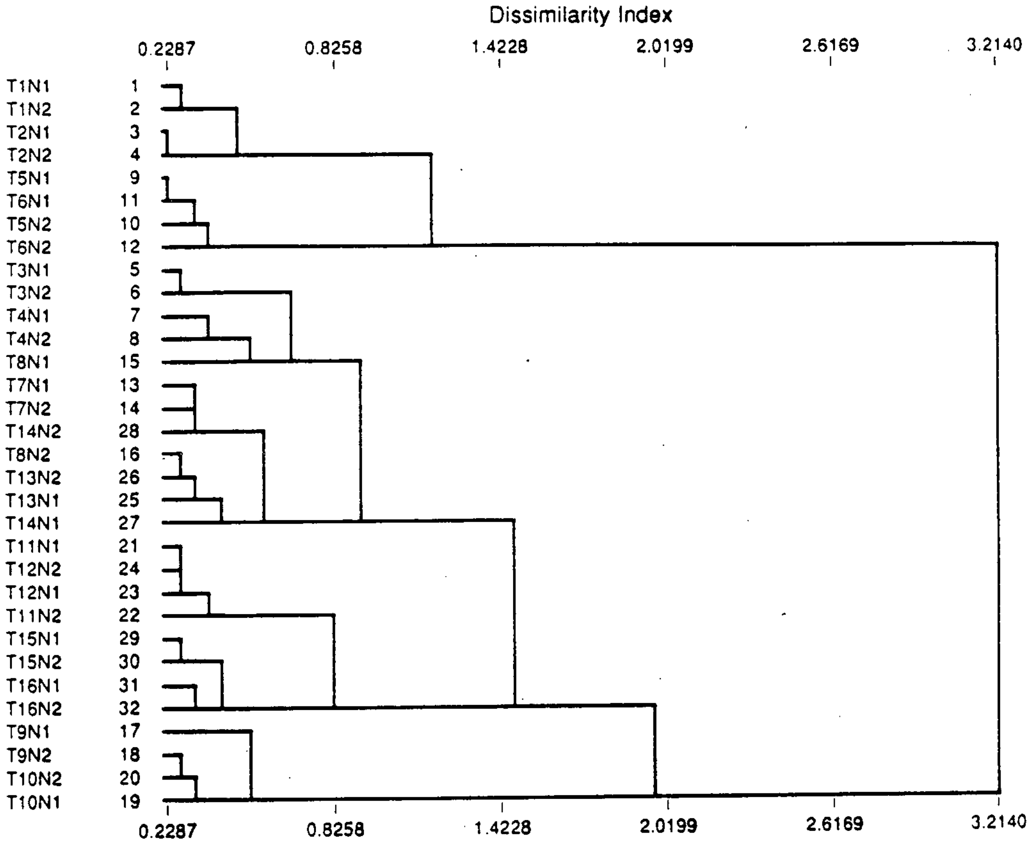
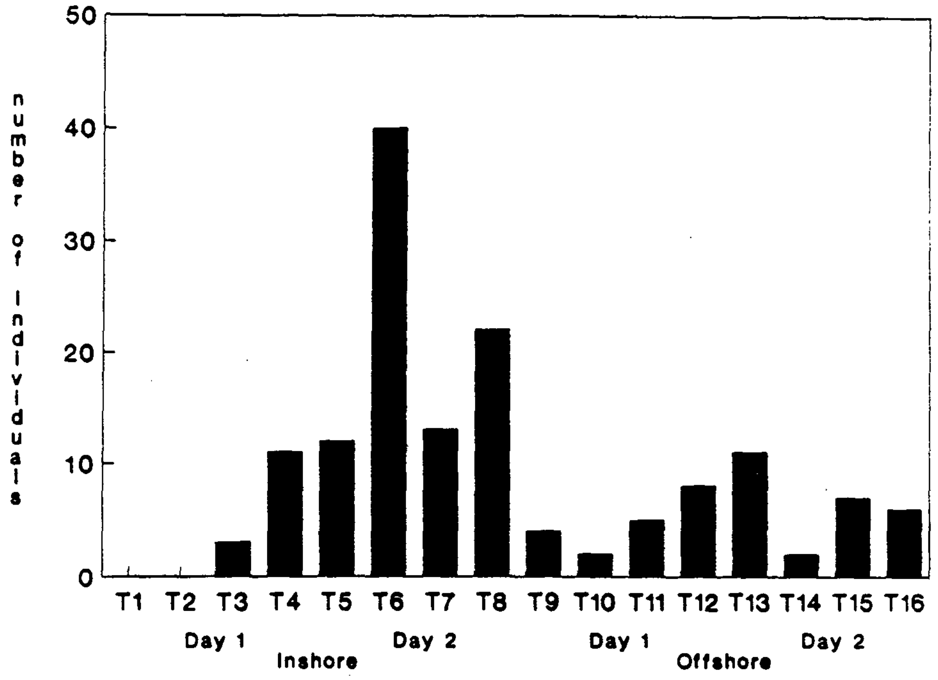

Dissimilarity Index
0.2287
0.8258
1.4228
2.0199
2.6169
3.2140
T1N1 1
T1N2 2
T2N1 3
T2N2 4
T5N1 9
T6N1 11
T5N2 10
T6N2 12
T3N1 5
T3N2 6
T4N1 7
T4N2 8
T8N1 15
T7N1 13
T7N2 14
T14N2 28
T8N2 16
T13N2 26
T13N1 25
T14N1 27
T11N1 21
T12N2 24
T12N1 23
T11N2 22
T15N1 29
T15N2 30
T16N1 31
T16N2 32
T9N1 17
T9N2 18
T10N2 20
T10N1 19
0.2287
0.8258
1.4228
2.0199
2.6169
3.2140

Figure 6. Patterns of abundance of a) *Sillago sihama* and b) *Torquigener whitleyi* in Cleveland Bay.


number of individuals
50
40
30
20
10
0
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
T13
T14
T15
T16
Day 1
Day 2
Inshore
Day 1
Day 2
Offshore

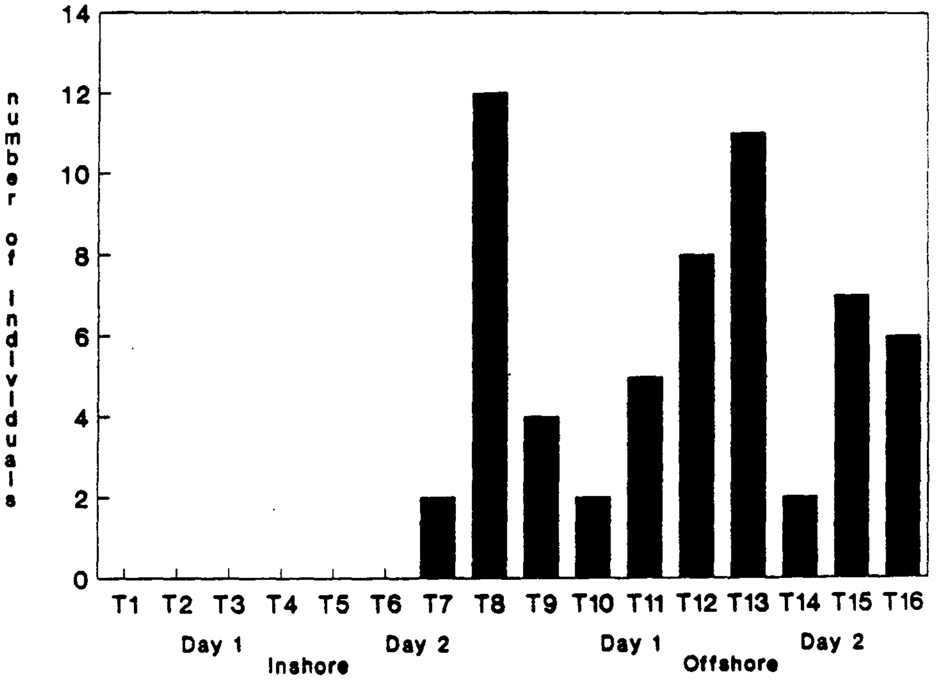
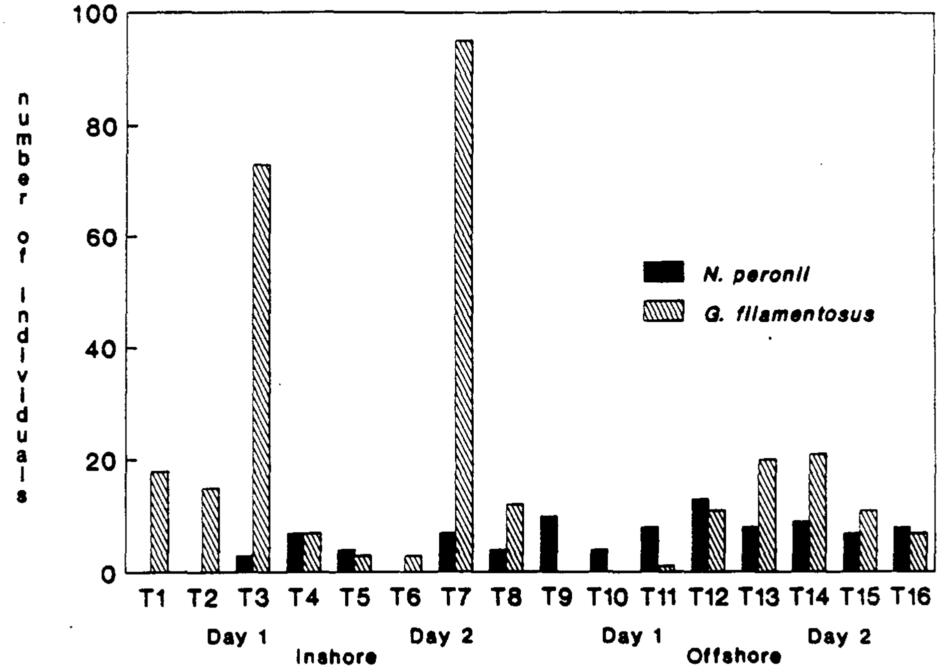

number of individuals
14
12
10
8
6
4
2
0
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
T13
T14
T15
T16
Day 1
Day 2
Inshore
Day 1
Day 2
Offshore

Figure 7. Patterns of abundance of a) *Nemipterus peronii* and *Gerres filamentosus* and b) *Secutor ruconius* and *Pomadasys maculatum* in Cleveland Bay.


number of individuals
100
80
60
40
20
0
N. peronii
G. filamentosus
T1 T2 T3 T4 T5 T6 T7 T8 T9 T10 T11 T12 T13 T14 T15 T16
Day 1
Day 2
Inshore
Day 1
Day 2
Offshore

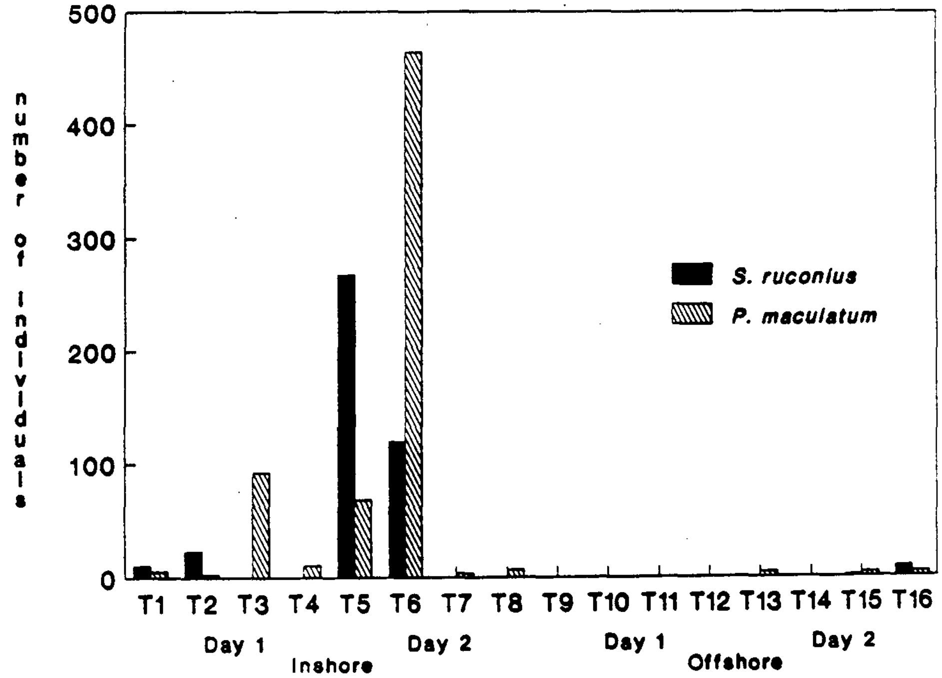
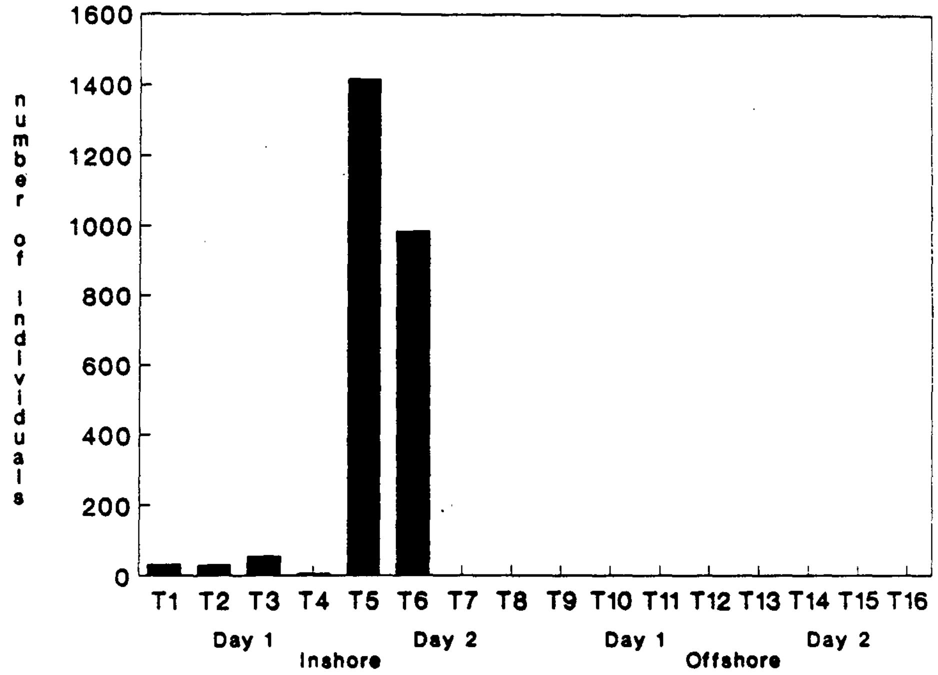

number of individuals
500
400
300
200
100
0
S. ruconius
P. maculatum
T1 T2 T3 T4 T5 T6 T7 T8 T9 T10 T11 T12 T13 T14 T15 T16
Day 1
Day 2
Inshore
Day 1
Day 2
Offshore

Figure 8. Patterns of abundance of a) *Leiognathus splendens* and b) *Saurida micropectoralis* in Cleveland Bay.


number of individuals
0
200
400
600
800
1000
1200
1400
1600
T1 T2 T3 T4 T5 T6 T7 T8 T9 T10 T11 T12 T13 T14 T15 T16
Day 1
Day 2
Inshore
Day 1
Day 2
Offshore

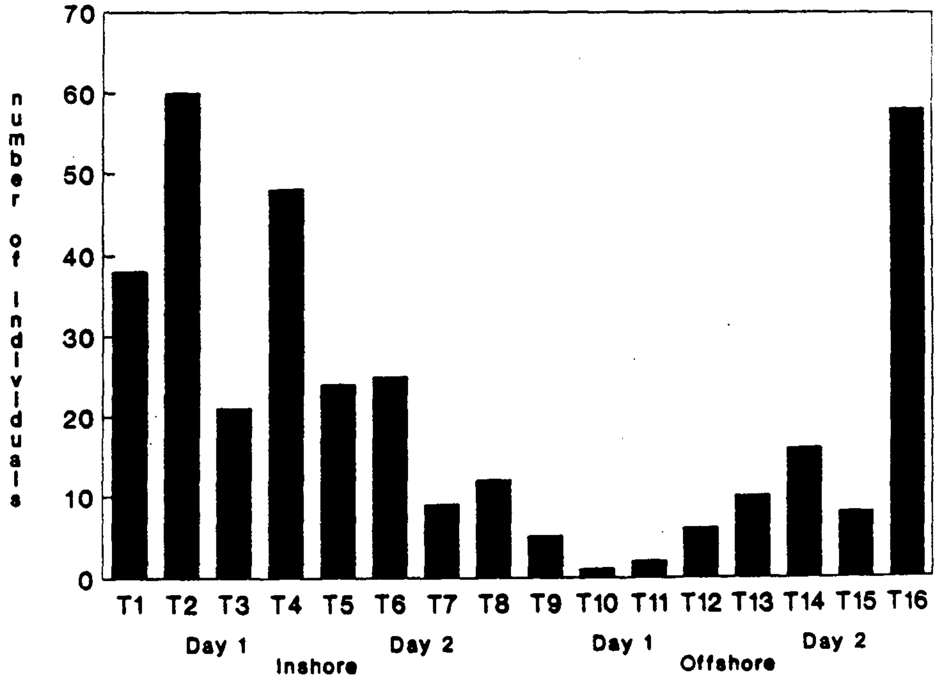

number of individuals
0
10
20
30
40
50
60
70
T1 T2 T3 T4 T5 T6 T7 T8 T9 T10 T11 T12 T13 T14 T15 T16
Day 1
Day 2
Inshore
Day 1
Day 2
Offshore

Figure 9. Patterns of abundance of *Pseudotriacanthus strigilifer* and *Upeneus sulphureus* in Cleveland Bay.

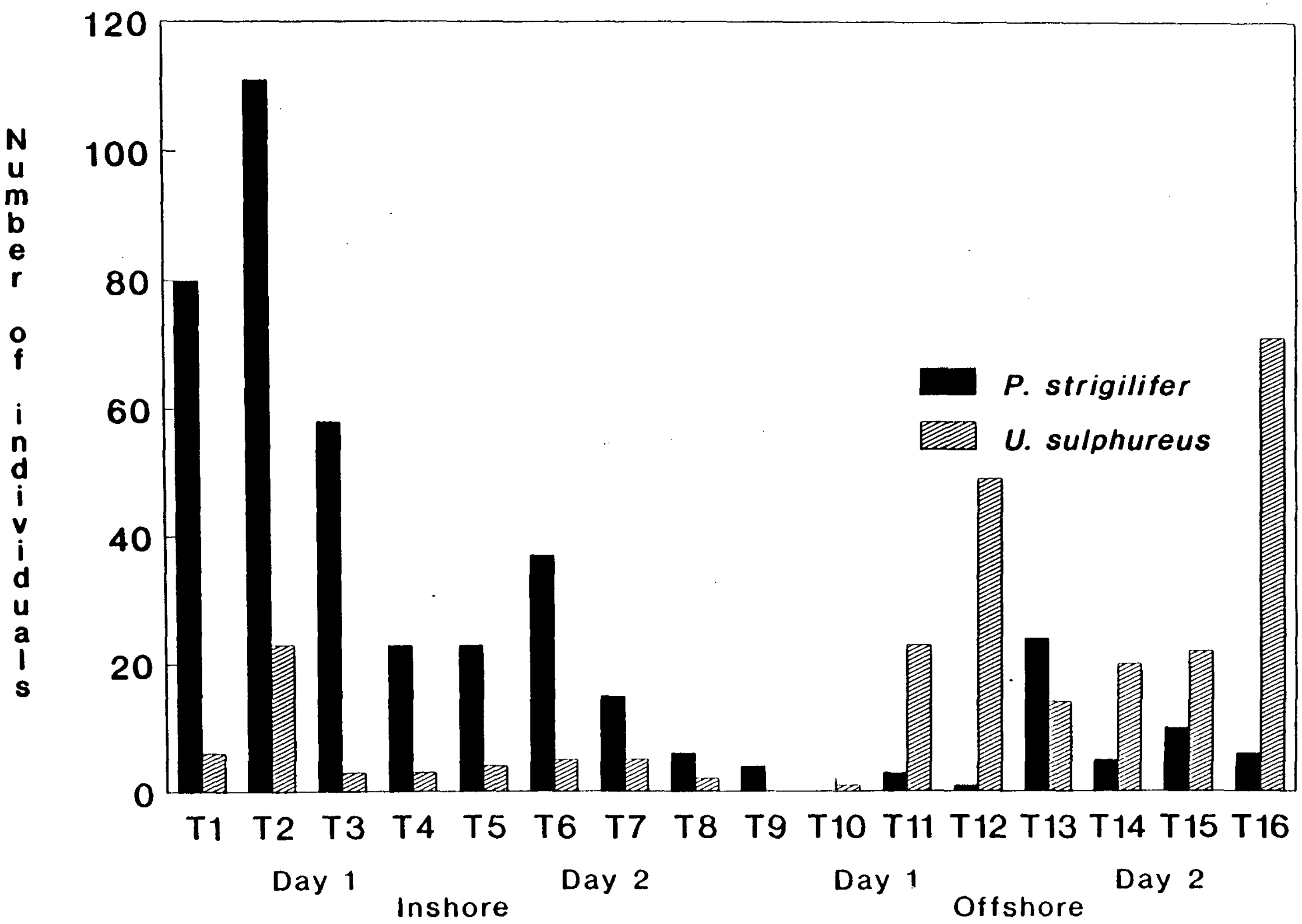

Number of individuals
120
100
80
60
40
20
0
P. strigilifer
U. sulphureus
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
T13
T14
T15
T16
Day 1
Day 2
Inshore
Day 1
Day 2
Offshore

Figure 10. Biomass (in weight) of leiognathids and all species of fishes (total).

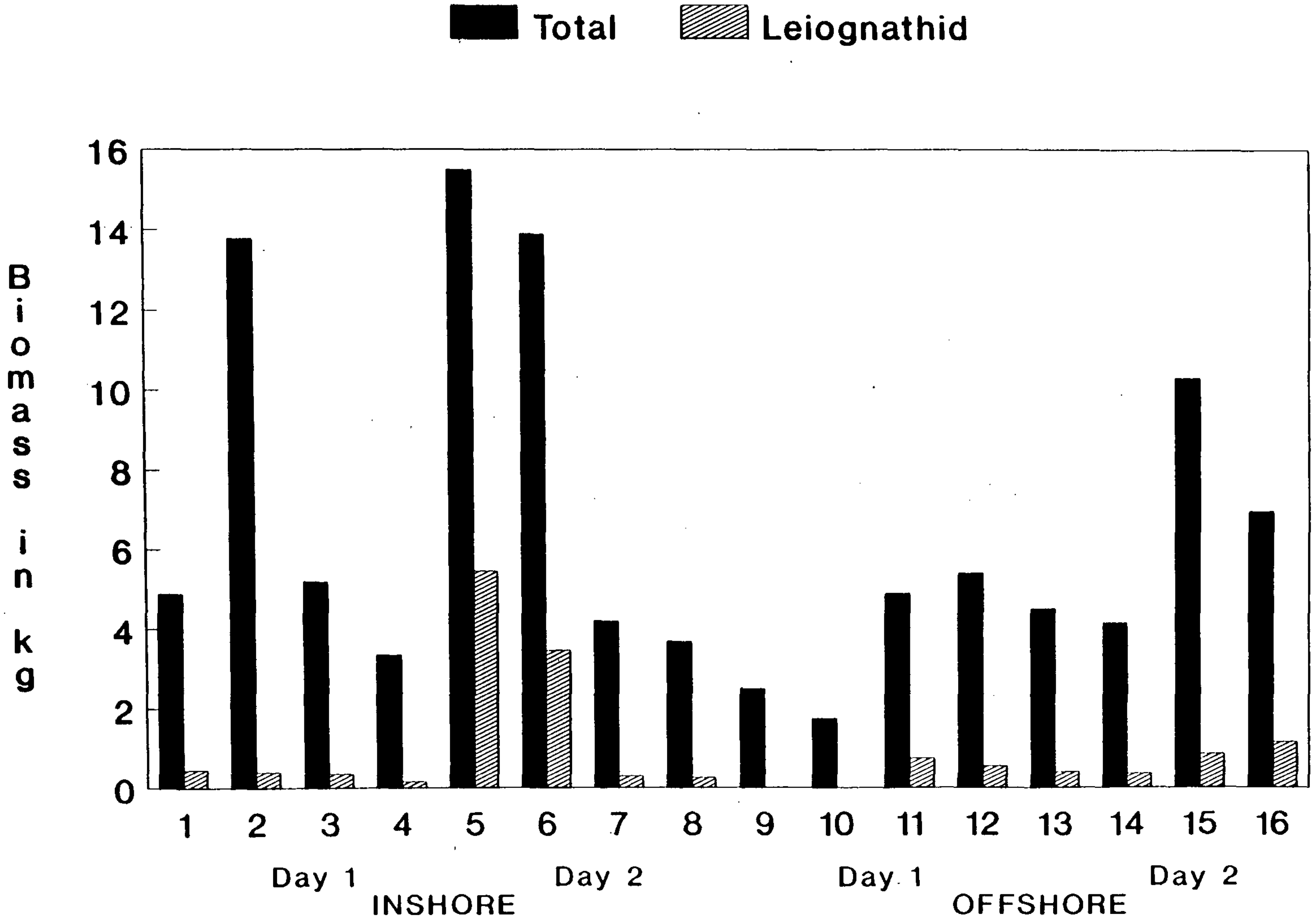

Total
Leiognathid
Biomass in kg
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Day 1
INSHORE
Day 2
Day 1
OFFSHORE
Day 2

Table 1. Results of the analyses of variance on number of species, biomass of leiognathids, total fish biomass and for several numerically abundant species. Numbers are F-ratios. The degrees of freedom for each F-ratio are indicated. Degrees of freedom in brackets are those used when pooling was carried out (see text for details). Levels of significance are * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. All F-ratios without an asterisk were not significant. SSI - *S. sihama*, TWT - *T. whitleyi*, PMA - *P. maculatum*, SRU - *S. ruconius*, NPE - *N. peronii*, GFI - *G. filamentosus*, LSP - *L. splendens*, SMI - *S. micropectoralis*, PST - *P. strigilifer*, ULP - *U. sulphureus*.

source of variation	d. f. of F - ratio	no. of species	leiognathid biomass	total biomass	SSI	TWT	PMA	SRU	NPE	GFI	LSP	SMI	PST	ULP
location	1,4(1,28)	2.241	2.106	1.401	0.0269	3.922	1.513	1.222	8.733*	1.836	31.654**	4.271*	25.275**	1.261
day	1,4(1,28)	1.014	9.261*	0.428	49.805**	1.800	0.647	0.408	0.0198	0.169	0.0459	$1.875\ 10^{-3}$	0.860	0.828
loc. x day	1,4(1,28)	$8.230\ 10^{-5}$	1.377	0.0236	1.138	0.200	0.573	0.408	0.317	0.0169	0.0459	3.257	16.810*	3.875
site	4,8(4,24)	10.762**	104.283***	7.240**	0.522	1.249	0.973	35.974***	1.942	0.150	82.623***	0.653	1.622	2.371
trawl	8,16	2.0715	3.785*	11.671***	0.950	1.147	12.518***	2.311	1.268	27.139***	8.639***	0.579	2.386	0.740
residual														

Table 2. Numerically important species found in each Site-group; * unique to this Site-group

Site-group 1 (Sites 1 and 3)

Anodostomata chacunda
Saurida micropectoralis
S. undosquamis
Terapon puta
*T. theraps**
Apogon quadrifasciatus
Caranx buccelentus
C. chrysophyrys
C. malabaricus
Leiognathus bindus
L. decorus
L. equulus
L. splendens
Secutor ruconius
Gerres filamentosus
Pomadasys maculatum
Upeneus sulphureus
Cynoglossus macrophthalmus
Pseudorhombus arsius
P. elevatus
Chelenodon patoca
Triacanthus biaculeatus
T. niehofi
Pseudotriacanthus strigilifer
Pellona dayi
Sillago sihama
Polydactylus multiradiatus

Site-group 2 (Sites 2, 4, 7)

Saurida micropectoralis
T. puta
Apogon quadrilineatus
S. sihama
L. moretoniensis
L. bindus
L. decorus
L. splendens
Nemipterus peronii
G. filamentosus
Pentaprion longimanus
P. maculatum
Upeneus sulphureus
P. arsius
P. elevatus
C. macrophthalmus
P. strigilifer
Torquigenr whitleyi
T. biaculeatus
A. chacunda
Carangoides hedlandensis

Table 2 (continued)

Site-group 3 (Sites 6 and 8)

*Dussumiera elopsoides**
S. micropectoralis
S. undosquamis
A. poecilopterus
A. quadrilineatus
S. sihama
C. chrysophrys
N. hexodon
N. peronii
G. filamentosus
P. longimanus
P. elevatus
P. maculatum
U. sulphureus
P. arsius
P. strigilifer
T. whitleyi
L. bindus
L. moretoniensis
S. ruconius
Platycephalus sp. 1
Platycephalus sp. 2
*Sillago maculatum burra**
*C. talamparoides**
*"Caranx" para**
*Secutor insidiator**
*Upeneus sundaicus**
*Callionymus superbus**
*Paramonacanthus filicauda**

Site-group 4 (Site 5)

S. undosquamis
Platycephalus sp. 1
Platycephalus sp. 2
*Epinephelus sexfasciatus**
A. poecilopterus
L. bindus
N. peronii
N. hexodon
P. longimanus
P. arsius
T. whitleyi

Table 3. Number of species and families recorded from trawling surveys in tropical waters (* - includes species from near-reef areas; + includes those in trawls only)

Region	**Species**	**Families**	**Reference**
Gulf of Thailand	>50	-	Pauly, 1979
Samar (Philippines)	83	16	McManus, 1986
Burma	88	42	Druzhinin and Phone Hlaing, 1972
Singapore	>95	50	Sinoda et al., 1978
Gulf of Guinea (Africa)	91,97	-	Fager and Longhurst, 1968
Northwestern Australia	114	-	Wei et al., 1973
Gulf of Carpentaria	115	57	Ramm et al., 1990
Malaysia	139	50	Chan and Liew, 1986
Sri Lanka	151	50	Fernando, 1972
North-western Australia	171	-	Seno and Matsuda, 1966
Visayan Sea (Philippines)	173	-	Aprieto and Villoso, 1977
Central Queensland Australia	175	-	Stark et al., 1975
Gulf of Carpentaria (Australia)	180	-	Rainer and Munro, 1982
Leyte? Philippines	226	82	Villoso and Hermosa, 1982
Java Sea and southern tip South China Sea	230	-	Widodo, 1976
New Caledonia	233*	59	Kulbicki and Wantiez, 1990
Florida (U.S.A.)	234	71	Darcy and Gutherz, 1984

Central Queensland	276* 118+	81 10	Dredge, 1989a,b
East Peninsular Malaysia	341	-	Anon., 1967 (in Pauly, 1979)
Gulf of Carpentaria	c.350	-	Rainer, 1984
Torres Strait (Australia)	-	101	Harris and Poiner, 1990

CHAPTER IV

DISTRIBUTION AND ABUNDANCE OF LEIOGNATHIDS IN CLEVELAND BAY, TROPICAL AUSTRALIA

Introduction

Rationale

Leiognathids are small fishes (less than 200 mm in standard length) which usually compose a high percentage of the biomass of ichthyofaunal communities and the catch of tropical demersal fisheries. Leiognathids have been reported to constitute between 0.40 % to 42 % of the catch (biomass) of demersal teleosts and invertebrates in many countries (Druzhinin and Phone Hlaing, 1972; Pauly, 1979; Venkataraman, *et al.*, 1981; Villoso and Hermosa, 1982; Morgan, 1985; Chan and Liew, 1986; Silvestre *et al.*, 1987; Harris and Poiner, 1990; Kulbicki and Wantiez, 1990). One species of leiognathid, *Leiognathus splendens,* constituted 3.6 % of the abundance (number) of fishes and ranked 23rd among 200 abundant species of fishes and invertebrates collected in the coastal areas of the central region of the Great Barrier Reef (Jones and Derbyshire, 1988; Dredge, 1989a,b).

In some countries, multispecific leiognathid stocks are exploited for human food [in India (Balan, 1967; James, 1975; Venkataraman *et al.*, 1981); Indonesia (Pauly, 1977); Philippines (Tiews *et al.*, 1968; Villoso and Hermosa, 1982; Qatar (Morgan, 1985)]. However, in Malaysia, Singapore, and Thailand, only one leiognathid species, *Leiognathus equulus*, which grows to about 200 mm, is commercially important (Pauly, 1978; Sinoda *et al.*, 1978). Leiognathids are also processed for fish meal, duck food, or organic fertilizer in Malaysia and Thailand (Pauly, 1977). In contrast, leiognathids are generally considered as by-catch of fish or prawn fisheries in Singapore (Sinoda *et al.*, 1978) Malaysia (Pauly, 1978), and Australia (Harris and Poiner, 1990)].

The Family Leiognathidae (Pisces) has three genera and 18 species that are distributed widely in the Indo-Pacific biogeographic region (James, 1975). In tropical Australian waters, 15 species of leiognathids have been recorded (Jones, 1985) and of these, ten species are present in Cleveland Bay (Townsville, Australia), the site of the study (Chapter II).

Despite the wide geographic distribution, high biomass, and various commercial uses of leiognathids, very few studies have been directed towards the biology and ecology of these fishes (Pauly and Wade-Pauly, 1981). In Pauly and Wade-Pauly's annotated bibliography on leiognathids, less than 20 papers dealt with the ecology and aspects of the biology that are considered requisites for managing the exploitation of populations. Further studies on the biology and ecology of the many species of leiognathids are therefore pertinent. Data on the variability of the most abundant group of species in a multspecific demersal ecosystem has theoretical and practical relevance. Construction of models for managing multispecific systems require information on the variability of populations being exploited or that are caught along with the target species of the fishery (Beddington, 1984; Gulland and Garcia, 1984; Paine, 1984; Steele, 1984; Sainsbury, 1988). In addition, data collected from a small and relatively unexploited system will be relevant to the management of leiognathid stocks which are currently exploited (*e. g.*, India - Balan, 1967; Venkataraman *et al.*, 1981; Indonesia - Pauly, 1977; Malaysia - Pauly, 1977; Philippines - Villoso and Hermosa, 1982; Silvestre *et al.*, 1987; Thailand - Pauly, 1977). Knowledge of the nature and magnitude of variability in abundance of fishes is one of the pieces of information necessasry for the management and conservation of populations of fishes (Sissenwine, 1984; Steele, 1984).

Variability in the biomass, distribution and numerical abundance of demersal fishes

Temporal variations in the biomass of some tropical demersal fish populations have been documented in many surveys. Interannual variations in catch-per-unit effort of Carangidae, Sphyraenidae, Gerreidae, Trichiuridae, Sciaenidae, Mullidae, Nemipteridae, Synodontidae, Parapercidae, Priacanthidae, Lutjanidae, and Ariidae were gleaned from surveys of demersal fishes in Burma, India, Philippines, Singapore, Australia, and New Caledonia (Druzhinin and Phone Hlaing, 1972; Liu *et al.*, 1978; Sinoda *et al.*, 1978; Silvestre *et al.*, 1987; Harris and Poiner, 1990; Kulbicki and Wantiez, 1990). Seasonal changes in catch-rates of 42 species of demersal fishes in the Gulf of Carpentaria (Australia) were reported by Rainer (1984) while monthly fluctuations in biomass of many important demersal fishes were recorded by Liu *et al.* (1978) in the Arafura and South China Seas.

There are a variety of patterns of distribution and abundance of demersal fishes (Rainer and Munro, 1982). Patterns of vertical (zonation through depth gradients) and horizontal (zonation by distance from shore) distributions for many demersal fishes were discussed by Rainer and Munro (1982); Villoso and Hermosa (1982); and Kulbicki and Wantiez (1990). These patterns were related to depth, salinity, and sediment type (Rainer and Munro, 1982; McManus, 1986; Ramm *et al.*, 1990).

The patterns of distribution and abundance of eight species of leiognathids in Cleveland Bay were studied over 25 months to acquire information on the temporal and spatial variability of the most abundant family of demersal fishes. The study employed a systematic sampling design to collect leiognathids in a shallow (0 - 17 m) and small (225 $km^{2)}$ demersal ecosystem.

Variability in the biomass, distribution, and numerical abundance of leiognathids

On the basis of many general surveys and some specific ecological studies, the biomass, distribution and numerical abundance of leiognathids are variable in time and space. The biomass, distribution and abundance of leiognathids vary among years, seasons, months, and days (Sinoda *et al.*, 1978; Rainer, 1984; Silvestre *et al.*, 1987; Wright, 1989a; Kulbicki and Wantiez, 1990; Chapter III) and with depth (Rainer and Munro, 1982; Villoso and Hermosa, 1982; McManus, 1986).

Various factors affect the temporal and spatial distribution of leiognathids.

Temperature and rainfall were factors correlated to temporal variability of biomass and abundance of leiognathids (Pauly, 1978; Rainer, 1984) while sediment type and salinity are factors related to the spatial variability of leiognathids (Pauly, 1978; Rainer and Munro, 1982; McManus, 1986). In addition, water turbidity may affect the distribution of leiognathids as mean depth of occurence of leiognathids is related possibly to the intensity of their countershading bioluminescence (Pauly, 1978).

Materials and Methods

Sampling design and period of sampling

The procedure in sampling of leiognathids was presented in Chapter II (General Materials and Methods). For completeness, Figure 1 shows the location of study sites and Figure 2 illustrates the sampling design. The sampling design was implemented approximately monthly over 25 months, from April 1988 to April 1990. Sampling was not possible on several occasions due to strong winds which prohibited trawling (3 out of 19 sampling periods).

Field and laboratory procedures

The catch of each net was sorted into leiognathids, all other teleosts, and invertebrates and then weighed (wet weight) and recorded on board ship. The weighing of the different components of the catch was started in July 1988, two months after the commencement of the sampling. When the catch of leiognathids was large (*i. e.*, filling the sorting tray of the vessel), the leiognathids were subsampled by halving or quartering the total catch for preservation. All (or sometimes subsamples of) leiognathids were preserved in ten percent seawater-formalin or 70 % alcohol. In the laboratory, samples were identified and counted.

Statistical analyses

The presence of missing data (missing trawls within some months) required pooling of the data from individual nets in a particular trawl. The mean catch of the two nets in a particular trawl (expressed as abundance per 6,000 m^2 - area swept by one net) was used as the variate in all the analyses of variance of abundance (ANOVA's). The data sets for eight species of leiognathids namely, *Gazza achlamys*, *Leiognathus bindus*, *L. decorus*, *L. equulus*, *L. moretoniensis*, *L. splendens*, *Secutor insidiator*, and *S. ruconius*, were tested for homogeneity of variances using Cochran's test (Underwood, 1981). When the data did not pass the test (at $p = 0.05$), the data were transformed using $\log_{10}$ (X + 0.0001 to 0.01). The transformed data were used in the analyses of variance using a computerized statistical package (*Statistix 3.0*). The sources of variation were Month, Location (Inshore, Offshore), Month x Location (interaction), Site, and Month x Site (interaction). Month, Location, and Site were considered fixed factors (*see* Chapter II for details). Sites were treated as fixed since sampling was carried out at each site each month. Thus, mean squares of all variables were tested against the mean square of the error term.

Further analyses were limited to the four most abundant species. In cases where there was a significant result of the Month x Location interaction, Student-Newman-Keuls (SNK) tests were used to determine the nature of these interactions. The SNK test was not employed in cases where there was a significant result in the Month x Site interaction. The abundance of leiognathids per site throughout each sampling period was illustrated, however.

Results

Biomass of leiognathids

The biomass of leiognathids was highly variable throughout the sampling period and within Cleveland Bay (variable at all spatial levels and with a significant Month x Location interaction; Table 1; Figure 3; Appendix 2). The biomass of leiognathids Inshore was equal to or greater than Offshore in all months, with the exception of April 1989, April 1990, and December 1989 (*i. e.*, 12 of 15 sampling periods - *see* Tables 2 and 3).

Most abundant species

There were ten species of leiognathid recorded in Cleveland Bay during the sampling period. However, only eight species were common, namely, *G. achlamys*, *L. bindus*, *L. decorus*, *L. equulus*, *L. moretoniensis*, *L. splendens*, *S. insidiator*, and *S. ruconius*. The two rare species were *G. minuta* and *L. leuciscus*. The leiognathid fauna was numerically dominated by two *L. splendens* and *L. bindus*.

Spatial and temporal variability

The patterns of distribution and abundance of leiognathids were different from species to species. The distribution and abundance of all species was highly variable (at all levels: time, location, site) with the exception of *L. bindus* (Table 4; Appendix 3). *L. bindus* was found commonly throughout the sampling period and throughout the Bay (Table 4). The abundance of *G. achlamys*, *L. decorus*, and *L. splendens* were highly variable with time (Month) and in space in the Bay (Location and Site levels). There were significant Month x Location and Month x Site interactions in abundance of these species (Tables 5a,b and 6). The densities of *L. equulus*, *S. insidiator*, and *S. ruconius* were variable but not at the level of Locations. However, significant Month x Location interactions were detected (Tables 5c, 6c). In addition, abundance of *S. insidiator* did not vary significantly at the level of Sites. *L. moretoniensis* was variable but did not display a significant Month x Site interaction.

Temporal variability The pattern of monthly abundance of *L. bindus* (Figure 5a), *L. decorus* (Figure 5b), *L. splendens* (Figure 5c), and *S. ruconius* (Figure 5d) show peaks in abundance. Brief peaks in abundances were recorded during the spawning season (September, October, November, December; Chapter V) and during the recruitment season (March, April). Low abundances were recorded during in May, June, July, August.

Spatial variability The detailed pattern of distribution and abundance of *L. decorus* (Figure 6), *L. splendens* (Figure 7), and *S. ruconius* (Figure 8) show that abundances were highly variable from location to location and from one site to another throughout the sampling period (Tables 5a-c). However, the patterns of distribution and abundance of *L. decorus*, *L. splendens*, and *S. ruconius* were similar and differed at the level of sites (Figures 6, 7, 8). *L. splendens* and *S. ruconius* had similar distributions in most months except in March and April 1990 (Figures 7 and 8). In March and April (1990), *L. splendens* was abundant at Site 2 Offshore (Figure 7) whereas *S. ruconius* was abundant at the Site 3 Offshore (Figure 8). *L. decorus* differed from *L. splendens* and *S. ruconius* in many samples. For example, in May 1989, *L. decorus* (Figure 6) was numerous at Site 2 Offshore whereas *L. splendens* and *S. ruconius* were not (Figures 7 and 8). In June 1989, there was a peak in abundance of *L. decorus* at Site 1 Inshore but *L. splendens* and *S. ruconius* were low in abundance there (Figures 6,7,8). In 1990, the peaks in abundance of *L. decorus* were at Site 2 Offshore in January, Site 2 Offshore in March (Figure 6) while *L. splendens* had peaks at Site 3 Offshore in January, Site 2 Inshore in February, Site 2 Offshore in May, and Site 2 Inshore in April (Figure 7). It is obvious from these examples that, although no multivariate statistical analysis was carried out, the patterns of distribution and abundance were similar for *L. bindus* and *L. splendens* but *L. decorus* differed from both.

<u>Month x Location interactions</u> There was no clear seasonal pattern in the abundance at either location for the three most abundant species of leiognathid. There was a significant interaction of the factors Month and Location for three of the most abundant species, *L. decorus*, *L. splendens*, and *S. ruconius*, in Cleveland Bay (Table 4) but the results of the Student-Newman-Keuls tests showed inconsistent patterns for these species (Tables 5a,b,c and 6). For instance, for *L. decorus* there were 9 months when there were more fish inshore than offshore, five months where they were more abundant offshore, and in the rest of the months there were no significant differences in numbers inshore and offshore. The months of similar abundance inshore and offshore were not, however, consecutive. For example, in April and May 1988, there were more *L. decorus* offshore than inshore while in the following month there was no significant difference in numbers between locations. In July there were

significantly more individuals Inshore than Offshore (Tables 5a,6). However, for calendar months that were sampled in at least two years, comparisons indicated interannual variation. For example, for *L. splendens* there were more collected inshore in April 1988 than April 1989 and 1990 (SNK - April 1988>April 1990> 1989; Table 5b). Similarly, there were more *S. ruconius* collected offshore in December 1989 than in December 1988 (Table 5c). However, there was no observable consistent period of either low or high abundance. For *L. decorus*, there were high numbers (> 50 % of largest mean) offshore in October 1988, April 1988 and March 1990 while the highest monthly means for the inshore location were in July 1988, April 1990, and December 1988 (Table 6a). On the other hand, for *L. splendens* there were few individuals inshore in May 1988, January 1990 and August 1989 while there were few individuals offshore in July 1988, May 1989, June 1989, August 1989 and November 1989 (Table 6b). Similar inconsistent patterns of abundance were observed for *S. ruconius* also (Table 6c).

Discussion

The large biomass [ranging from a mean of 0.001 to 64.700 kg/6,000 m^2] of leiognathids and abundances of leiognathid species (Figures 4, 5a-d, 6, 7, 8) in Cleveland Bay, tropical Australia were highly variable at very small spatial scales (Sites) and temporal scales (Months). Variation in densities of fish over scales of 1-2 km were just as important in determining patterns of abundance as those at larger (~ 10 km) scales. This finding has obvious implications for the design of sampling programs targetting tropical demersal fish taxa.

Schooling behaviour and local migration could be the possible causes of spatial and temporal variations in densities (significant variation in Site, Location, Month effects and daily effects *see* Chapter II). Recruitment variability and intense predation may explain long-term variability (month, year; *see* Chapters V and VI).

Variability in abundance

Seasonality in the abundance of leiognathids in Cleveland Bay was not detected (results of SNK tests - Tables 2, 3, 5a-c, 6-8). The high variability in densities of leiognathids may have prohibited detection of seasonality. Nevertheless, seasonal change in temperature is one factor that is expected to affect the abundance of adult leiognathids in Cleveland Bay as juveniles of leiognathids show a very seasonal pattern of abundance in the mangrove creeks fringing the Bay (Penridge, 1971; Robertson and Duke, 1987, 1990; Chapter V). However, seasonal variations in biomass and densities appear to be typical of leiognathid and other demersal fish populations. Catch-rates and densities of leiognathids (and other species) varied among seasons in the Gulf of Carpentaria (Rainer, 1984) and in New Caledonia (Kulbicki and Wantiez, 1990). In New Caledonia, maximum catches of leiognathids (mainly *L. bindus*) occured during the dry season between August and November (Kulbicki and Wantiez (1990).

Schooling behaviour and local migration

Schooling and local migration of leiognathids are factors that may explain the spatial pattern of distribution and abundance of leiognathids [*i. e.*, significant at the level of Sites and Month x Location interactions (Tables 5a-c and 6a-c)] in Cleveland Bay. Leiognathids are facultative schoolers inhabiting sandy coastline, murky estuarine and demersal habitats (Pauly, 1977). It is most likely that variability in the catch of leiognathids was a function of when the trawl encountered schools or not.

By forming schools, leiognathids gain protection from many predatory fishes (Lagler *et al.*, 1976; Cech and Moyle, 1982) such as synodontids (Sainsbury and Whitelaw, MS; Chapter VI). Leiognathid schools appear multispecific but dominated by *L. splendens* in Cleveland Bay (Tables 5a-c, 6a-c). Despite the murky waters, schooling has adaptive value against the predatory fishes (*e. g.*, synodontids, sharks) that have apparently adapted good vision. It is also possible that schooling may assist in the acquisition of food. However, it is not possible that schooling is due to the pattern of settlement of larval cohorts (as in coral reef fishes; *see* Williams, 1986). Demersal fishes are not site-limited as reef-fishes are; these fishes live in an environment with no or very little relief.

Leiognathids were also mobile, probably migrating locally (10's km). Within Cleveland Bay, there was no consistent trend for leiognathids to stay

Inshore or Offshore for periods of time (thus the presence of significant interactions between Month and Location; Tables 5a-c and 6a-c). Furthermore, the significant differences between Sites indicates that leiognathids form schools and that schools were found both Inshore and Offshore. Leiognathids are found in extensive depths in tropical areas [*e. g.*, in the Gulf of Carpentaria (Rainer and Munro, 1982); in Indonesia (Pauly, 1977); in the Philippines (McManus, 1986)]. Leiognathid recruits (<40 mm SL; Millington, 1973; Chapter VI) are found in estuarine areas while adults can be found up to depths of 60 m (Pauly, 1977). These patterns suggest potential migrations offshore as size increases.

Local migration may be related to search for food and spawning activity. The relation of local migration to spawning activity is further discussed below.

Spawning periodicity, recruitment variability, and predation pressure

Spawning periodicity, recruitment variability, predation pressure, and migratory behaviour are several plausible factors that may explain the variability of biomass and densities of leiognathids in Cleveland Bay. These biological and environmental factors act together in causing temporal and spatial variability.

The observed peaks in abundance coincided with spawning season and recruitment period. This indicated that leiognathids may have migrated into the Bay from deeper waters to spawn (Chapter V). A similar trend occurs in Mexico, where densities of some demersal fishes were high during the summer season due to local migration to coastal waters for spawning (*e. g.*, *Cynoscion arenarius*, Tapia-Garcia *et al.*, 1988). In addition, the appearance of new recruits into the population resulted in the peaks in abundance after December (Chapter V). This could have been more obvious in the length-frequency data were it not for the selectivity of the nets for bigger fishes (Chapter II).

The magnitude of recruitment (= the arrival of individuals in the population) may well determine the size of adult populations (in coral reefs Doherty and Williams, 1988). Recruitment may vary due to, among other factors, the magnitude of larval supply (*e. g.*, Victor, 1986; Williams, 1986 and references therein) and/or pressure by predation on larvae and recruits. In Cleveland Bay, the size of recruitment may be affected substantially by predation (Chapter VI).

In New Caledonia, Kulbicki and Wantiez (1990) also found interannual variation in the biomass of leiognathids. In the Gulf of Carpentaria, Rainer (1984) reported fluctuating catch-rates of leiognathid species. Failure in recruitment is a possible reason for the ocurrence of low biomass in a particular year (Kulbicki and Wantiez, 1990). Furthermore, success or failure of recruitment could generate long-term variability (Kulbicki and Wantiez, 1990).

Increased abundances of other demersal fishes have been correlated with recruitment. The maximum densities of *Cynoscion arenarius* and *C. nothus* (Sciaenidae) in coastal waters of Mexico are correlated with recruitment in June to November (Tapia-Garcia *et al.*, 1988).

Natural mortality caused by predation by *Saurida* species on postlarvae and recruits was high (Chapter VI), thus affecting the size of the subsequent adult populations. The densities of recruits of *L. decorus* and *L. splendens* in mangrove areas near Cleveland Bay varied from year to year (Robertson and Duke, 1990; Chapter VI). In addition, because of cannibalism in synodontids (Chapter VI), fluctuations in the populations of these predators could also translate to fluctuations in the abundance of recruits of leiognathids each year.

Implications of variability in sampling demersal ichthyofauna

The observed small-scale variability of leiognathids at the scale of Site and Months persisted through time (interannual). Daily variations were also reported in Chapter III. This variability has some bearing in studies of the abundances of populations and of community structure. In studies of community structure, different scales of sampling have resulted to different conclusions (Ramm *et al.*, 1990; Chapter III). This study has measured the variability at this scale and perhaps could have made a definite statement on seasonality had there been more regular trawling. (This was not possible during the study due to limited funds and ship-time.) In future studies, comparisons of community structure and population abundance at larger spatial and temporal scales will have to take into account the high variability in abundance at small spatial scales by ensuring adequate replication in sampling designs. In addition, physico-chemical parameters, especially nutrient levels, should be collected simultaneously to be explain variability in abundances.

Furthermore, several techniques may be undertaken to document the schooling behaviour of leiognathids and test the hypothesis that leiognathids migrate. Underwater photography and readings from an echo-sounder during sampling will show definite proof of schooling.

The migratory behaviour of leiognathids can be tested by tagging individuals from inside and outside of Cleveland Bay during non-spawning and spawning periods. This will be difficult due to the small size of these fishes. Secondly, these fishes get stressed as they are hauled up so a large number die or cannot take additional stress from tagging. However, these logistical problems can be circumvented.

Figure 1. Map of Cleveland Bay off Townsville, showing Sites 1 to 3 in the Inshore Location and Sites 4 to 6 in the Offshore Location. Inset-map of Australia showing location of Townsville.

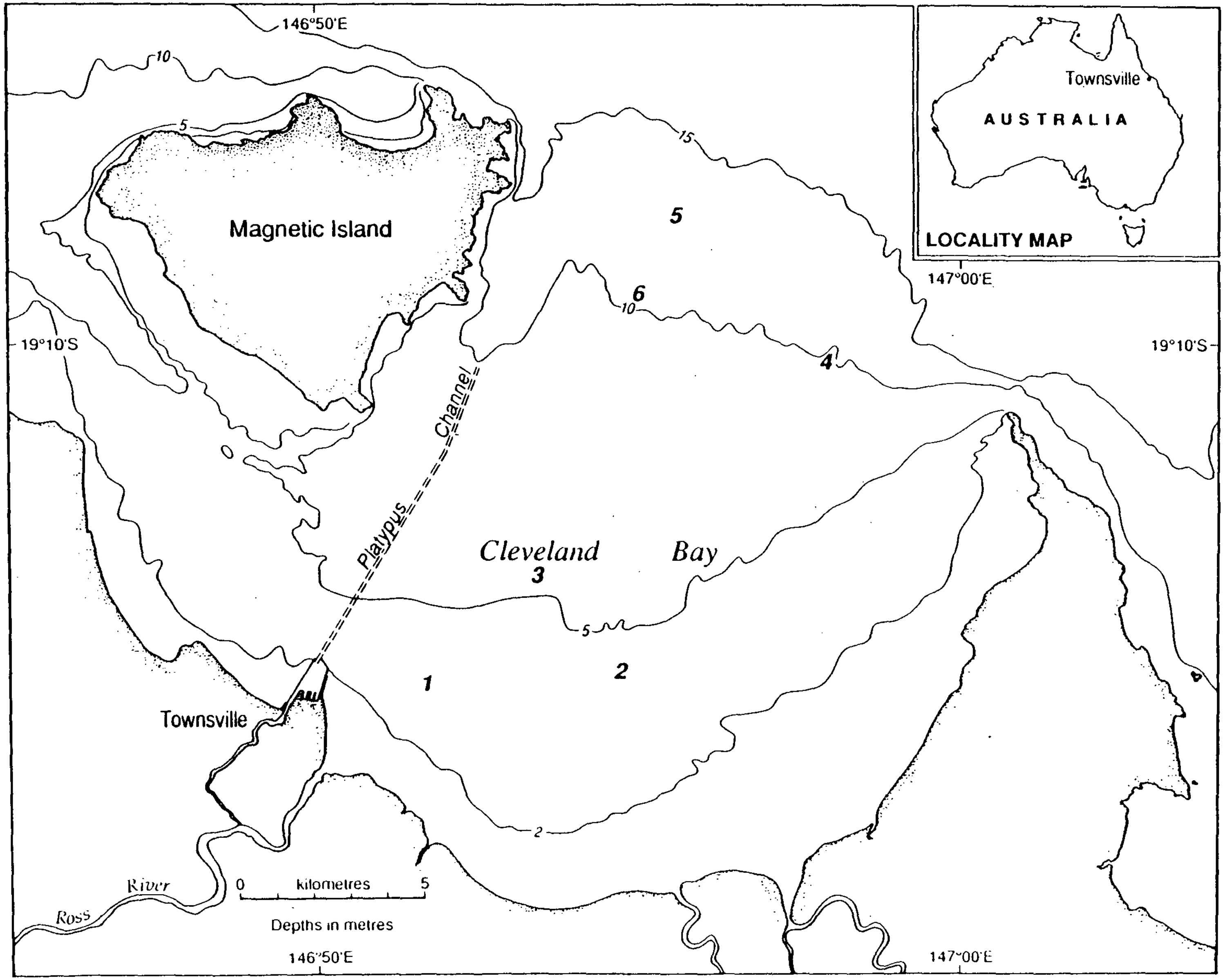
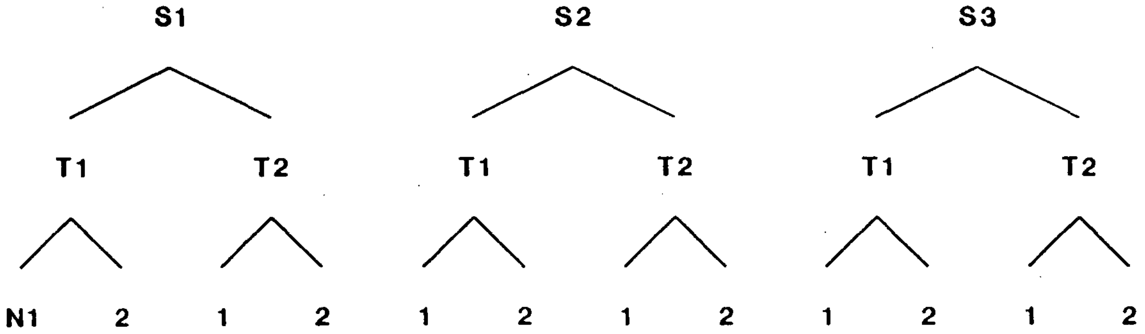
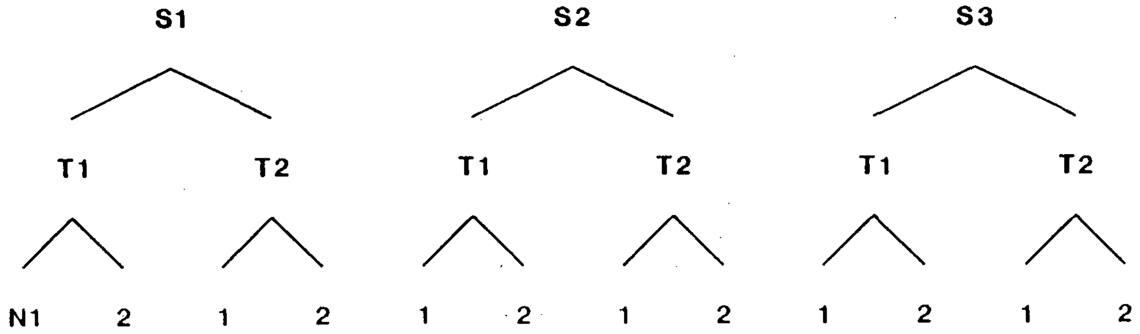

146°50'E
10
5
Magnetic Island
15
5
6
10
4
19°10'S
19°10'S
147°00'E
Platypus Channel
Cleveland Bay
3
5
1
2
Townsville
2
Ross River
0 kilometres 5
Depths in metres
146°50'E
147°00'E
Townsville
AUSTRALIA
LOCALITY MAP

Figure 2. Sampling design for long-term monitoring of distribution and abundance of leiognathids in Cleveland Bay.

S = Site, T = Trawl, N = Net.



Inshore



Offshore

Figure 3. Mean biomass of leiognathids per $6000m^2$ from July 1988 to April 1990 in Cleveland Bay.

Open Symbols = Offshore; Shaded Symbols = Inshore.

Standard errors omitted for clarity. Asterisks indicate where the SNK analysis detected a significant difference in abundance between inshore and offshore locations for any particular month.

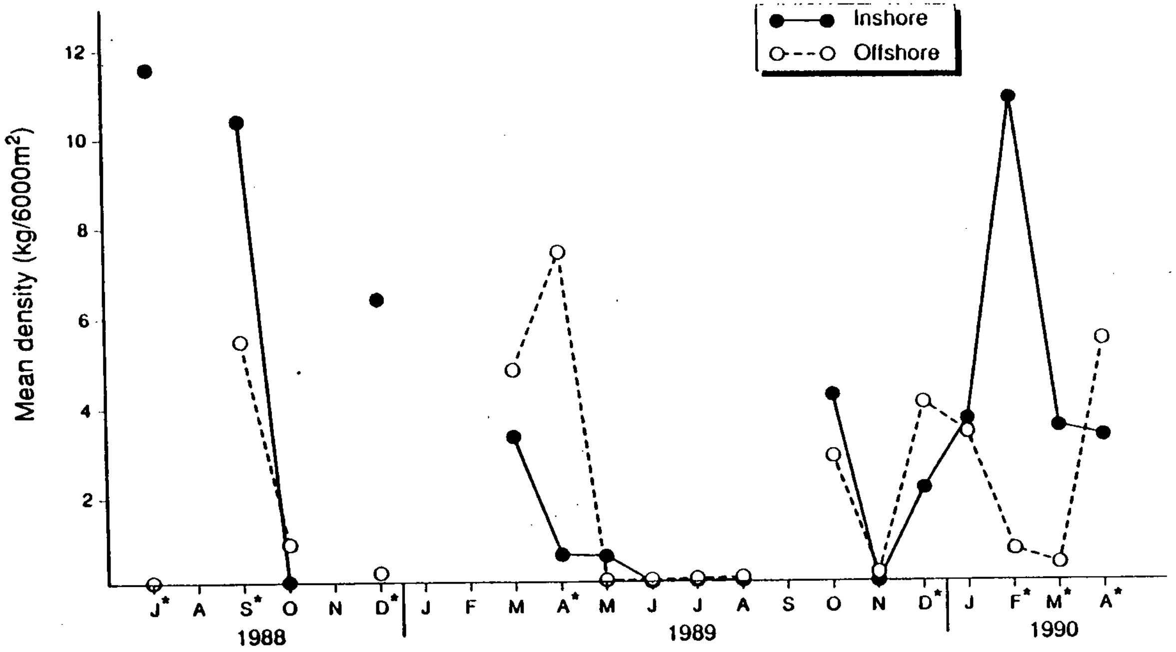

Mean density (kg/6000m²)
12
10
8
6
4
2
Inshore
Offshore
J*
A
S*
O
N
D*
J
F
M
A*
M
J
J
A
S
O
N
D*
J
F*
M*
A*
1988
1989
1990

Figure 4. Mean numbers per $6000m^2$ (± SE) of eight leiognathid species collected in Cleveland Bay from April 1988 to April 1990; numbers in parentheses are the number of nets sampled over the period.

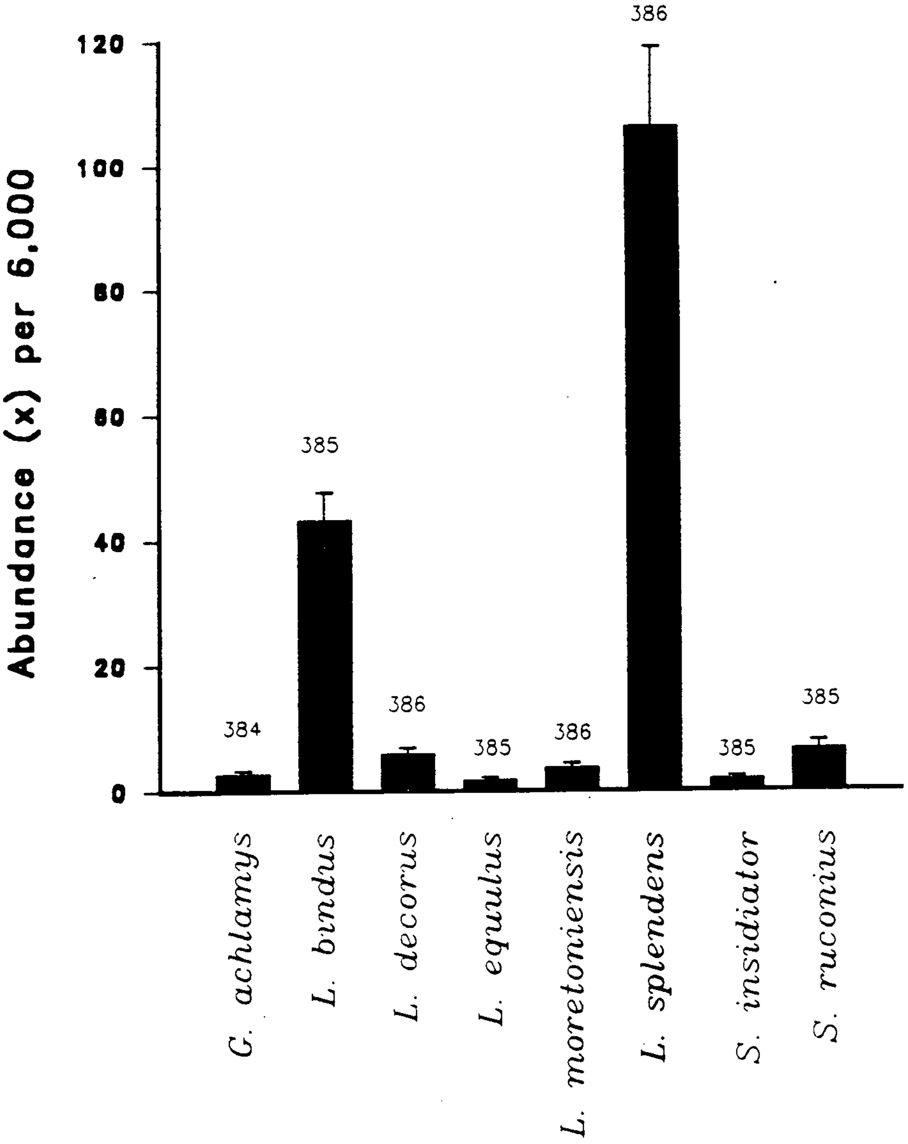

Abundance (x) per 6,000
120
100
80
60
40
20
0
384
385
386
385
386
386
385
385
G. achlamys
L. bindus
L. decorus
L. equulus
L. moretoniensis
L. splendens
S. insidiator
S. ruconius

Figure 5a. Mean number per $6000m^2$ of *L. bindus* in Cleveland Bay from April 1988 to April 1990. Standard error for total data set shown.

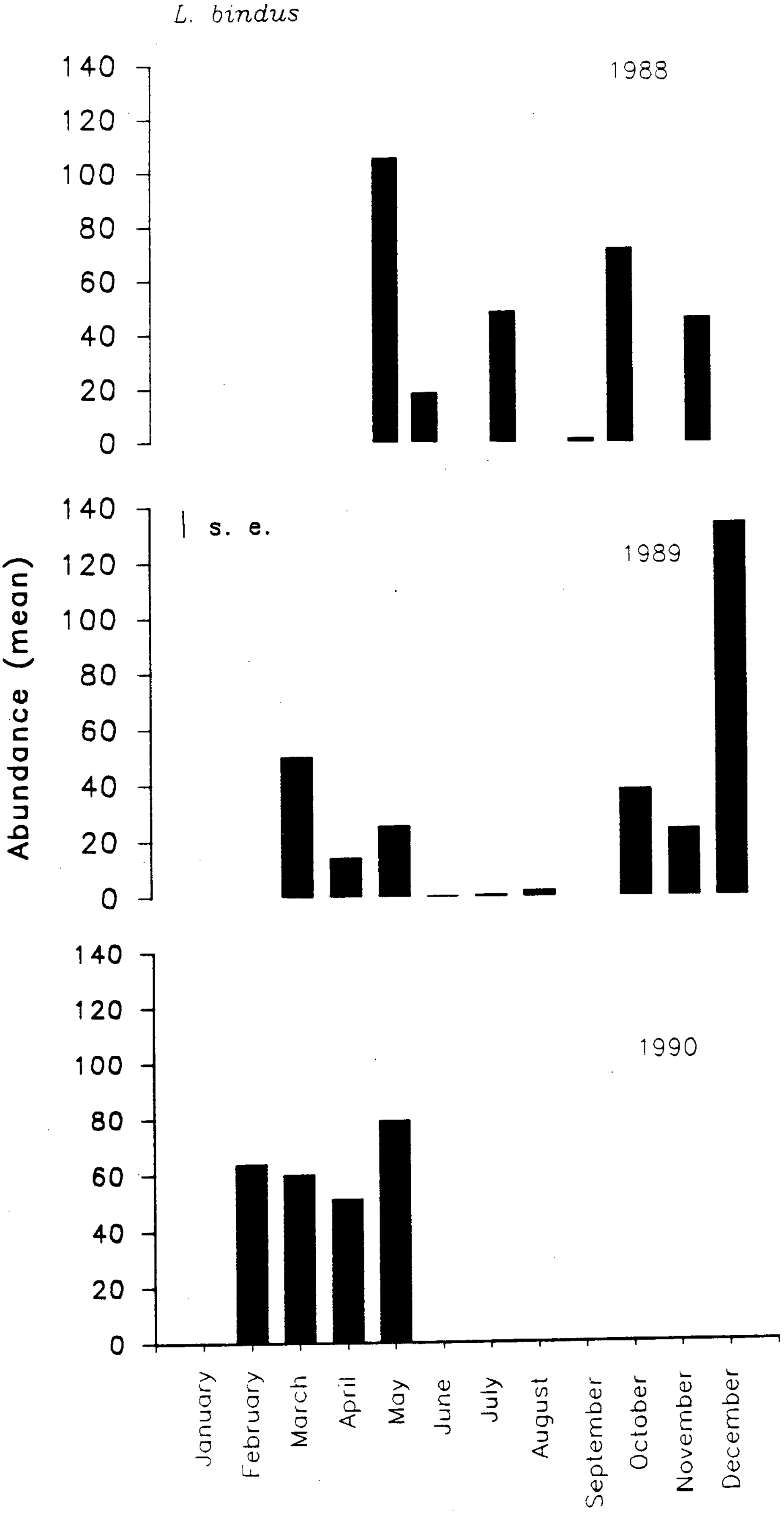

L. bindus
1988
1989
1990
| s. e.
Abundance (mean)
0
20
40
60
80
100
120
140
January
February
March
April
May
June
July
August
September
October
November
December

Figure 5b. Mean number per $6000m^2$ of *L. decorus* in Cleveland Bay from April 1988 to April 1990.

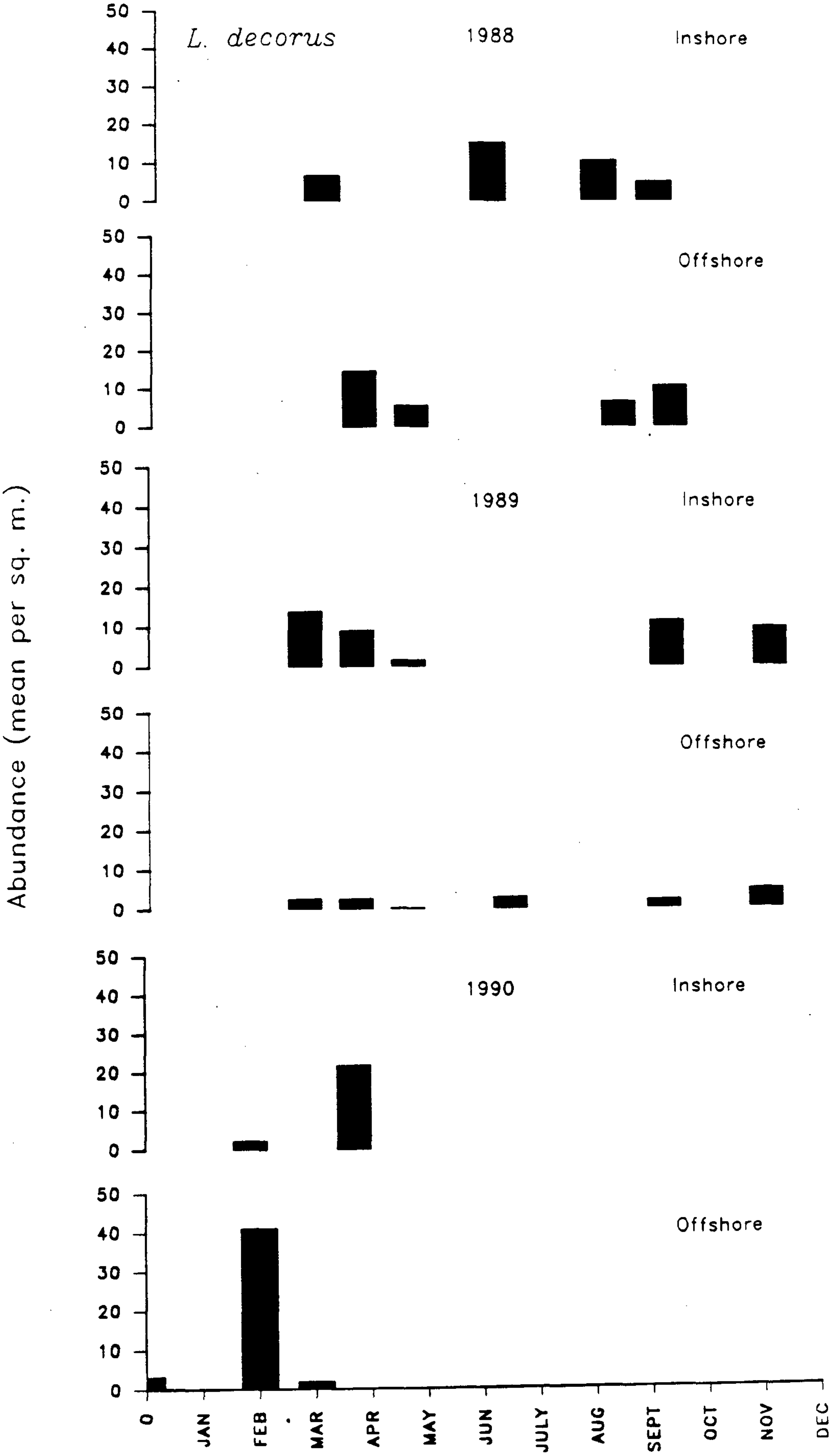

L. decorus
1988
Inshore
Offshore
1989
Inshore
Offshore
1990
Inshore
Offshore
Abundance (mean per sq. m.)
0
10
20
30
40
50
0
JAN
FEB
MAR
APR
MAY
JUN
JULY
AUG
SEPT
OCT
NOV
DEC

Figure 5c. Mean number per $6000m^2$ of *L. splendens* in Cleveland Bay from April 1988 to April 1990.

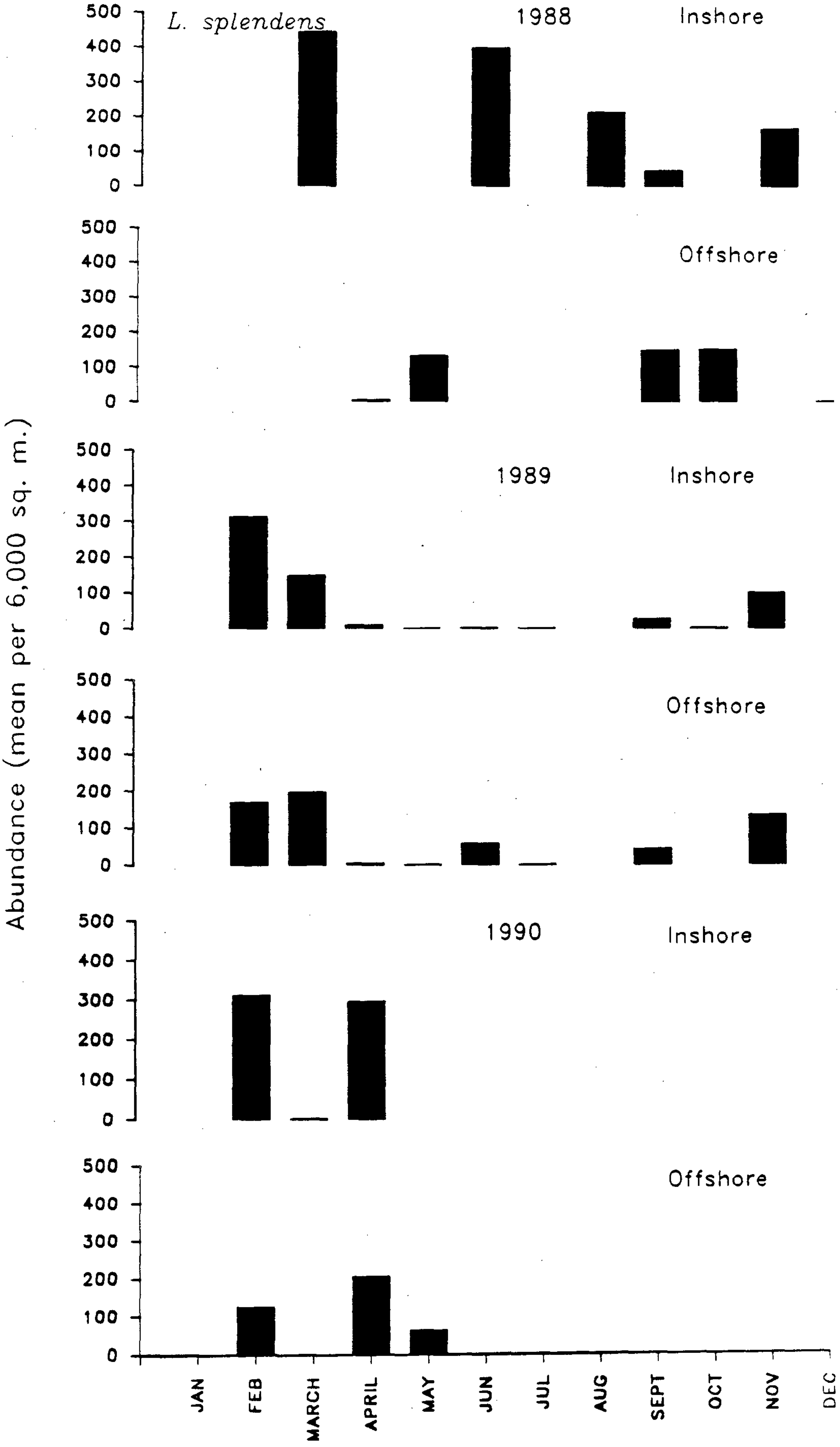
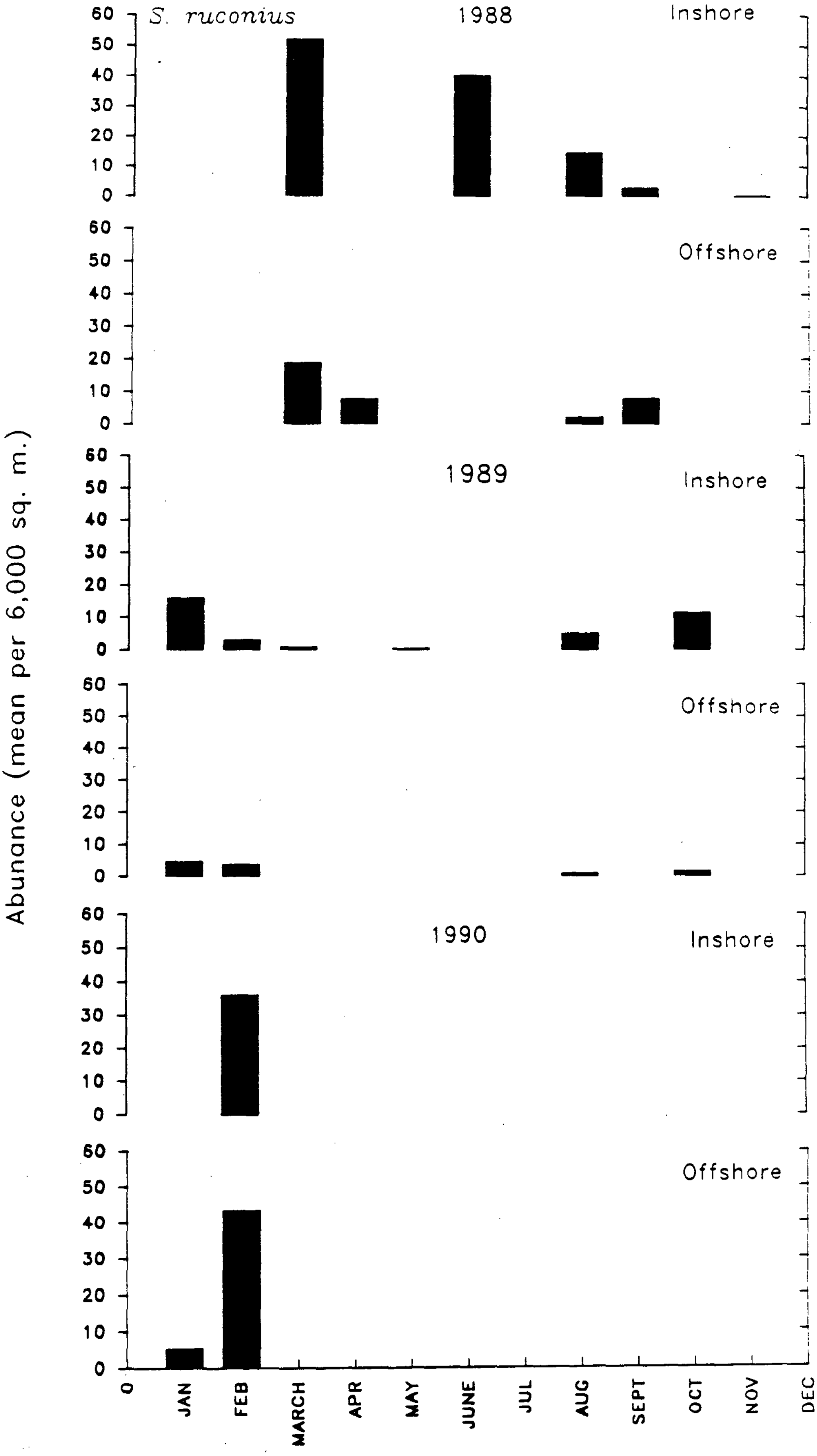

L. splendens
1988
Inshore
Offshore
1989
Inshore
Offshore
1990
Inshore
Offshore
Abundance (mean per 6,000 sq. m.)
500
400
300
200
100
0
JAN
FEB
MARCH
APRIL
MAY
JUN
JUL
AUG
SEPT
OCT
NOV
DEC

Figure 5d. Mean number per $6000m^2$ of *S. ruconius* in Cleveland Bay from April 1988 to April 1990.



S. ruconius
1988
Inshore
Offshore
1989
Inshore
Offshore
1990
Inshore
Offshore
Abunance (mean per 6,000 sq. m.)
0
10
20
30
40
50
60
0
JAN
FEB
MARCH
APR
MAY
JUNE
JUL
AUG
SEPT
OCT
NOV
DEC

Figure 6. Number per $6000m^2$ of *Leiognathus decorus* at Inshore and Offshore locations (Sites numbered 1-3 within a location) of Cleveland Bay from April 1988 to April 1990.

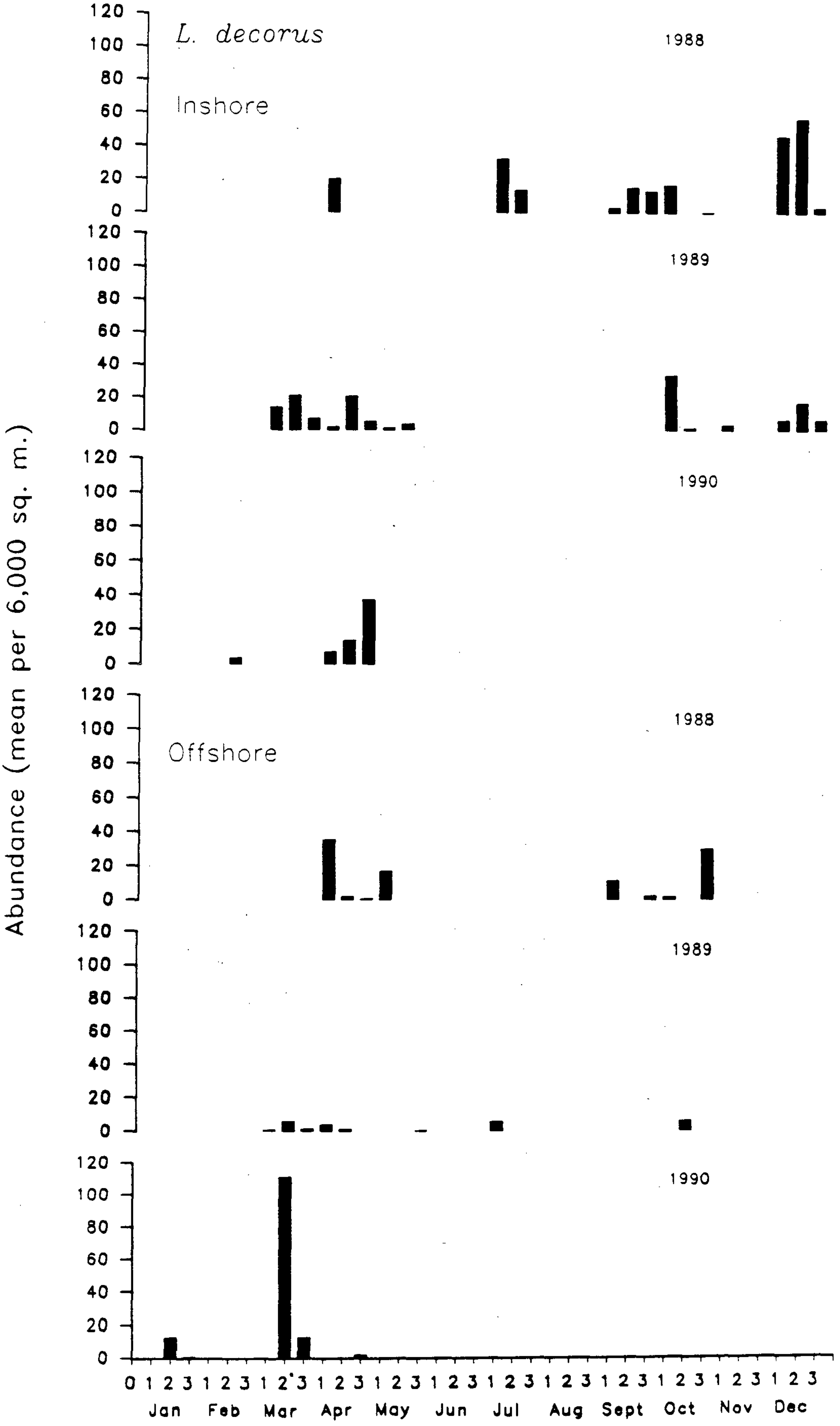

L. decorus
Inshore
Offshore
1988
1989
1990
1988
1989
1990
Abundance (mean per 6,000 sq. m.)
0
20
40
60
80
100
120
0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec

Figure 7. Number per $6000m^2$ of *Leiognathus splendens* at Inshore and Offshore locations (Sites numbered 1-3 within a location) from April 1988 to April 1990.

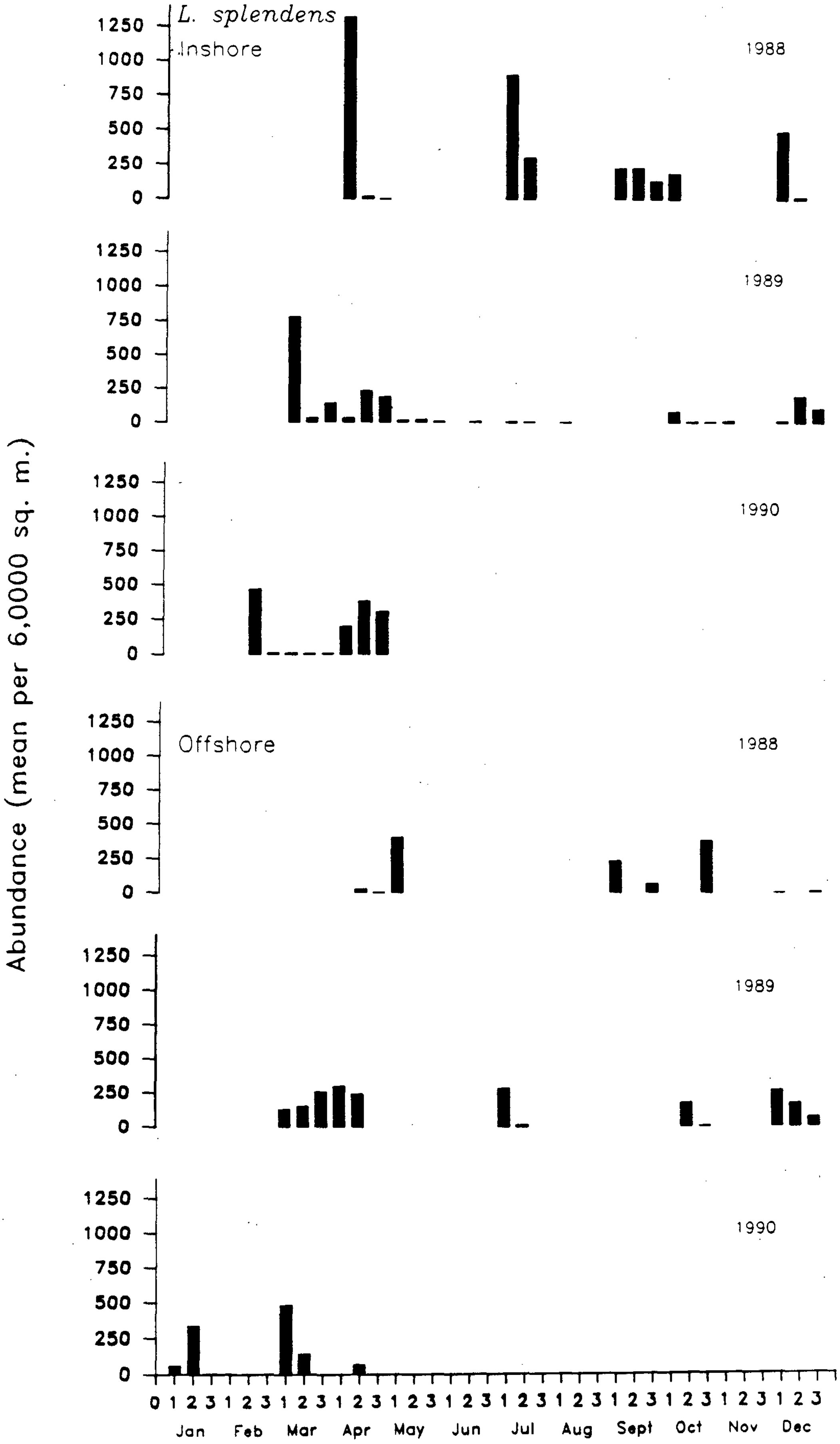

L. splendens
Inshore
Offshore
1988
1989
1990
1988
1989
1990
Abundance (mean per 6,0000 sq. m.)
1250
1000
750
500
250
0
0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec

Figure 8. Number per $6000m^2$ of *Secutor ruconius* at Inshore and Offshore locations (Sites numbered 1-3 within a location) from April 1988 to April 1990.

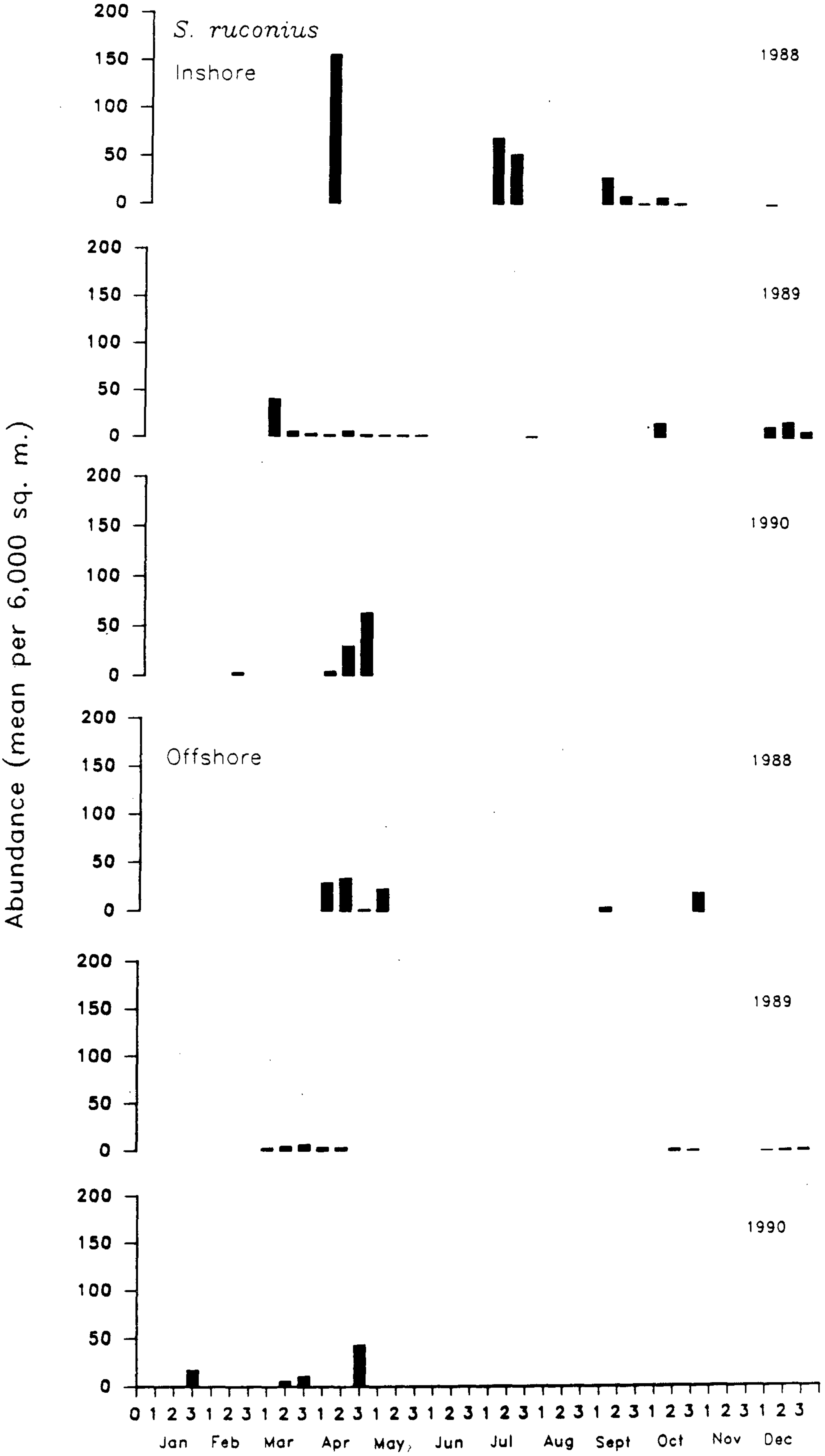

S. ruconius
Inshore
Offshore
1988
1989
1990
Abundance (mean per 6,000 sq. m.)
0
50
100
150
200
0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec

Table 1. Results of the analysis of variance on the biomass of leiognathids from July 1988 to April 1990 (* - significant at $p = 0.05$, ** - significant at $p = 0.01$; df - degree of freedom).

Variate	**df**	**Result**
Month (M)	12	**
Location (L)	1	**
M x L	12	**
Site (S)	4	**
M x S	24	**
Trawl	78	*
Error	80	

Table 2. Summary of Student-Newman-Keuls tests of leiognathid biomasses (kg/6000m^2) performed due to the significant Location x Month interaction in Table 1. Inshore (I) and Offshore (O) comparisons by month; $p < 0.05$; annual comparisons are in bold.

Month	**Inshore**	**SNK**	**Offshore**
July 1988	11.575	I > 0	0.0002
July 1989	0.077	I = 0	0
	July 1988 > 1989		**July 1988 = 1989**
September 1988	10.475	I > 0	5.45
October 1988	0.067	I = 0	0.938
November 1989	0.063	I = 0	0.126
December 1988	6.438	I > 0	0.249
December 1989	2.161	0 > I	4.092
	December 1988 > 1989		**December 1989 > 1988**
January 1990	3.702	I = 0	3.361
February 1990	10.964	I > 0	0.704
March 1990	3.475	I > 0	0.421
April 1989	0.623	0 > I	7.5
April 1990	3.267	0 > I	5.5
	April 1990 > 1989		**April 1989 = 1990**
May 1989	0.558	I = 0	0.086
June 1989	0.010	I = 0	0

Table 3. Results of the Student-Newman-Keuls test on the biomasses of leiognathids (kg/6000m^2) over 19 months (numbers in parentheses were of samples excluded in the analysis of variance). These tests were performed due to the significant Location x Month interaction (Table 1). Monthly comparisons of abundance ($p < 0.05$) are made for each location.

Inshore

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Month	Aug '89	Jun '89	Nov '89	Oct '88	Jul'89	May'89	Apr '89
Mean	0.005	(0.010)	0.063	0.067	0.077	0.558	0.623
Rank	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Month	Dec '89	Apr '90	Mar '89	Mar '90	Jan '90	Oct '89	Dec '88
Mean	2.162	(3.267)	3.306	3.475	3.702	(4.227)	(6.438)
Rank	**15**	**16**	**17**				
Month	Sept '88	Feb '90	Jul '88				
Mean	10.475	10.964	11.575				

Table 3 (continued)

Offshore

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Month	June '89	Jul '89	Jul '88	May '89	Aug '89	Nov '89	Dec '88
Mean	(0)	0	0.0002	0.086	0.095	0.126	(0.249)
Rank	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Month	Mar '90	Feb '90	Oct '88	Oct '89	Jan '90	Dec '89	Mar '89
Mean	0.421	0.704	0.938	(2.877)	3.361	4.092	4.825
Rank	**15**	**16**	**17**				
Month	Sept '88	Apr '90	Apr '89				
Mean	5.45	5.5	(7.5)				

Table 4. Results of the analyses of variance on the densities (number/$6000 m^2$) of leiognathid species (ACH - *A. achlamys*, BIN - *L. bindus*, DEC - *L. decorus*, EQU - *L. equulus*, MOR - *L. moretoniensis*, SPL - *L. splendens*, INS - *S. insidiator*, RUC - *S. ruconius*; df - degree of freedom, * - $p < 0.05$; ** - $p < 0.01$; ns - not significant).

Variate	**df**	**Species**							
		ACH	BIN	DEC	EQU	MOR	SPL	INS	RUC
Month (M)	13	**	ns	**	**	**	**	**	**
Location (L)	1	**	ns	**	ns	**	**	ns	ns
M x L	13	**	ns	**	*	**	**	**	**
Site (S)	4	**	ns	**	**	**	**	ns	**
M x S	52	**	ns	**	ns	ns	**	**	**
Error	80								

Table 5a. Results of the Student-Newman-Keuls tests comparing mean densities (number/6000m^2) of *L. decorus* Inshore and Offshore through time (I - Inshore; O - Offshore; M - Month, L - Location). Annual comparisons in bold. Significance level 0.05.

Month	**Inshore**	**SNK**	**Offshore**
April 1988	6.667	O > I	14.500
April 1989	9.000	I > O	2.500
April 1990	18.430	I > O	3.636
	April 1990 > 1989 > 1988		**April 1988 > 1989 = 1990**
May 1988	0	O > I	5.500
May 1989	1.5	I = O	0.833
	May 1989 > 1988		**May 1988 > 1989**
June 1989	0	I = O	0
July 1988	15.250	I > O	0
July 1989	0	O = I	0
	July 1988 > 1989		**July 1989 = 1988**
August 1989	0	I = O	0
September 1988	11.00	I > O	8.750
October 1988	5.667	O > I	12.200
October 1989	13.600	I > O	2.182
	October 1989 > 1988		**October 1988 > 1989**
November 1989	0.667	I = O	0
December 1988	20.080	I > O	0
December 1989	9.583	I > O	0
	December 1988 > 1989		**December 1988 = 1989**
January 1990	0	O > I	3.636
February 1990	2.800	I > O	0
March 1989	13.180	I > O	2.727
March 1990	0	O > I	41.080
	March 1989 > 1990		**March 1990 > 1989**

Table 5b. Results of the Student-Newman-Keuls tests comparing mean densities (number/6000m^2) of *L. splendens* Inshore and Offshore through time; annual comparisons are in bold (I - Inshore, O - Offshore; M - Month; L - Location; Significance level 0.05).

Month	**Inshore**	**SNK**	**Offshore**
April 1988	445.700	I > O	5.100
April 1989	148.200	O > I	269.900
April 1990	304.9	I > O	64.000
	April 1988 > 1990 > 1989		**April 1989 > 1990 > 1988**
May 1988	0	O > I	132.900
May 1989	9.583	I > O	0
	May 1989 > 1988		**May 1988 > 1989**
June 1989	0.583	I = O	0
July 1988	399.600	I > O	0
July 1989	0.500	O > I	162.600
	July 1988 > 1989		**July 1989 > 1988**
August 1989	0.008	I = O	0
September 1988	202.400	I > O	184.000
October 1988	168.200	I > O	62.560
October 1989	32.300	O > I	63.180
	October 1988 > 1989		**October 1988 = 1989**
November 1989	2.444	I > O	0
December 1988	169.100	I > O	2.250
December 1989	179.200	I > O	101.600
	December 1988 = 1989		**December 1989 > 1988**
January 1990	0	O > I	137.300
February 1990	373.200	I > O	0.555
March 1989	339.900	I > O	172.800
March 1990	2.182	O > I	206.200
	March 1989 > 1990		**March 1990 > 1989**

Table 5c. Results of the Student-Newman-Keuls tests comparing mean densities (number/6000m^2) of *S. ruconius* through time; annual comparisons are in bold (I - Inshore, O - Offshore; M - Month; L - Location; Significance level 0.05).

Month	**Inshore**	**SNK**	**Offshore**
April 1988	52.08	I > O	18.80
April 1989	2.917	I = O	3.750
April 1990	31.860	O > I	43.500
	April 1988 > 1990 > 1989		**April 1990 > 1988 > 1989**
May 1988	0	O > I	7.583
May 1989	0.750	I = O	0
	May 1989 > 1988		**May 1988 > 1989**
June 1989	0	I = O	0
July 1988	0	O > I	5.500
July 1989	0.167	I = O	0
	July 1988 = 1989		**July 1988 > 1989**
August 1989	0	I = O	0
September 1988	11.570	I > O	3.000
October 1988	2.444	O > I	8.556
October 1989	6.000	I > O	0.909
	October 1989 > 1988		**October 1988 > 1989**
November 1989	0	I = O	0
December 1988	0.167	I = O	0
December 1989	11.580	I > O	1.222
	December 1989 > 1988		**December 1989 > 1988**
January 1990	0	O > I	6.273
February 1990	2.000	I > O	0
March 1989	17.27	I > O	4.727
March 1990	31.860	I > O	5.5
	March 1990 > 1989		**March 1989 = 1990**

Table 6a. Summary of the Student-Newman-Keuls test on the mean densities (number/6000m^2) of *L.decorus* through time at each location.

Inshore

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Month	July '89	May '88	June '89	March '90	Jun '90	Aug '89	Nov '89
Mean	(0)	0	0	0	0	0	0.667
Rank	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Month	May '89	Feb '90	Oct '88	Apr '88	Apr '89	Dec '89	Sept '88
Mean	1.500	(2.800)	5.667	6.667	(9.000)	9.583	(11.000)
Rank	**15**	**16**	**17**	**18**	**19**		
Month	March '89	Oct '89	Jul '88	Apr '90	Dec '88		
Mean	13.180	13.600	15.250	(18.430)	20.080		

Table 6a. (continued)

Offshore

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Month	Nov '89	Dec '89	Jun '89	Aug '89	Dec '88	Jul '88	Feb '90
Mean	0	0	0	0	0	0	(0)
Rank	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Month	May '89	Apr '90	Oct '89	Apr '89	Mar '89	Jul '89	Jan '90
Mean	0.833	(2.000)	2.182	(2.500)	2.727	(3.143)	3.636
Rank	**15**	**16**	**17**	**18**	**19**		
Month	May '88	Sept '88	Oct '88	Apr '88	Mar '90		
Mean	5.500	(8.750)	12.200	14.500	41.080		

Table 6b Summary of the Student-Newman-Keuls test on the mean densities (number/6000m^2) of *L. splendens* through time at each location

Inshore

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Month	May '88	Jan '90	Aug '89	Jul '89	Jun '89	Mar '90	Nov '89
Mean	0	0	0.008	(0.500)	0.583	2.182	2.444
Rank	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Month	May '89	Oct '89	Oct '88	Dec '89	Apr '89	Dec '88	Sept '88
Mean	9.583	32.300	62.560	101.600	(148.200)	169.100	(202.400)
Rank	**15**	**16**	**17**	**18**	**19**		
Month	Apr '90	Mar '89	Feb '90	Jul '88	Apr '88		
Mean	(304.900)	339.900	(373.200)	399.600	445.700		

Table 6b (continued)

Offshore

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Month	Aug '89	Nov '89	May '89	Jul '88	Jun '89	Feb '90	Dec '88
Mean	0	0	0	0	0	(0.555)	2.250
Rank	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Month	Apr '88	Oct '89	Apr '90	May '88	Jan '90	Jul '89	Oct '88
Mean	64.000	132.900	(137.300)	162.600	168.200	(172.800)	168.200
Rank	**15**	**16**	**17**	**18**	**19**		
Month	Mar '89	Dec '89	Sept '88	Mar '90	Apr '89		
Mean	172.800	179.200	(184.000)	206.600	(269.900)		

Table 6c. Summary of the Student-Newman-Keuls test on the mean densitites (number/6000m^2) of *S. ruconius* through time at each location

S. ruconius

Inshore

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Month	Aug '89	May '88	Jan '90	Jun '89	Nov '89	Mar '90	Dec '88
Mean	0	0	0	0	0	0	0.167
Rank	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Month	Jul '89	May '89	Feb '90	Oct '88	Apr '89	Oct '89	Sept '88
Mean	(0.167)	0.750	(2.000)	2.444	(2.917)	6.000	(11.570)
Rank	**15**	**16**	**17**	**18**	**19**		
Month	Dec '89	Mar '89	Apr '90	Jul '88	Apr '88		
Mean	11.580	17.270	(31.860)	40.170	52.080		

Table 6c (continued)

Offshore

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Month	Aug '89	Jun '89	Dec '88	May '89	Jul '89	Nov '89	Jul '88
Mean	0	0	0	0	(0)	0	0
Rank	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Month	Feb '90	Oct '89	Dec '89	Sept '88	Apr '89	Mar '89	Mar '90
Mean	(0)	0.909	1.222	(3.000)	(3.750)	4.727	5.500
Rank	**15**	**16**	**17**	**18**	**19**		
Month	Jan '90	May '88	Oct '88	Apr '88	Apr '90		
Mean	6.273	7.583	8.556	18.800	(43.500)		

CHAPTER V

THE GROWTH, REPRODUCTION, AND RECRUITMENT
OF SOME LEIOGNATHID SPECIES
IN CLEVELAND BAY, TROPICAL AUSTRALIA

Introduction

The members of the Family Leiognathidae (Pisces) are abundant fishes in tropical coastal areas (Chapter III, IV) but studies on their biology and population dynamics are few. Leiognathids have been mentioned *en passant* in numerous studies of demersal fish communites (*see* Pauly and Wade-Pauly, 1981). Those studies that have been conducted on population dynamics of leiognathids are summarized below.

Growth parameters were estimated for *Leiognathus bindus* by Murty (1983b) and for *L. splendens* by Pauly (1977) in Indonesia. Studies on the reproductive biology of *L. bindus* (Murty, 1983b; 1986), *L. decorus* (Wright, 1989a), and *L. splendens* (Jayabalan, 1986) showed that spawning occurs in the tropics throughout the year, but with two seasonal peaks. Estimates of mortality rates were high for *L. bindus* (Murty, 1983b in India) and *L. splendens* (Pauly, 1977 in Indonesia) where populations are exploited heavily. New recruits of many leiognathids occur in intertidal (Robertson and Duke, 1987; Wright, 1989b) and estuarine areas as "long-term" temporary residents (Robertson and Duke, 1990). Recruits remain in these areas for ~ 1 year. Recruitment to these inshore habitats is seasonal and follows a spawning run (Wright, 1989a,b; Robertson and Duke, 1990). There is a glaring need for information on the biology of tropical demersal fishes, especially of those that are highly abundant and currently exploited (*e. g.*, leiognathids in Southeast Asia - *see* Chapter III; Sainsbury, 1982). An understanding of the growth, reproduction, and recruitment of leiognathids forms the basis for managing populations (Pauly, 1988). Furthermore, such information assists in providing a better understanding of the multispecies community of tropical demersal ichthyofauna (bottom-up approach *sensu* Gulland and Garcia, 1984). This approach will allow better understanding of biotic factors, *e. g.*, competition, predator-prey interactions, and so forth, which are assumed to be more important than abiotic factors in controlling population size (MacArthur, 1970). For fisheries science to be more predictive, more data on biology and ecology of the organisms are necessary to help generate and test hypotheses (Larkin, 1978; Sainsbury, 1982).

Only a few families of fishes in tropical demersal fish faunas have been studied in detail so far (Table 3), *e.g.*, the Nemipteridae. In fisheries that have begun recently, the biology of commercially important fishes of the families Lutjanidae and Serranidae are currently being investigated (Sainsbury, 1984; Ralston and Polovina, xxxx).

In this chapter, growth, reproductive activity, and recruitment of four leiognathid species, *L. bindus*, *L. decorus*, *L. splendens*, and *Secutor ruconius*, have been studied. Growth parameters were estimated using length-frequency analysis and length-at-age data from samples collected in Cleveland Bay from April 1988 to April 1990. In addition, sexual maturity and spawning season were investigated by gonadal examination through time. The abundance of recruits was monitored over two years in a small mangrove-lined creek which connects with Cleveland Bay (Figure 1).

The results of these biological studies show that the four most abundant leiognathid species in Cleveland Bay are fast-growing, reaching sexual maturity early in line with similar results from other species of small tropical fishes. In contrast to the biomadal pattern of reproductive activity of some leiognathids and demersal fishes in other tropical areas, there was one single spawning season in September-December for *L. bindus*, *L. decorus*, *L. splendens*, *S. ruconius*. There was one pulse of recruitment for two species, which corresponded to the single spawning season.

Materials and Methods

Sampling - The samples used in the study of growth and reproduction were collected in Cleveland Bay from April 1988 to April 1990 (*see* Chapter II). All samples were preserved in ten percent seawater formalin (buffered with borax) or 70 % alcohol in the field and returned to the laboratory for later analyses. The small changes in size from dehydration in these preservatives were not crucial in the studies. Gonads for histological examination were preserved in formol-acetic-acid (Winsor, 1984).

Recruits were collected at 4-6 week intervals at a tributary of Ross River (Figure 1). Three 10-step shots were made with a 20 mm-mesh beach seine (1 m x 2.5 m). The recruits were preserved in ten percent sea-water formalin or 70 % alcohol.

Length-weight relationships The standard length (SL) of fishes was measured to the nearest millimeter (mm) using a metallic ruler on a measuring board. After drying with a tissue, fresh weights (g) were measured to the nearest 0.1 g using a top-loading balance. The mean weights (based on n = 5 or more fish) in five mm length-classes were used in the calculation of the length-weight regressions.

Estimation of growth parameters - Two methods were used to estimate growth parameters; length-frequency based analysis and otolith-based size-at-age analysis. Length-frequency data were collected monthly from April 1988 to April 1990. Standard lengths were recorded for large subsamples of fish of each species (as above) and grouped into 5 mm length-classes. Five mm class intervals were chosen based on Wolff (1989) where the interval size was approximately ten percent of the maximum length and the number of assumed modal groups. The data (pooled for both females and males) were corrected for the selectivity of the nets (*see* Chapter II). The software package **FISAT** (Pauly and Sparre, 1990) was used in estimating the growth parameter K of the von Bertalanffy growth model. Values of L_{∞} were estimated using Powell-Wetherall method (Wetherall, 1986) and used for the length-frequency analysis which followed.

The length-at-age data were based on opaque rings found in otoliths (Figure 2). Although (assumed) daily rings (Figure 3) were found in leiognathid otoliths, these rings become tightly packed as the fish grows, such that low-resolution light microscopy (1,000 x magnification) did not allow clear separation of rings. Anomalous readings arise from microscopic examination of daily rings using standard microscopy (Morales-Nin, 1988). Thus, the opaque rings found in leiognathid otoliths which were assumed to be deposited annually were used in estimating the age of leiognathids. Rings of similar appearance were also found in several species of engraulid, sciaenid, and serranid species that co-occur with leiognathids in Cleveland Bay (Hoedt, 1990; Yap, 1990; Ferreira, MS). Ferreira (MS) was able to validate the deposition of opaque rings in *Epinephelus sexfasciatus* (Family Serranidae) by immersing the fish in tetracycline.

Otoliths (sagittae) from a wide range of sizes of fish of both sex were used. Otoliths were imbedded in Spurr's resin for ease in handling and cutting. A diamond blade was used to cut the otoliths through a dorso-ventral plane. The otolith section (about 2 mm thick) was ground using increasing grades of carborundum paper (600, 800, 1,200) and polished using 0.05 aluminium powder on a polishing pad. The number of rings in the otoliths was counted under 500 x magnification with reflected light. At least three readings of the otoliths were made at different time intervals to avoid bias and checked independently by another reader.

Size-at-age data were then input in the program **ETAL** (Gaschutz *et al.*, 1980). This program fits the von Bertalanffy growth equation to the size-at-age data.

The estimates of the growth parameters (K and L_{∞}) from these two methods were compared. Since the results were different from the estimates using length-frequency analysis, the L_{∞} was fixed on the value estimated by the Powell-Wetherall method. This analysis was done in the non-linear routine incorporated in the **FiSAT** (Pauly and Sparre, 1991) which also fits the von Bertalanffy growth equation to the size-at-age data. The ratio of the K values that were derived from this routine and from the length-frequency analysis was calculated.

Reproduction

Each month, a subsample of individuals (at least 50) were dissected and examined macroscopically to determine sex and reproductive maturity. Leiognathids are known to be dioecious. Maturity stages were based on Bagenal's (1978) 7-stage scale.

The percentage of mature (Stage V, VI, VII) individuals in each 5 mm length-class was calculated and plotted. The length where 50 % of the individuals were mature (Stage IV) was considered to estimate length-at-first maturity.

Sampling was not frequent (once a month) during the spawning season and thus some samples of mature individuals of *L. bindus* and *S. ruconius* may have possibly been missed. These are smaller species of of leiognathids and therefore may mature and spawn earlier.

Histological sections were made to determine whether leiognathids were serial spawners and to confirm the macroscopic staging. Different stages were sectioned. The appearance of different stages of oocytes in the gonads was the main criterion used. The macroscopic stagings were accurate.

Recruitment

In the laboratory, samples of leiognathids from the creeks were identified, counted, and measured to the nearest millimeter using a metallic ruler on a board.

Results

Life histories

Leiognathus bindus

L. bindus grow in weight allometrically (Figure 4a). There was no difference in the growth in weight of both sexes (Table 1).

The estimates of the growth parameter K for *L. bindus* differed depending on the method used. The maximum length (L_{00}) estimate was 100 mm and the growth rate (K) estimates were 0.82 (K_1) and 0.28 (K_{2b}) (Table 2). The ratio of K from length-frequency analysis was almost thrice from that of the length-at-age analysis (Table 2). The growth curves are illustrated in Figures 5a and 6a.

The overall sex ratio of captured fish was 1.00:1.00 (n = 788). However, the sex ratio fluctuated slightly during the year. The peak in percentage maturity at a length class of around 75-80 mm SL (Figure 7a) is likely not to have attained 50% due to the small sampling fraction obtained in this study. Spawning was during October to December (Figure 8a) and possibly in batches (Figure 9a).

No recruits of *L. bindus* were ever recorded in the mangrove-lined tributary of Ross River. However, recruits of this species were found at the shoreline at Cape Pallarenda, a sandy-muddy subtidal area along the northern end of Cleveland Bay (Cabanban, pers. obs.), and in trawls in April 1990 (Chapter II, IV).

Leiognathus decorus

The length-weight relationships for females or males of *L. decorus* show that the growth in weight was allometric (Table 1; Figure 4b).

The L_{∞} for *L. decorus* was about 120 mm (Table 2). Based on length-frequency analysis, growth was fast (K = 1.20; Figure 5b) but slow based on the length-at-age analysis (K = 0.455; Figure 6b).

Sexual maturity was attained at ~ 92 mm (Figure 7b).

There were more males than females in the overall sex ratio (0.466:1.000, n = 828). There was no apparent trend for changes in proportions of females to males in the months that were sampled. Spawning activity (Figure 8b) was from September to December with the peak of spawning occurring in October. *Leiognathus decorus* could spawn several times in one season (Figure 9b).

Leiognathus decorus was the most numerous of the recruits that were collected in the mangrove-lined creek (Figure 10a). Recruits were abundant in January (1990), March (1989), and June (1988 and 1989) but were also present in smaller numbers in other months of the year (Figure 10a).

Leiognathus splendens

Growth in weight was allometric for both sexes of this species (Figure 4c). This species had a L_{∞} of 115 mm (length-frequency data; see Table 2). Estimates of growth was high ($K_1 = 1.30$ y^{-1}) based on length-frequency analysis by relatively slower ($K = 0.459$) based on length-at-age data analysis (Figures 5c and 6c).

There were more males than females in the overall proportion of sexes (0.796:1.000) and in most of the months sampled. *Leiognathus splendens* mature at about 91 mm (Figure 7c) and spawn in October. Mature gonads show stages of eggs in different batches, suggesting that spawning was serial (Figure 9c).

Recruits of *Leiognathus splendens* were abundant in the mangrove-lined creek (Figure 10b). High numbers of recruits were collected in October (1988), March (1989), December (1989), January (1990) and February (1990).

Secutor ruconius

Secutor ruconius, one of the small species, had an estimated L_{∞} of 80 mm (Table 2). Growth in weight of both sexes of this species was allometric (Figures 4d; Table 1). Growth rate in length was rapid with $K = 1.00$ y^{-1} (Table 2; Figure 5d). No age-based data were collected to corroborate length-frequency analysis due to insufficient laboratory time.

The overall ratio of females to males was 0.944:1.000 (n = 243). The onset of maturity (Stage IV) was around 52 mm SL (Figure 7d). Reproductive activity was observed in March (Figure 8c) and spawning may be serial (Figure 9d).

Only 8 recruits of *Secutor ruconius* were recorded in the mangrove-lined creek during 2 years of sampling, but recruits were captured in good numbers in Cleveland Bay in April 1990 (Chapter II).

In summary, leiognathids, particularly *Leiognathus bindus*, *L. decorus*, *L. splendens*, and *Secutor ruconius*, are small (~ 120 mm SL) and most likely short-lived (Figures 5a-d, 6a-d; Table 2). Recruits of various species occur at different times of the year.

Discussion

The abundance of leiognathids in Cleveland Bay and in other tropical demersal communities (Chapter III, IV) can be explained partly by their biology and their ecological adaptations. Furthermore, the resilience of these populations of small, prey species against high rates of predation (Chapter VI) could be due to their reproductive strategy and adaptability to environmental conditions.

Leiognathids - small, fast-growing species

Pertinent to this section is the discussion on the estimates of growth rates that varied between length-frequency data and age data and the selection of the preferred estimate. The growth parameter **K** estimated from length-frequency analysis for *L. bindus*, and *L. decorus*, and *L. splendens* were almost thrice higher than those derived from age-at-length analysis (Table 2). This disparity could be higher due to the general trend of the ELEFAN I program incorporated in the **FiSAT** to underestimate **K** (Isaac, 1990).

However, comparison of the growth performance (ø'; Pauly and Munro, 1984) based on age-at-length data show that the growth parameters (L_{00} and K) of the stocks of these species in Cleveland Bay (Table 2) were within the distribution of ø' *L. splendens* (Figure 11) from many stocks. In addition, the ø' for *L. decorus* is comparable to the other estimate (ø' = 2.228) for this species from Indonesia (Dwiponggo et al., 1987 while the ø' for *S.* ruconius (ø' = 1.988) is within the variation of 3 estimates (ø' = 1.988 +/- 0.037) for this species from the Philippines (Pauly and Ingles, 1984). As for *L. bindus*, the ø' may considered to be on the lower end of the distribution.

The age of the these three leiognathids were based on the presumed annual rings found in otoliths. If the assumption that the rings are laid annually was correct, then the growth of these three leiognathids are slow. Based on the ratio between the K values from length-frequency data and the otolith data, the rings could be laid more often than once a year (for reasons unknown), then the growth rate of these fishes are high. (This disparity can be pursued later as a research topic.) Thus, due to the non-validation of the rings found in the otoliths, the estimates of growth rate from length-frequency analysis were used in the interpretation on the growth of leiognathids from Cleveland Bay. Each leiognathid species considered in this study, namely, *Leiognathus bindus*, *L. decorus*, *L. splendens*, and *Secutor ruconius*, were small, fast-growing species (Table 2; Figures 5a-d, 6a-d). All grow in weight allometrically and the growth rates in length, particularly based on length-frequency analysis, were similar (range of K = 0.82-1.30).

Estimates of the growth rates of these species are few. Furthermore, comparisons between estimates are made difficult by differences in the methods used at arriving at estimates. *L. bindus* was found to grow rapidly in Indian waters based on modal progression analysis of length-frequency data (Murty, 1986). However, the use of modal progression is inherently biased because of the subjective assignment of ages to cohorts which could underestimate the rate of growth and the asymptotic length (Pauly and David, 1981).

The similar growth rates of these fishes that school together for protection (Lagler *et al.*, 1977; Moyle and Cech, 1982) indicate the potential for competition for resources, particularly food, or for fine specialization of niches. Diets of leiognathids are generally composed of benthic zooplankton but differences in the proportions of prey items occur among genera and species (Tiews *et al.*, 1968) and between life stages (Wright, 1989a). Thus, growth-rates of schooling, closely related species in species-rich, tropical demersal waters may not be affected substantially by density-dependent factors such as competition. The leiognathids possibly employ an array of strategies which may include resource partitioning and behavioural activities (Chapter IV).

The life spans of the small leiognathids in the Bay were possibly short whether the rings were laid once or thrice a year. However, although the periodicity of the rings remains unvalidated for leiognathids, it appears that many leiognathids do not live for just one year.

Many small (< 200 mm) demersal fishes in the tropics appear to grow fast and to not have a life span of greater than 10 years, *e. g.*, *Nemipterus japonicus* (Table 3). Leiognathids are species that have a short life span, with the exception of *L. equulus* which has a life span of 8 years (Figure 6d).

Estimates of growth of small, tropical demersal fishes are limited to a few families (Table 3) such that the biological generalization that small species (<200 mm) are fast-growing and short-lived has not been demonstrated robustly in these fishes. The growth estimates of leiognathids in the present study are additions to the few examples available in the tropics (*see* Table 3) and support the biological generalization that small species rapidly complete their life cycle.

Reproductive biology of leiognathids in tropical Australia

Reproductive activity in the tropics has been reported to be all year round with two seasonal peaks which are related to monsoonal patterns (Navaluna and Pauly, 1986). In contrast, in tropical Australia, there was only one distinct spawning season during September to December. The onset of the peak in spawning in tropical Australia appears to be around November. The data presented for leiognathids have some limitations (small sample size for some months which resulted from subsampling being done on board the vessel and in the laboratory and subsequent random selection of samples to be processed) with some crucial months not sampled. The emerging pattern of seasonality of reproduction from studies of leiognathids, engraulids, and carcharinids in this Bay is that spawning does peak in the austral spring (Figures 8a-c; Hoedt pers. comm.; Simpendorfer, pers. comm.).

The possible reason for this disparity of spawning frequency is the difference is temperature regimes between other tropical areas (in Southeast Asia) and tropical Australia. The temperature of Cleveland Bay (Chapter II) decreases to 20.9 °C during winter (Walker and O'Donnell, 1981) whereas in other tropical areas the range in temperature is narrow (26 °C - 30 °C; *e. g.*, Cabanban, 1984). Temperature and photoperiod, associated with monsoonal changes, are environmental factors that appear to initiate gonadal development and spawning activity (*see* Moyle and Cech, 1982).

Spawning during the austral spring to summer (= wet season) is favorable for larval growth during the wet and post-wet season. With this strategy, by the time the egg yolk has been utilized and the larva has begun to feed, planktonic food would be abundant in the environment. This is crucial when starvation is one of the major causes of high mortality in larval life (Moyle and Cech, 1982).

This is discussed further under the section on recruitment.

During the wet season, nutrients (nitrates and phosphates) are flushed from Ross and Burdekin Rivers (Walker and O'Donnell, 1981; Belperio, 1983). The nutrients are deposited in the sediments and are resuspended by intermittent wind-driven wave action (Walker and O'Donnell, 1981; Belperio, 1983). Insufficient levels of nitrates were found to limit phytoplankton blooms while adequate levels of nitrates and phosphates produced maximum planktonic growth (Walker and O'Donnell, 1981). It follows that zooplankton blooms are dependent on this primary productivity. Spawning at the onset of the wet season would therefore be favourable for larval survival.

A corollary to this finding is the observation that the frequency of spawning decreases as one moves away from the equator. For example, *L. splendens* spawns all year but has two spawning runs (October-December, April-May) in Porto Novo, India (Jayabalan, 1986) and Java, Indonesia (March-April, September; Pauly, 1977) while in Cleveland Bay, Australia and Kuwait there is only one spawning season (in Australia October-December). Coral reef fishes at low latitudes display this bimodal reproductive activity also (*see* Munro and Williams, 1985). In addition, the leiognathid species in Cleveland Bay were iteroparous (Figures 9a-d) which has the advantage of increasing the possibility of survival of offspring in an unpredictable environment. It is unknown whether the leiognathid species in Kuwait exhibit a similar reproductive strategy (Wright, 1988; 1989a, b). Nevertheless, the incidence of iteroparity increases with increasing latitude in *Alosa sapidissima*, the American freshwater shad fishes (Leggett and Carscadden, 1978). The single and protracted spawning season may be advantageous energetically (Moyle and Cech, 1982).

The size at maturation of *L. bindus*, *L. decorus*, and *L. splendens* in Cleveland Bay was the same as those in India, Indonesia, and Kuwait (Murty, 1983b; Jayabalan, 1986; Wright, 1989a, b; Pauly, 1977).

The peak of spawning of the four species of leiognathids suggests asynchrony and serial reproductive activity. *Leiognathus bindus*, *L. decorus*, and *L. splendens* spawn during September to December however the peaks of spawning activity appeared to differ among species (Figure 8a - b). *Secutor ruconius*, on the other hand, has a peak in spawning in March (Figure 8c). It could be hypothesized that species from the two genera differ in their reproductive pattern because they prey on different diets (Tiews *et al.*, 1968; Wright, 1989a, b) whose productivity in Cleveland Bay may also differ. Further studies on gonadal maturation and diet involving weekly sampling of leiognathids during September to December are necessary to confirm this.

Recruitment pattern

The timing and pulsatory nature of recruitment of *L. decorus*, *L. equulus*, and *L. splendens* in a tributary on Ross River further support the iteroparous strategy of leiognathids in tropical Australia. In addition, variability in the recruitment of these species could indicate that either the spawning patterns of the species are different or the rate of survival of larvae varies with species.

L. bindus and *S. ruconius* were present in Cleveland Bay as recruits (mesh selection experiment - Chapter II). However, the former was absent in Ross River while the latter was rare. It is possible that these species prefer other nursery sites (*e. g.* coastal shorelines, seagrass beds; Robertson and Duke, 1990).

The appearance of abundant recruits in estuarine areas usually follows the spawning and wet seasons but may vary among species. For example, *Leiognathus splendens* recruits peak in abundance during the wet (December) and post-wet (March) seasons whereas *L. decorus* recruits were abundant during the wet and dry seasons in Ross River and Alligator Creek (Robertson and Duke, 1990). In contrast, *L. equulus* recruits were abundant during the dry season (May, June) in Cleveland Bay, during the wet season (December) and post-wet season (February; Robertson and Duke, 1990) in Alligator Creek, and in March to early May and August to October in Three Mile Creek (Penridge, 1971). If spawning activity was at regular intervals, these differences may be due to variability in survival of larvae in estuarine areas.

The timing of recruitment into estuarine areas near Cleveland Bay during the wet or post-wet seasons can perhaps be considered as an adaptation of leiognathid species to environmental conditions. Likewise, in the northern hemisphere, recruitment of leiognathid species was also correlated with warm water temperature and high rainfall (*e. g.* Wright, 1988). During these times of the year, the nutrient levels (in particular, nitrogen; Walker and O'Donnell, 1981) are high and the food available for the larvae is likely to be abundant.

In addition, one or two pulse/s of recruitment of *Leiognathus decorus* and *L. splendens* in Cleveland Bay supports the finding of serial spawning within a single season in tropical Australia (Figures 10a-b). A number of pulses of recruitment of *L. decorus*, *L. equulus*, and *L. splendens* were reported also in nearby estuarine areas (Alligator Creek - Robertson and Duke, 1990; Three Mile Creek - Penridge, 1971). *L. equulus* and *L. splendens* had two pulses of recruitment while *L. decorus* had only one in the creek near the mouth of Ross River but two at Three Mile Creek. The bimodal recruitment of *L. equulus* was reported also in nearby Alligator Creek and Three Mile Creek. Likewise, *L. splendens* recruits peak in abundance at Ross River and Alligator Creeks.

The time of appearance of recruits in these creeks differs slightly between species. For example, *L. splendens* recruits were abundant during the wet (December) and post-wet seasons (March) whereas *L. decorus* recruits were numerous during the wet and dry seasons. In contrast, *L. equulus* recruits were abundant during the dry season (May, June). These differences may be due to variability in the survival of larvae in the wild and in the spawning runs among the years in which the recruits were sampled.

Leiognathids use estuarine areas as nursery sites. *Leiognathus decorus* remained in the tributary at Ross River until they had reached about 50 mm while *L. splendens* and *L. equulus* remained until about 45 mm. Recruits of leiognathid species appear in the estuarine areas around 10 mm (Figure 10a, b; Robertson and Lenanton, 1984). Leiognathids have been termed as "long-term" temporary residents of estuarine areas (Robertson and Duke, 1990).

Comparison of two methods of estimating parameters of growth

The estimates of growth parameters of *L. bindus*, *L. decorus*, and *L. splendens* from two different methods (length-frequency analysis and length-at-age data analysis) were different (Table 2). Generally, estimates of K were lower based on size at age data. This applied even with the use of the length-infinity derived from length-frequency analysis in the length-at-age analysis (Table 2). This possibly resulted from the range of sizes used in estimating length-at-age being limited or lie with the assignment of ages from counts in otoliths; rings in otoliths were assumed annual and t_0 (< 0) as subsequently calculated. However, in length-frequency analysis, t_0 was set at 0. Thus the growth curve from length-at-age data analysis was "flatter" than that from length-frequency analysis; the **K** values from length-at-age data analysis were about 3 times less than those derived from length-frequency data analysis (Table 2).

Isaac (1990) in a review of length-frequency-based data analyses concluded that ELEFAN (in FiSAT) is a valid analysis for short-lived and fast-growing species and that this program consistently underestimates the **K**. Therefore, the estimates of **K** that were derived from length-frequency analysis could be higher and it follows that the difference between the results of the two methods would be bigger. Only a validation of the periodicity of the rings in the otoliths could resolve this disparity.

However, the growth performance index (ø') of *L. bindus*, *L. decorus*, and *L. splendens*, using the growth parameters from length-at-age-data analysis, were within the variation of indices from different tropical stocks (Figure 11). As such, both estimates derived from the two methods can be viewed as upper and lower limits for growth parameters.

Good correspondence between methods was observed by Hoedt (1990) for engraulid species in Cleveland Bay, tropical Australia. These results show reliability of the length-frequency analysis [ELEFAN (Pauly and David, 1981)] for short-lived, fast-growing species (Isaac, 1990). This finding has significance in fisheries biology where many estimates of growth-parameters of tropical fishes are based on length-frequency analysis alone (Table 3) despite the finding of Panella (1971) of growth rings in otoliths of tropical fish. Wherever possible, estimates of growth parameters should be made using at least two independent methods (*e. g.*, size-at-age data, length-frequency data or mark-recapture data).

Conclusion

The general biological characteristics of leiognathids largely explain the high abundance of this family of fishes (Chapter III, IV) despite high rates of predation on the family (Chapter VI) in Cleveland Bay. These biological characteristics are the relatively fast rate of growth, iteroparous reproduction, high fecundity [*e. g.*, 7,000-21,000 ova in *L. splendens*; Jayabalan, 1986), and recruitment at periods of high availability of food. These characteristics are likely to apply in other tropical areas where leiognathids are the dominant family of the demersal, soft-substratum ichthyofauna.

This study of the most abundant members of the zoobenthic feeding fishes in the demersal community may provide some information to assist in the understanding of the community of demersal fishes, although this approach may "provide disappointingly few generalizations, testable predictions or insights into the dynamics of the community" (Sainsbury 1988). Nevertheless, more of these population level studies are necessary to understand the biological processes, such as competition, that may structure the diverse communities of tropical demersal fishes (Sainsbury, 1982, 1988).

Figure 1. Map of Cleveland Bay,Townsville showing position of the tributary of Ross River (Stuart Creek), sampled for leiognathid recruits. Sites 1-6 in Cleveland Bay were sites sampled in long-term monitoring of leiognathids (Chapter IV).

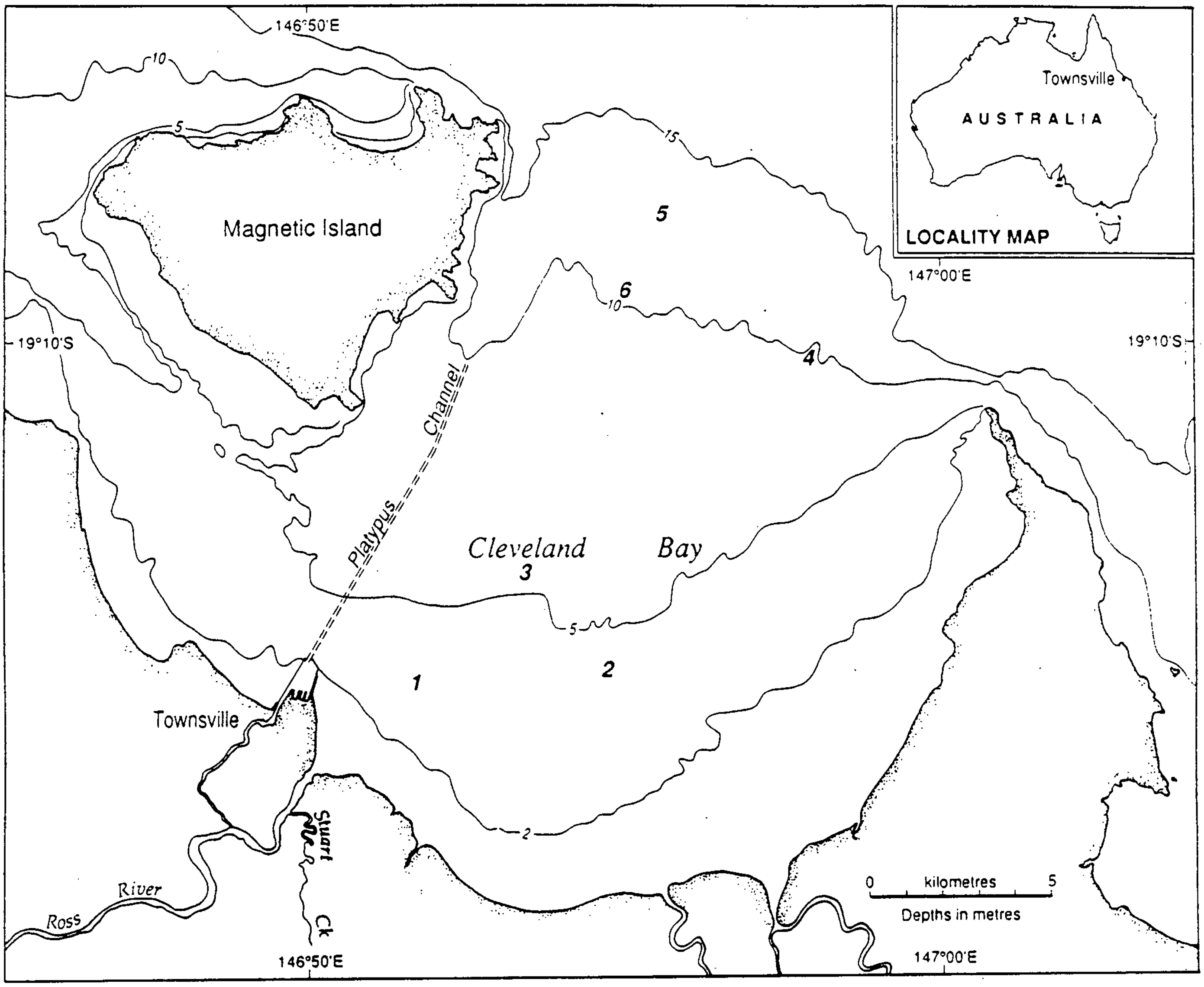

146°50'E
10
5
Magnetic Island
15
5
6
10
4
19°10'S
Platypus Channel
Cleveland Bay
3
5
1
2
2
Townsville
Stuart Ck
Ross River
146°50'E
147°00'E
0 kilometres 5
Depths in metres
147°00'E
19°10'S
Townsville
AUSTRALIA
LOCALITY MAP

Figure 2. Sectioned sagitta of *Leiognathus splendens* showing bands assumed to be annuli. X500

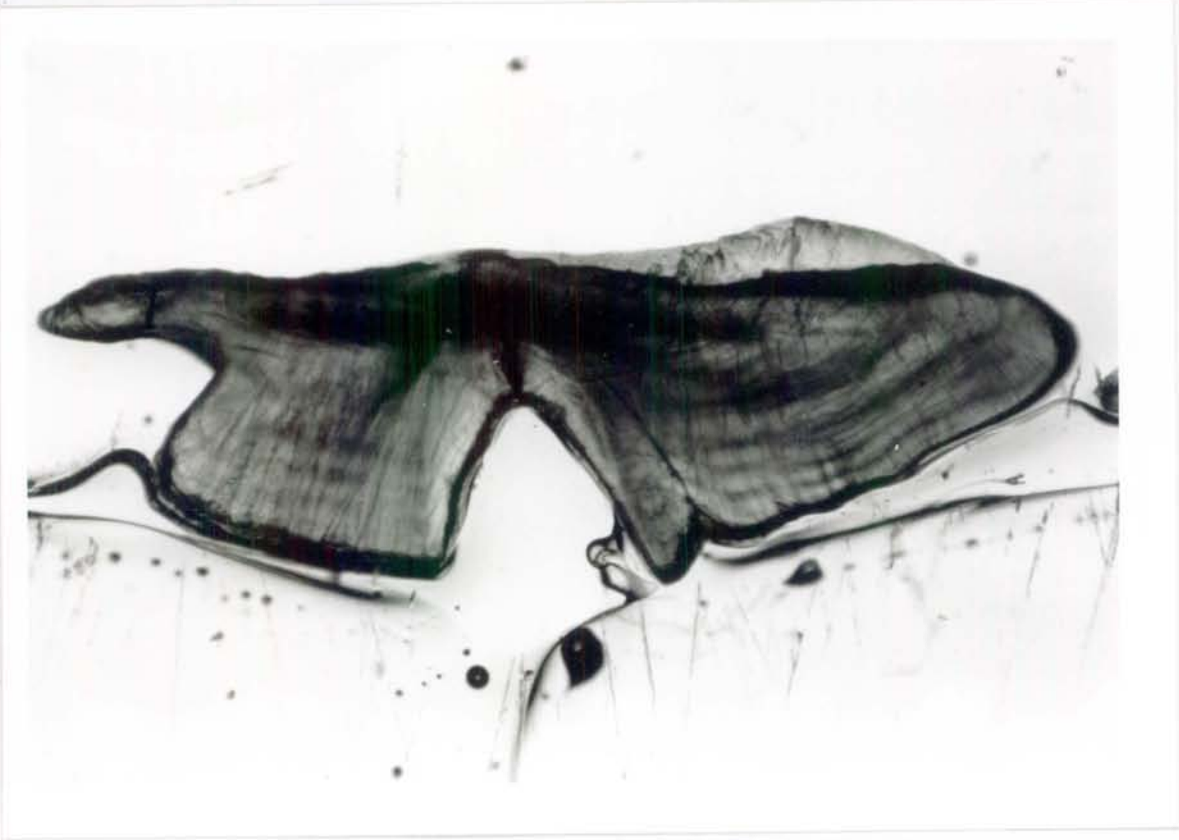


Figure 3. Sectioned sagitta of *Leiognathus splendens* showing bands assumed to be laid down daily. X1000

Figure 4a. Length-weight relationship for *Leiognathus bindus*. Length = Standard Length, Female = shaded symbols, male = open symbols.

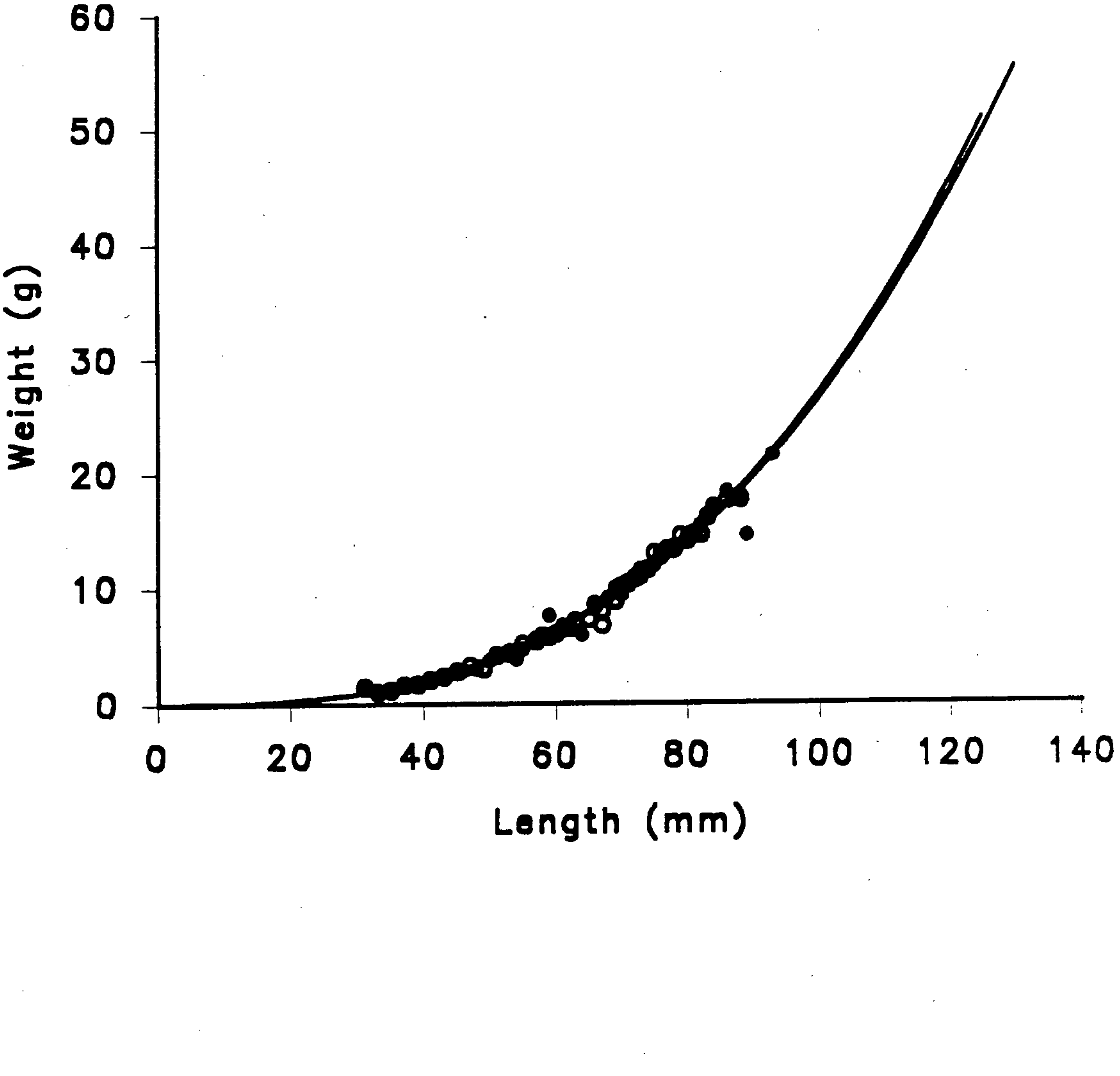

60
50
40
30
20
10
0
Weight (g)
0
20
40
60
80
100
120
140
Length (mm)

Figure 4b. Length-Weight relationship for *Leiognathus decorus*. Length = Standard Length, Female = shaded symbols, male = open symbols.

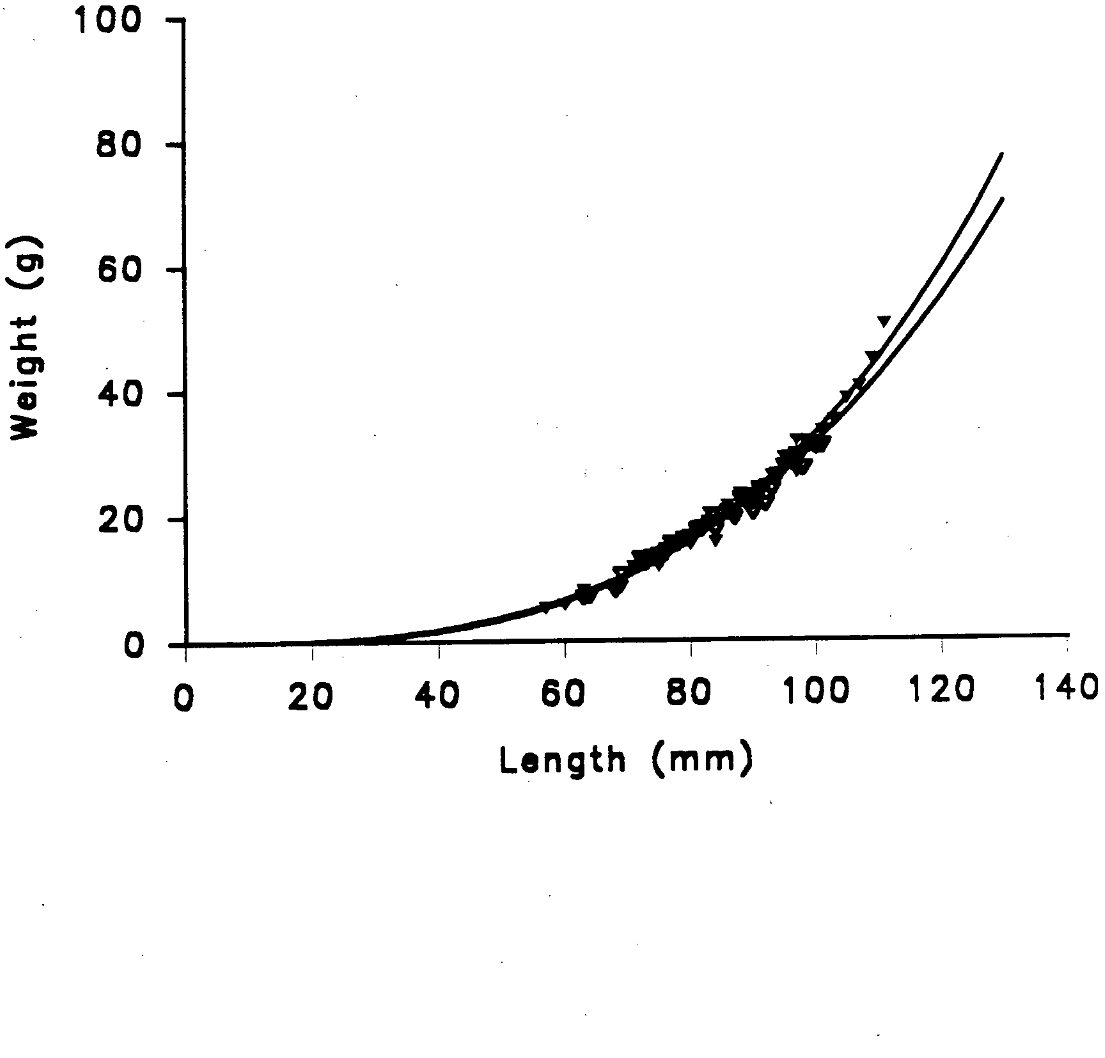

100
80
60
40
20
0
Weight (g)
0
20
40
60
80
100
120
140
Length (mm)

Figure 4c. Length-Weight relationship for *Leiognathus splendens*. Length = Standard Length, Female = shaded symbols, Male = open symbols.

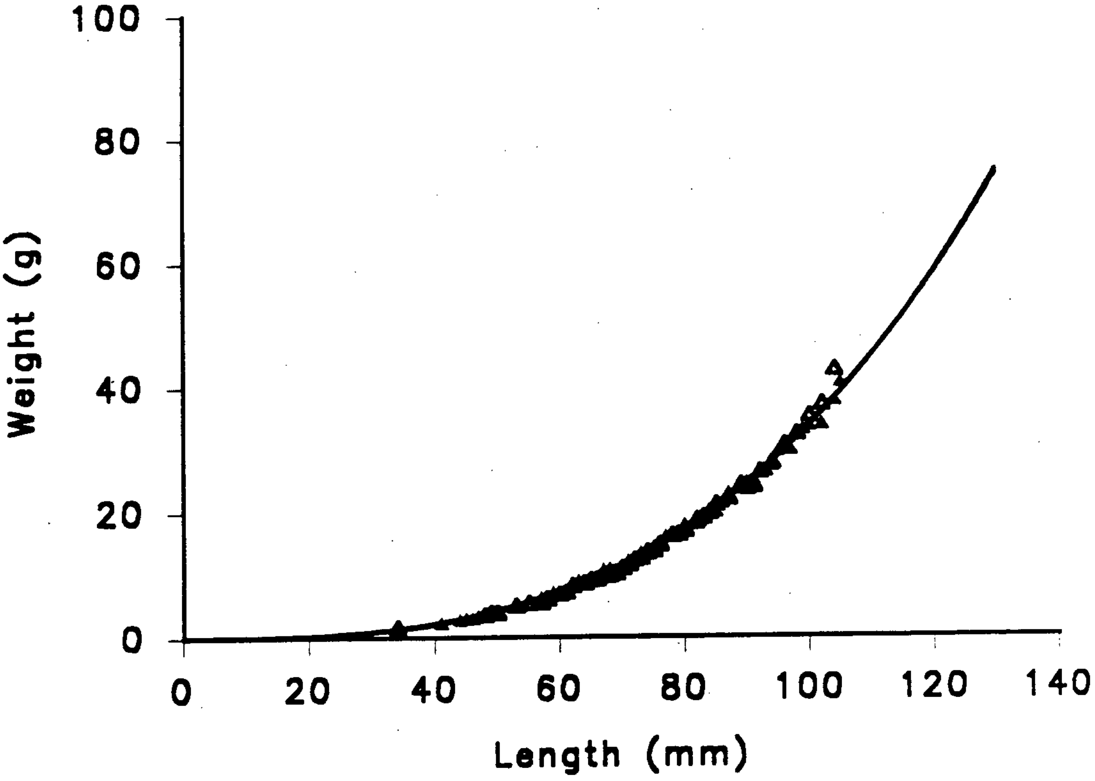

100
80
60
40
20
0
Weight (g)
0
20
40
60
80
100
120
140
Length (mm)

Figure 4d. Length-Weight relationship for *Secutor ruconius*. Length = Standard Length, Female = shaded symbols, Male = open symbols.

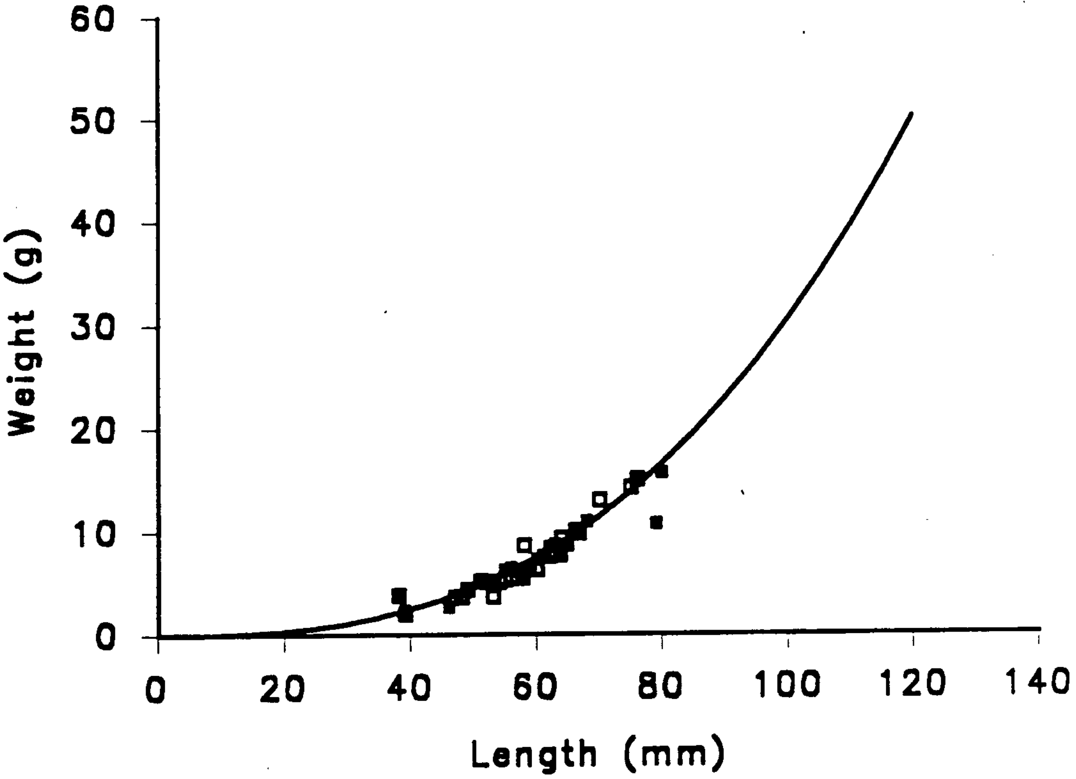

60
50
40
30
20
10
0
Weight (g)
0
20
40
60
80
100
120
140
Length (mm)

Figure 5a. Von Bertalanffy growth curve fitted to length frequency data of *Leiognathus bindus* from Cleveland Bay. Curve shown is the best fit as determined by ELEFAN (Rn = 0.279).

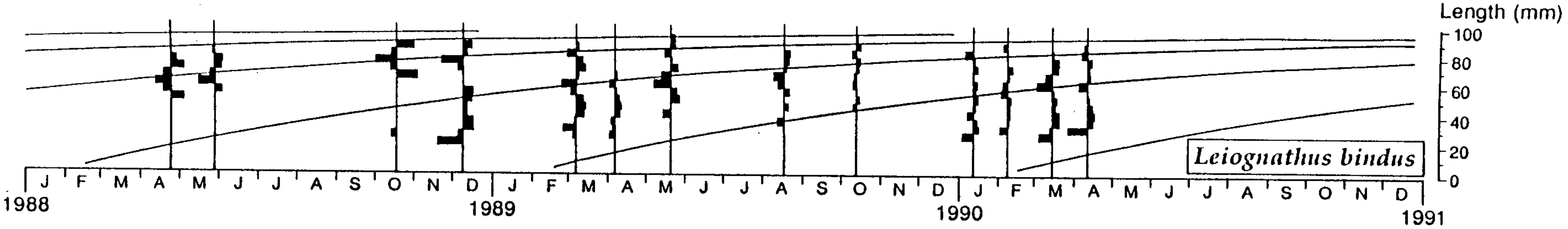

Length (mm)
100
80
60
40
20
0
Leiognathus bindus
J F M A M J J A S O N D
J F M A M J J A S O N D
J F M A M J J A S O N D
1988
1989
1990
1991

Figure 5b. Von Bertalanffy growth curve fitted to length frequency data of *Leiognathus decorus* from Cleveland Bay. Curve shown is the best fit as determined by ELEFAN (Rn = 0.299).

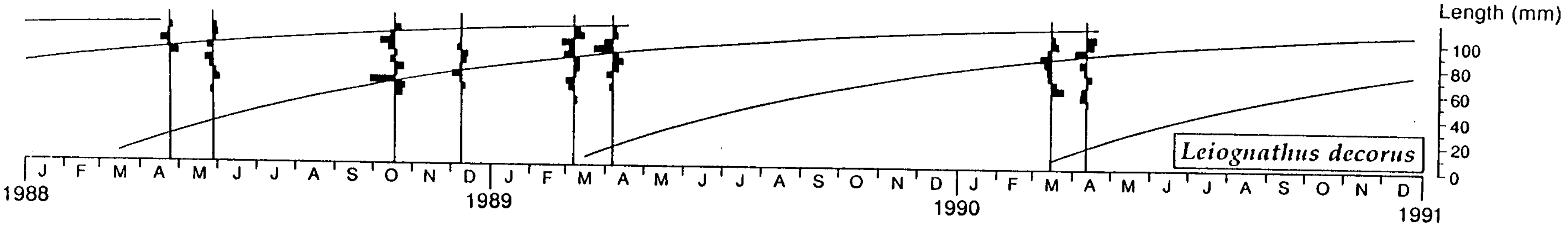

Length (mm)
100
80
60
40
20
0
Leiognathus decorus
J
F
M
A
M
J
J
A
S
O
N
D
1988
1989
1990
1991

Figure 5c. Von Bertalanffy growth curve fitted to length frequency data of *Leiognathus splendens* from Cleveland Bay. Curve shown is the best fit as determined by ELEFAN (Rn = 0.213).

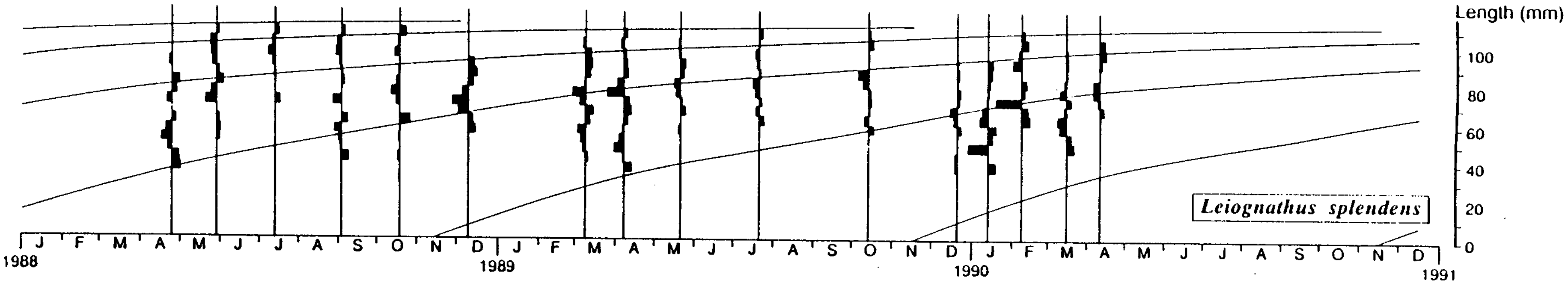

Length (mm)
100
80
60
40
20
0
Leiognathus splendens
J F M A M J J A S O N D
1988
J F M A M J J A S O N D
1989
J F M A M J J A S O N D
1990
1991

Figure 5d. Von Bertalanffy growth curve fitted to length frequency data of *Secutor ruconius* from Cleveland Bay. Curve shown is the best fit as determined by ELEFAN.

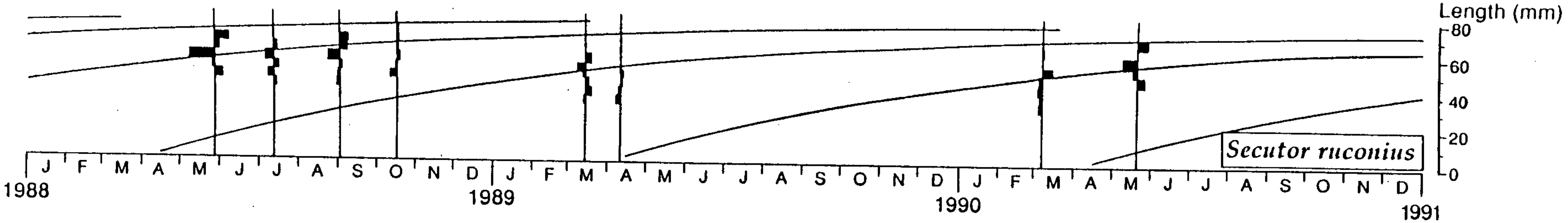

Length (mm)
80
60
40
20
0
Secutor ruconius
J F M A M J J A S O N D
J F M A M J J A S O N D
J F M A M J J A S O N D
1988
1989
1990
1991

Figure 6a. Von Bertalanffy growth curves for *Leiognathus bindus* derived from size at age data (solid line), length frequency data (broken line), and size at age with L_{∞} fixed based on estimate from length-frequency data (dotted line; see text)

Size at age Curve: K = 0.289, L_{∞} = 104.5 mm SL, t_o = -1.513 yr.

Length Frequency Curve: K = 0.82, L_{∞} = 100.0 mm SL.

Size at age Curve (L_{∞} fixed): K = 0.284, L_{∞} 100 mm SL, t_o = -1.576 yr

L. bindus

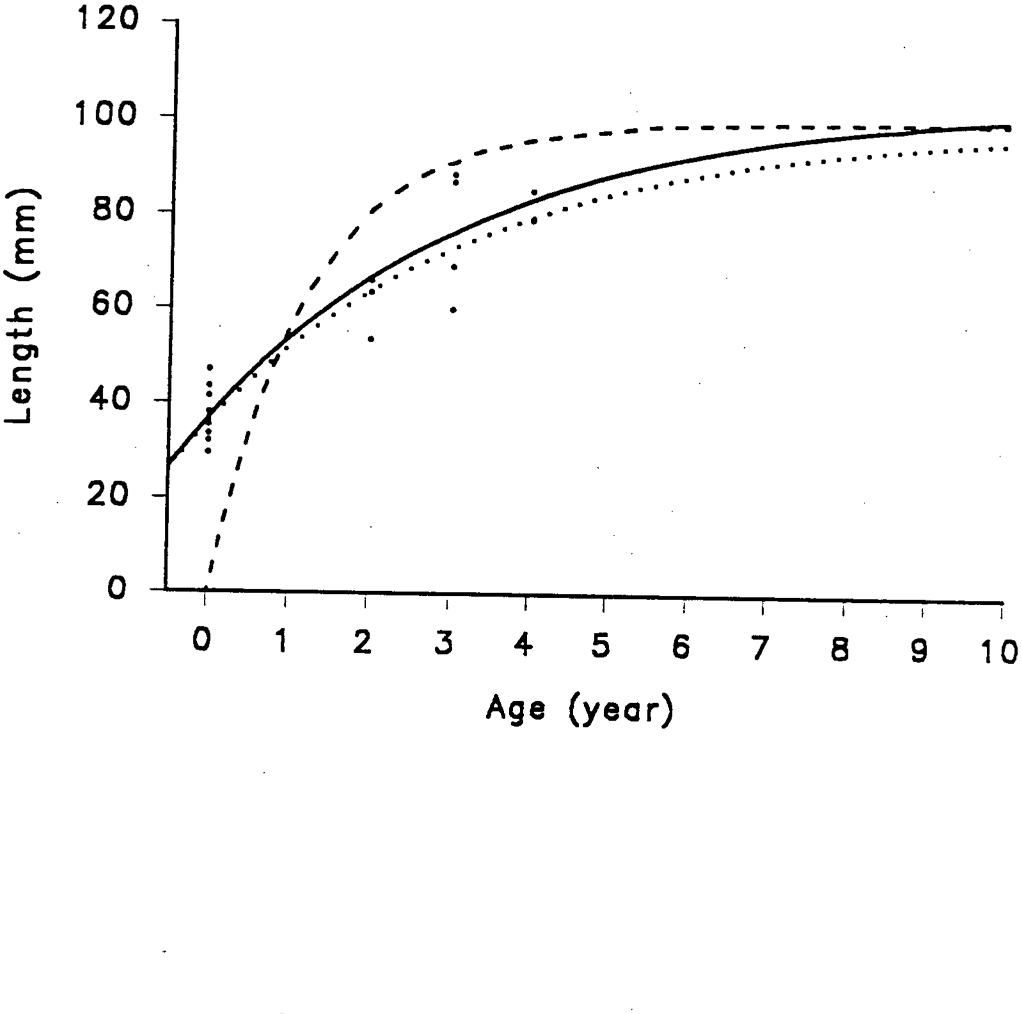


Figure 6b. Von Bertalanffy growth curves for *Leiognathus decorus* derived from size at age data (solid line), length frequency data (broken line), and size at age data with L_{∞} fixed from estimate from length-frequency data (dotted line; see text).

Size at age Curve: $K = 0.526$, $L_{\infty} = 119$ mm SL, $t_o = -0.795$ yr.

Length Frequency Curve: $K = 1.20$, $L_{\infty} = 120$ mm SL.

Size at age Curve (L_{∞} fixed): $K = 0.455$, $L_{\infty} = 120$,

$t_o = -0.854$

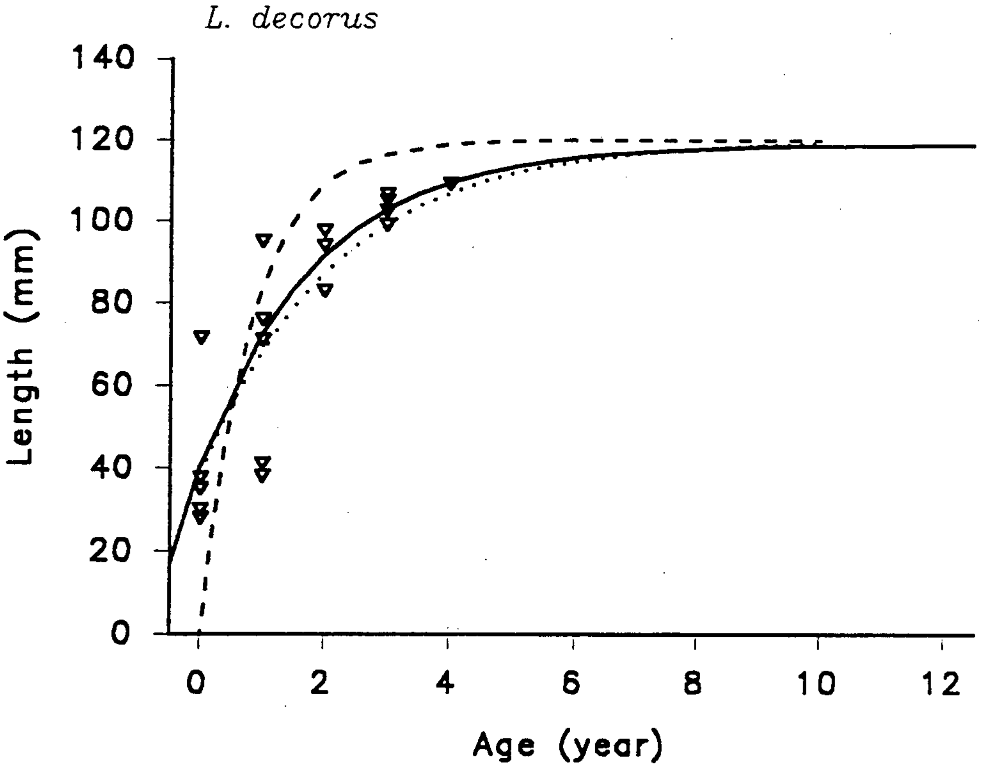

L. decorus
140
120
100
80
60
40
20
0
Length (mm)
0
2
4
6
8
10
12
Age (year)

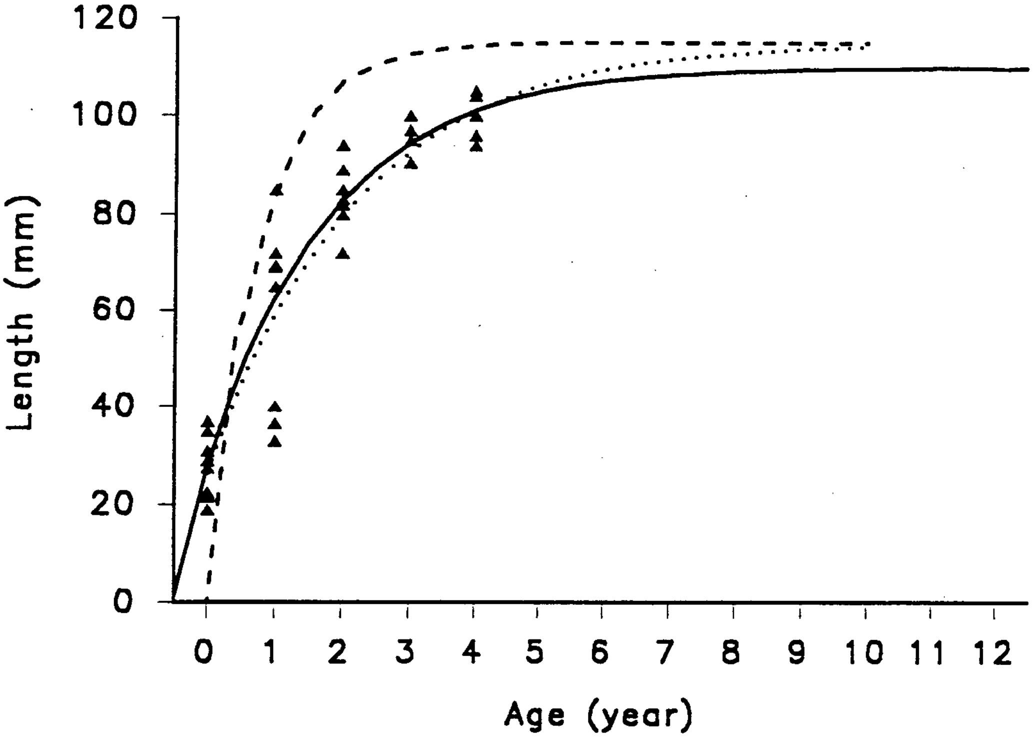
Figure 6c. Von Bertalanffy growth curves for *Leiognathus splendens* derived from size at age data (solid line), length frequency data (broken line), and size at age with L_{∞} fixed from length-frequency data (dotted line; see text).

Size at age Curve: K = 0.556, L_{∞}= 110 mm SL, t_o = -0.52 yr.

Length frequency Curve: K = 1.30, L_{∞} = 115 mm SL.

Size at age (L_{∞} fixed) = K = 0.459, L_{∞} =115 mm SL,

t_o = -0.567 yr.



L. splendens

Figure 6d. Von Bertalanffy growth curve for *Leiognathus equulus* derived from size at age data.

$K = 0.354$, $L_{\infty} = 160$ mm SL, $t_o = -0.457$ yr.

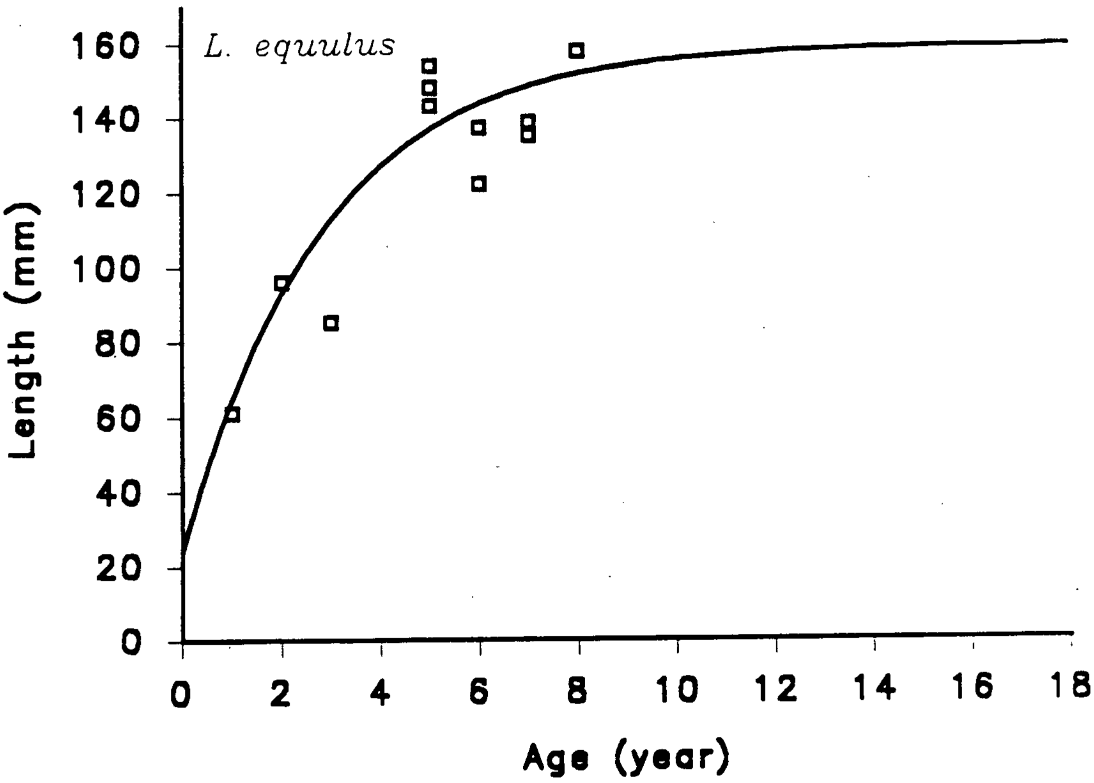

L. equulus
Length (mm)
0
20
40
60
80
100
120
140
160
Age (year)
0
2
4
6
8
10
12
14
16
18

Figure 7a. Percentage of individuals with mature gonads versus length class (standard length) for *Leiognathus bindus*.

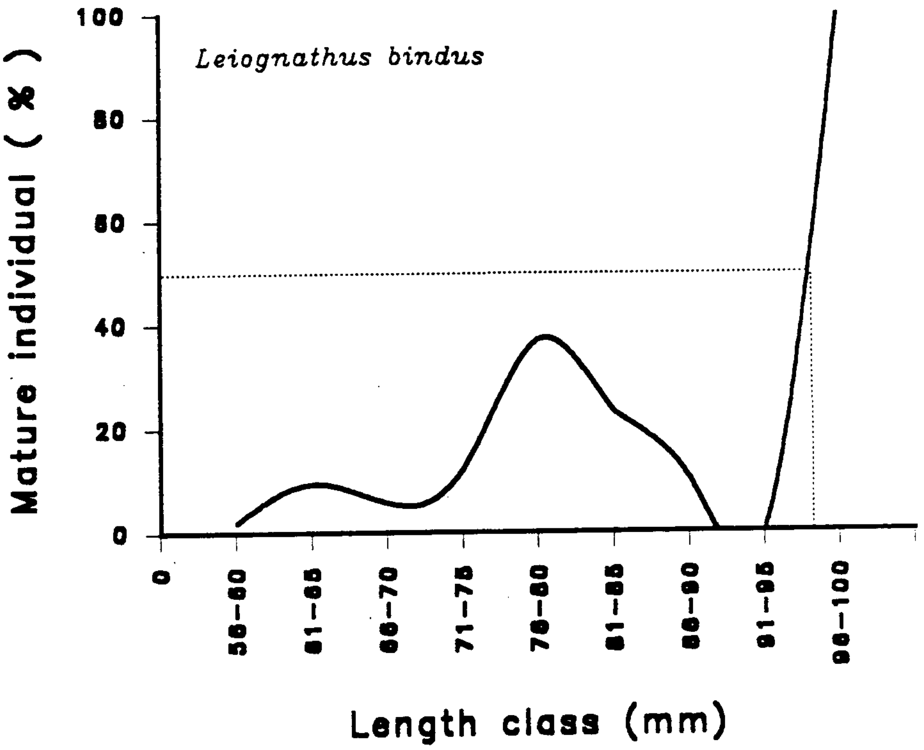

Leiognathus bindus
Mature individual (%)
100
80
60
40
20
0
0
56-60
61-65
66-70
71-75
76-80
81-85
86-90
91-95
96-100
Length class (mm)

Figure 7b. Percentage of individuals with mature gonads versus length class (standard length) for *Leiognathus decorus*.

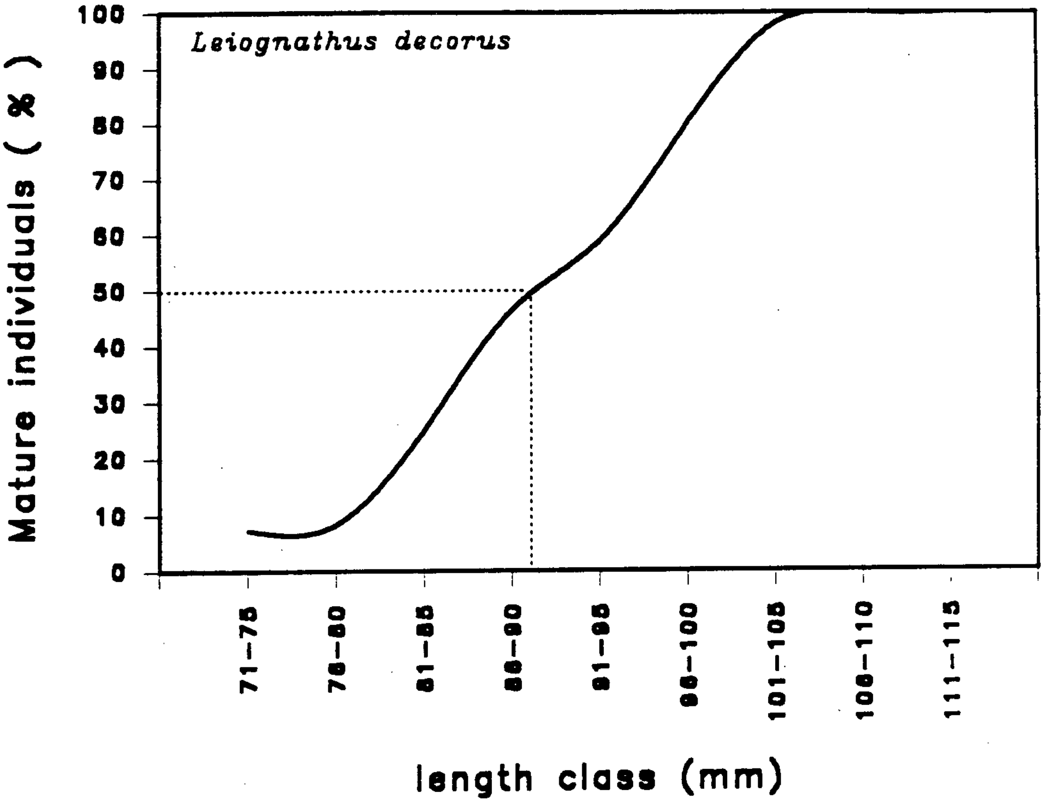

Leiognathus decorus
Mature individuals (%)
100
90
80
70
60
50
40
30
20
10
0
71–75
76–80
81–85
86–90
91–95
96–100
101–105
106–110
111–115
length class (mm)

Figure 7c. Percentage of individuals with mature gonads versus length class (standard length) for *Leiognathus splendens*.

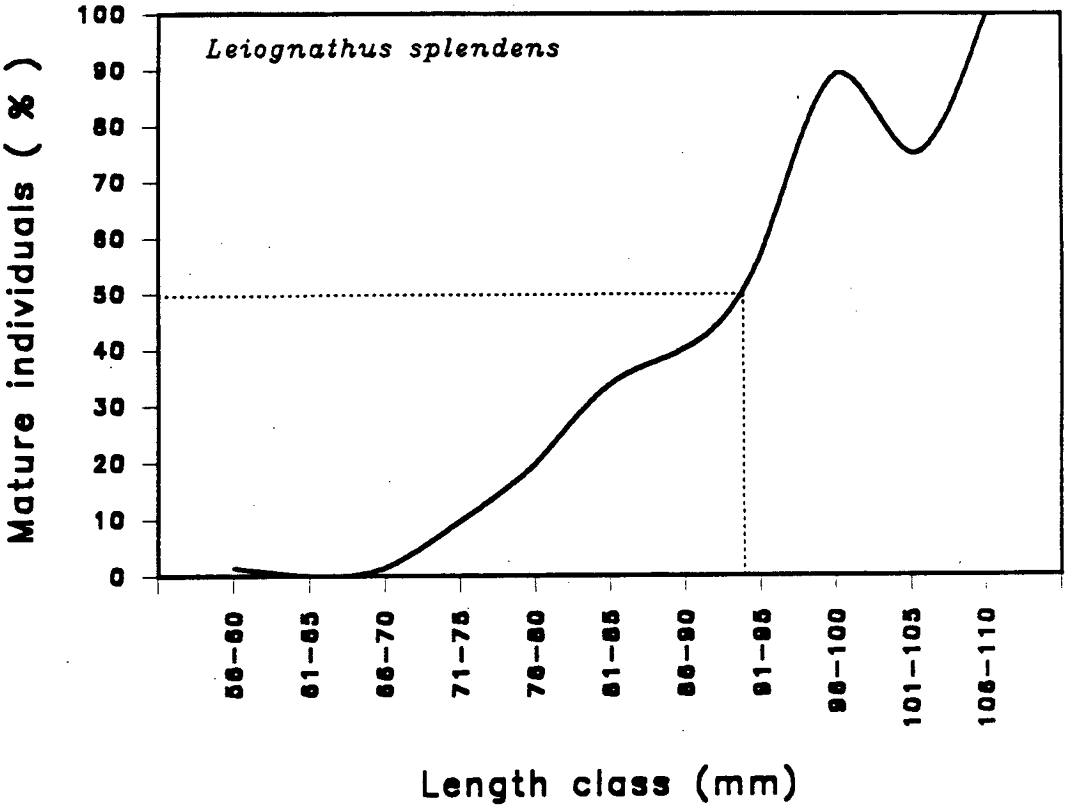

Leiognathus splendens
Mature individuals (%)
100
90
80
70
60
50
40
30
20
10
0
56–60
61–65
66–70
71–75
76–80
81–85
86–90
91–95
96–100
101–105
106–110
Length class (mm)

Figure 7d. Percentage of individuals with mature gonads versus length class (standard length) for *Secutor ruconius*.

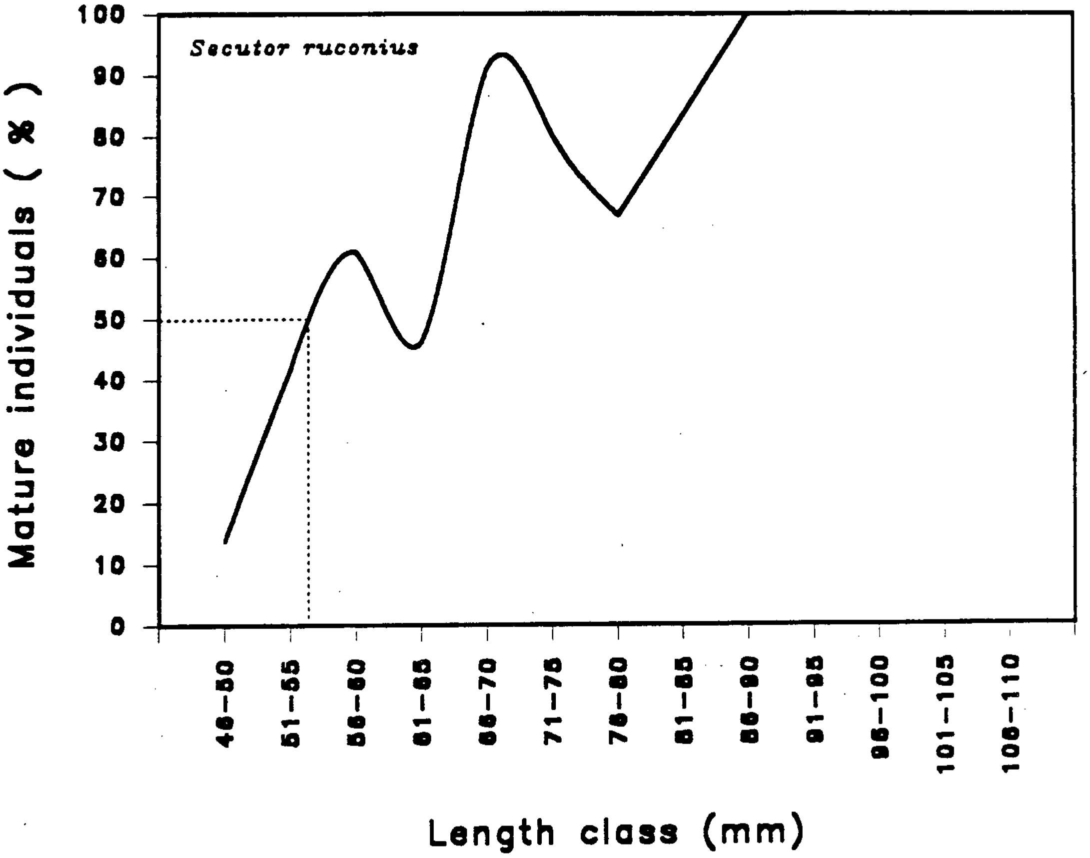
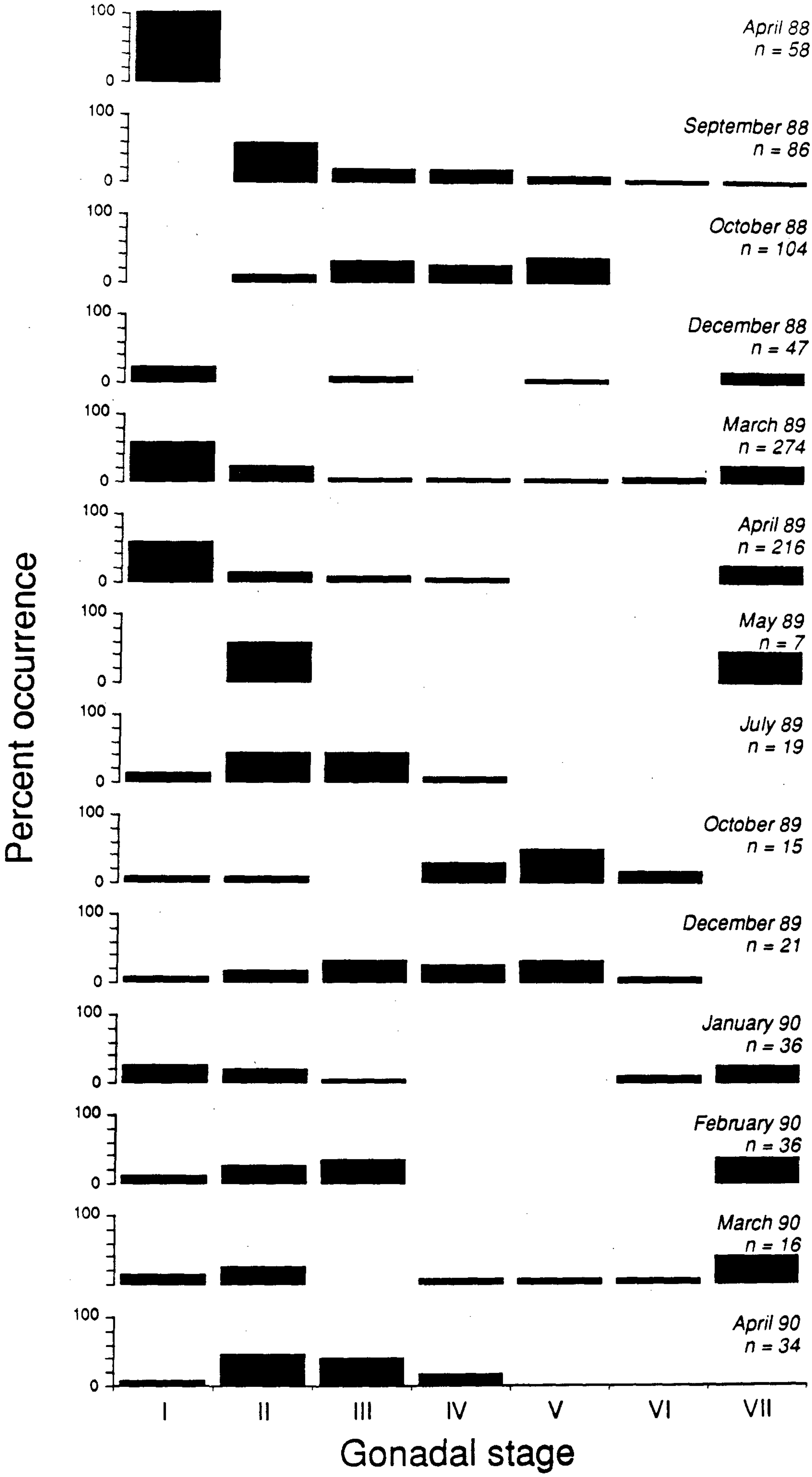

Secutor ruconius
Mature individuals (%)
100
90
80
70
60
50
40
30
20
10
0
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
86-90
91-95
96-100
101-105
106-110
Length class (mm)

Figure 8a. Percentage occurrence of 7 gonadal stages in samples of *Leiognathus bindus* from April 1988 to April 1990.



100
0
April 88
n = 58
September 88
n = 86
October 88
n = 104
December 88
n = 47
March 89
n = 274
April 89
n = 216
May 89
n = 7
July 89
n = 19
October 89
n = 15
December 89
n = 21
January 90
n = 36
February 90
n = 36
March 90
n = 16
April 90
n = 34
Percent occurrence
I
II
III
IV
V
VI
VII
Gonadal stage

Figure 8b. Percentage occurrence of 7 gonadal stages in samples of *Leiognathus decorus* from April 1988 to April 1990.

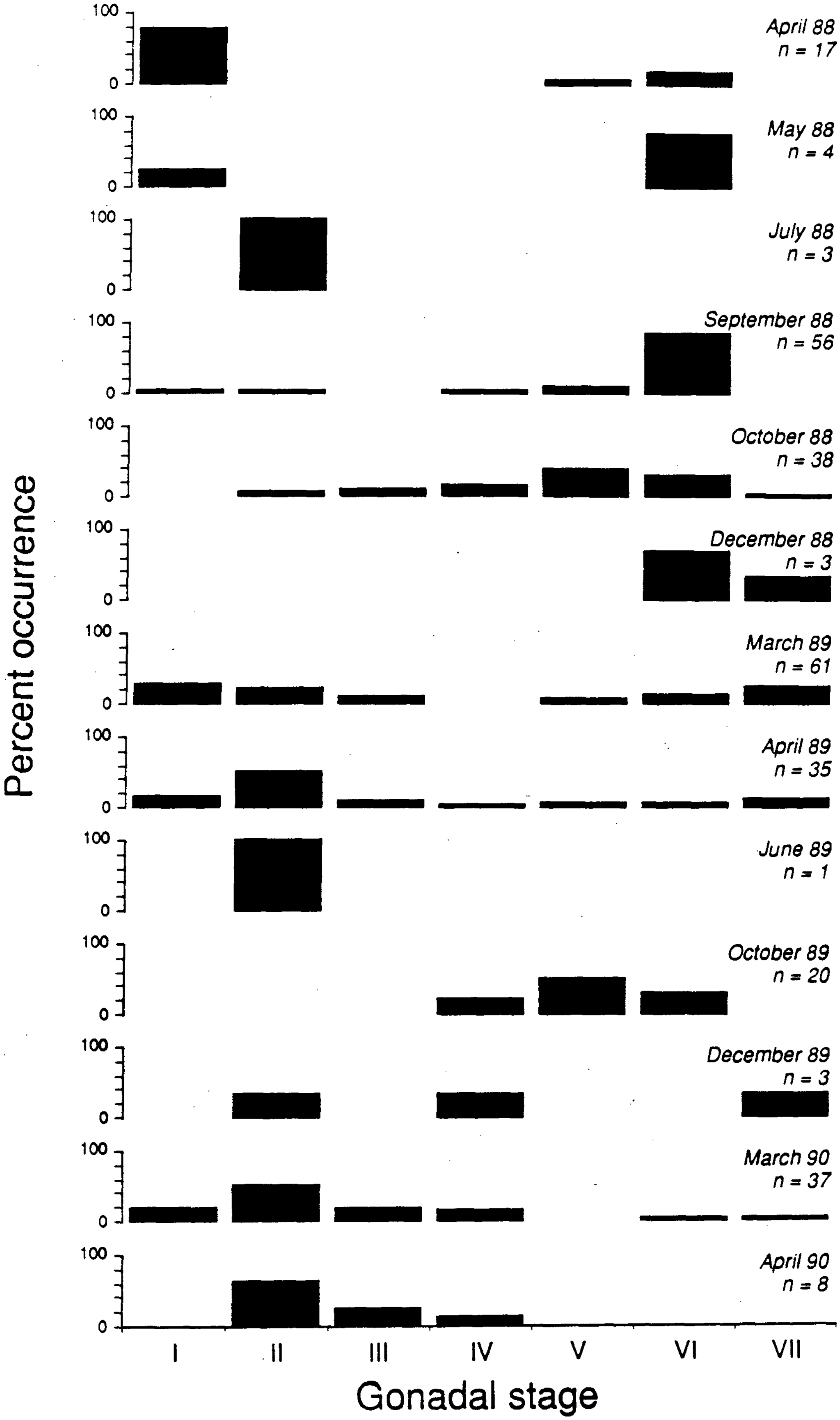

Percent occurrence
100
0
April 88
n = 17
May 88
n = 4
July 88
n = 3
September 88
n = 56
October 88
n = 38
December 88
n = 3
March 89
n = 61
April 89
n = 35
June 89
n = 1
October 89
n = 20
December 89
n = 3
March 90
n = 37
April 90
n = 8
I
II
III
IV
V
VI
VII
Gonadal stage

Figure 8c. Percentage occurrence of 7 gonadal stages in samples of *Secutor ruconius* from April 1988 to October 1989.

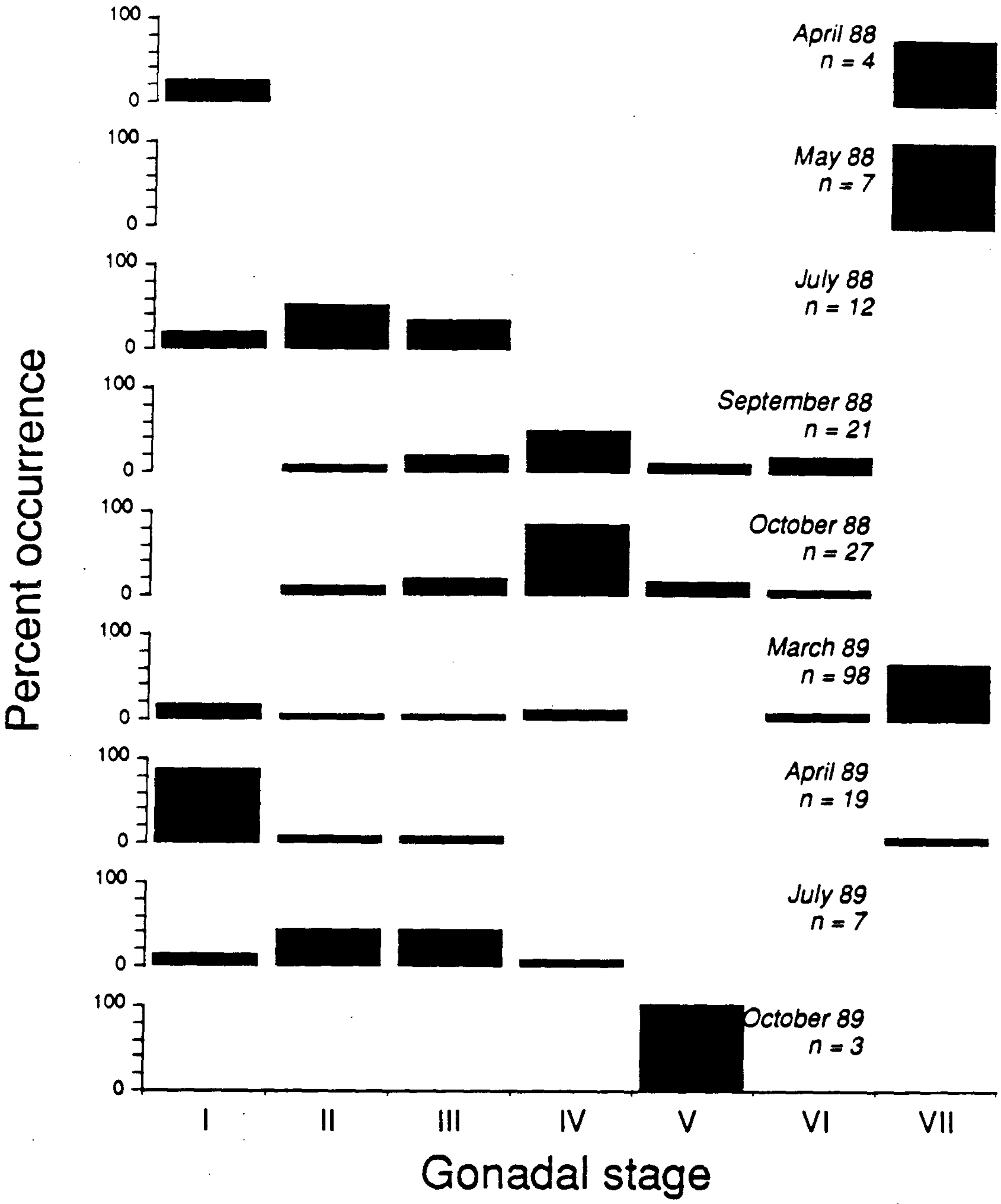

Percent occurrence
100
0
April 88
n = 4
May 88
n = 7
July 88
n = 12
September 88
n = 21
October 88
n = 27
March 89
n = 98
April 89
n = 19
July 89
n = 7
October 89
n = 3
I
II
III
IV
V
VI
VII
Gonadal stage

Figure 9a. Histological section of a mature ovary of *Leiognathus bindus* showing a wide range of developmental stages of eggs, suggesting serial spawning.

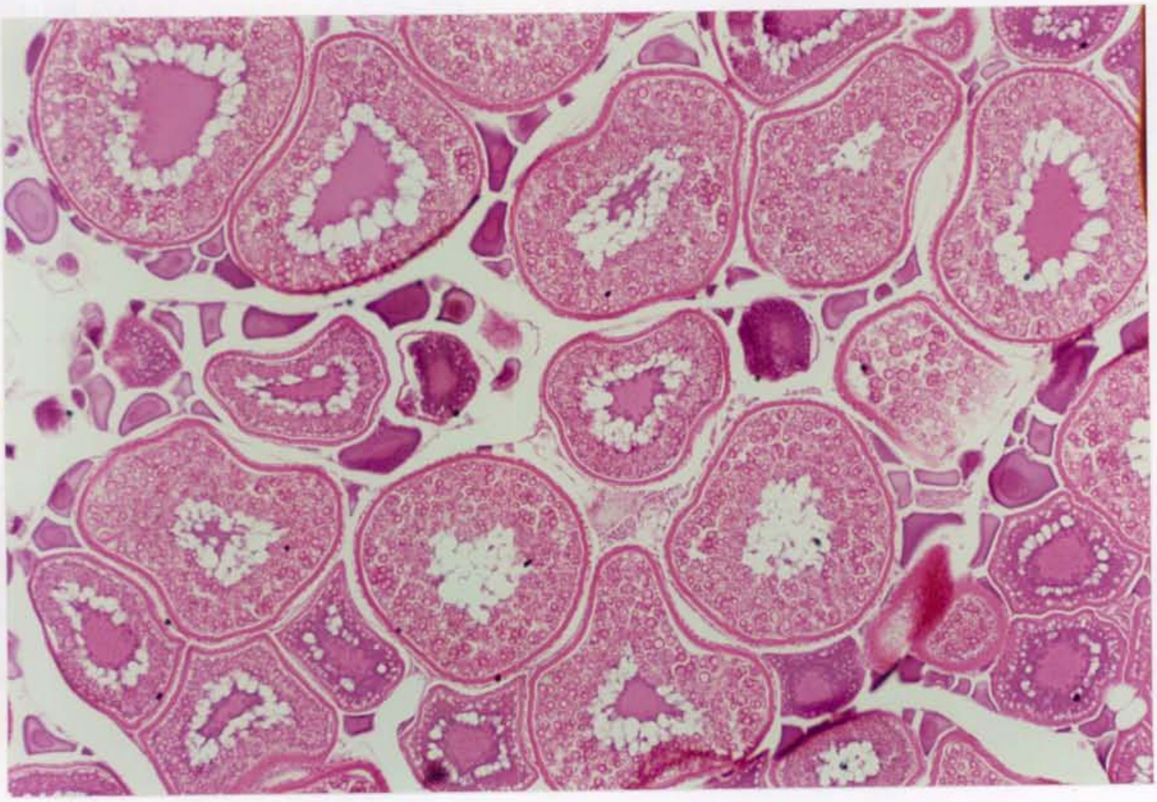


Figure 9b. Histological section of a mature ovary of *Leiognathus decorus* showing a wide range of developmental stages of eggs, suggesting serial spawning.

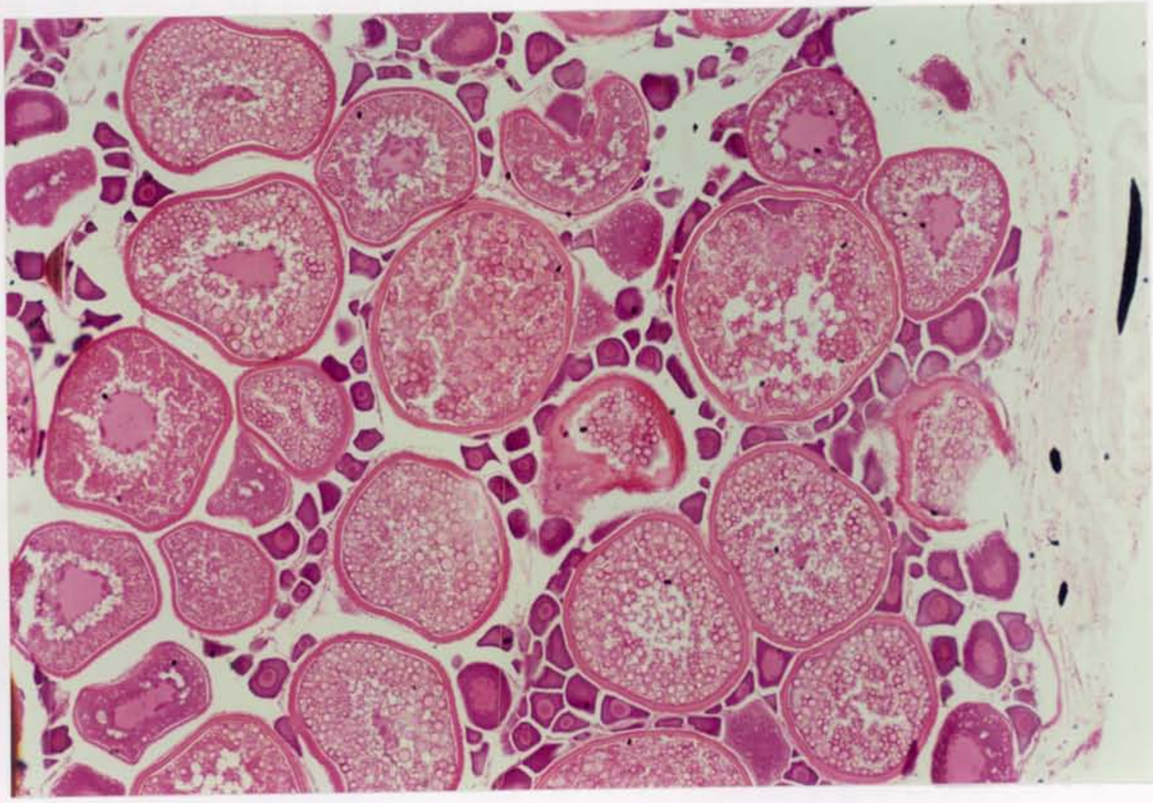


Figure 9c. Histological section of a mature ovary of *Leiognathus splendens* showing a wide range of developmental stages of eggs, suggesting serial spawning.

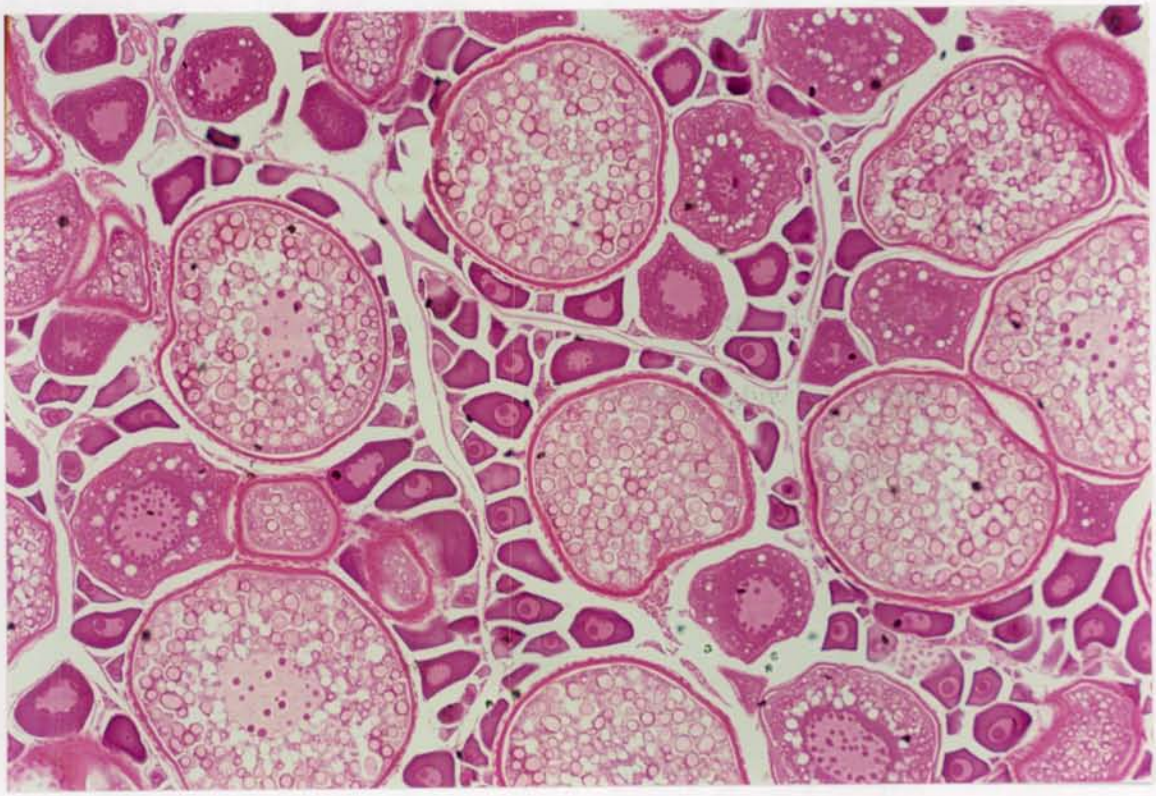


Figure 9d. Histological section of a mature ovary of *Secutor ruconius* showing a wide range of developmental stages of eggs, suggesting serial spawning.

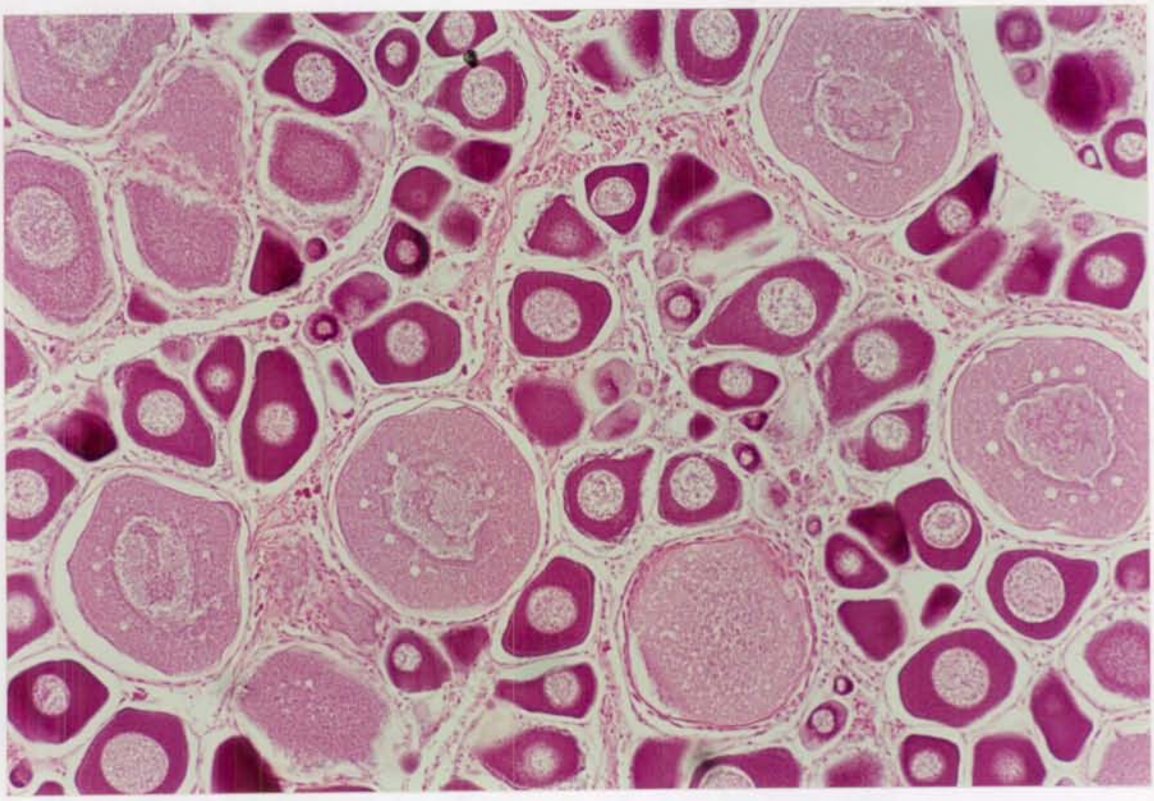


Figure 10a. Percentage abundance of length classes of juvenile *Leiognathus decorus* in Stuart Creek, a mangrove-lined creek draining into Cleveland Bay.

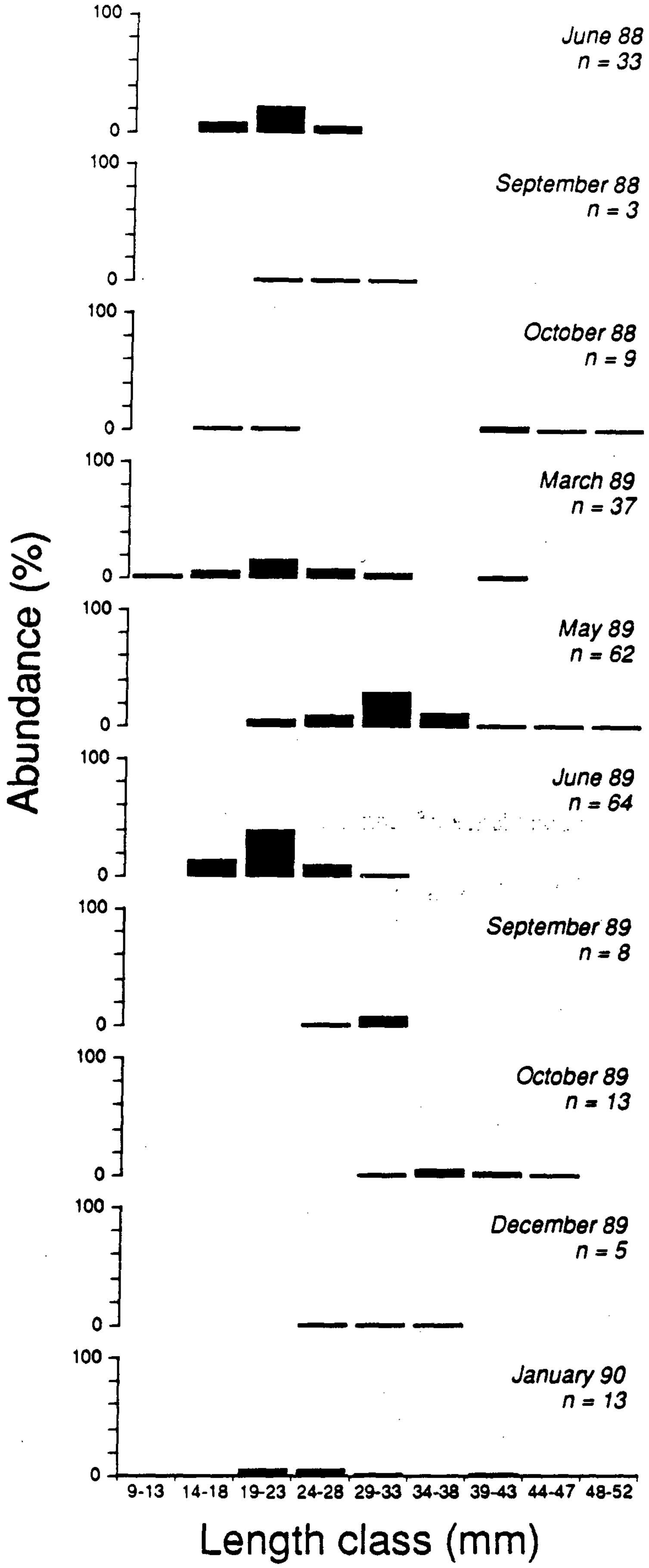

Abundance (%)
100
0
June 88
n = 33
September 88
n = 3
October 88
n = 9
March 89
n = 37
May 89
n = 62
June 89
n = 64
September 89
n = 8
October 89
n = 13
December 89
n = 5
January 90
n = 13
9-13
14-18
19-23
24-28
29-33
34-38
39-43
44-47
48-52
Length class (mm)

Figure 10b. Percentage abundance of length classes of juvenile *Leiognathus splendens* in Stuart Creek, a mangrove-lined creek draining into Cleveland Bay.

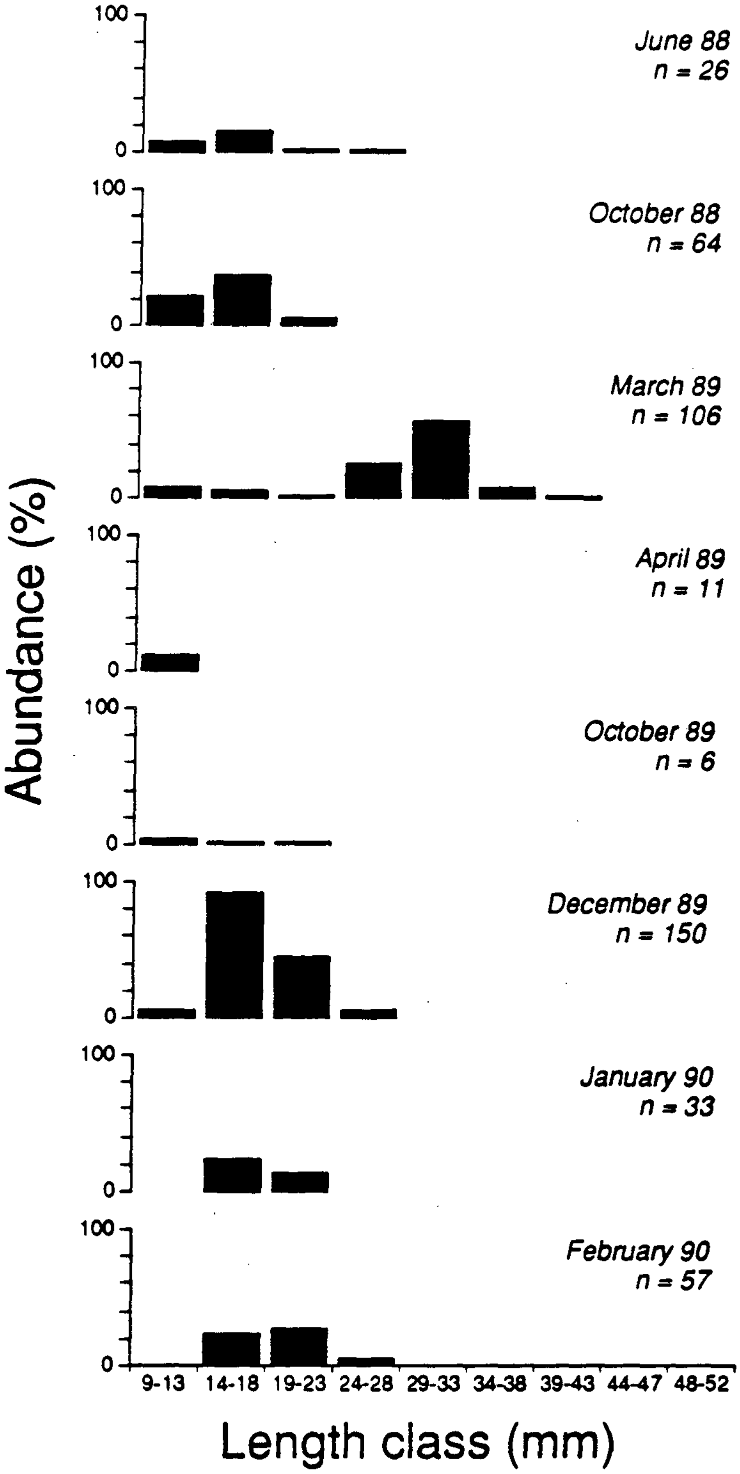

Abundance (%)
100
0
June 88
n = 26
October 88
n = 64
March 89
n = 106
April 89
n = 11
October 89
n = 6
December 89
n = 150
January 90
n = 33
February 90
n = 57
9-13
14-18
19-23
24-28
29-33
34-38
39-43
44-47
48-52
Length class (mm)

Figure 11. Published values of the growth performance index (∅') for two species of *Leiognathus*. Data from Dwiponggo (1987) and Pauly and Ingles (1984).

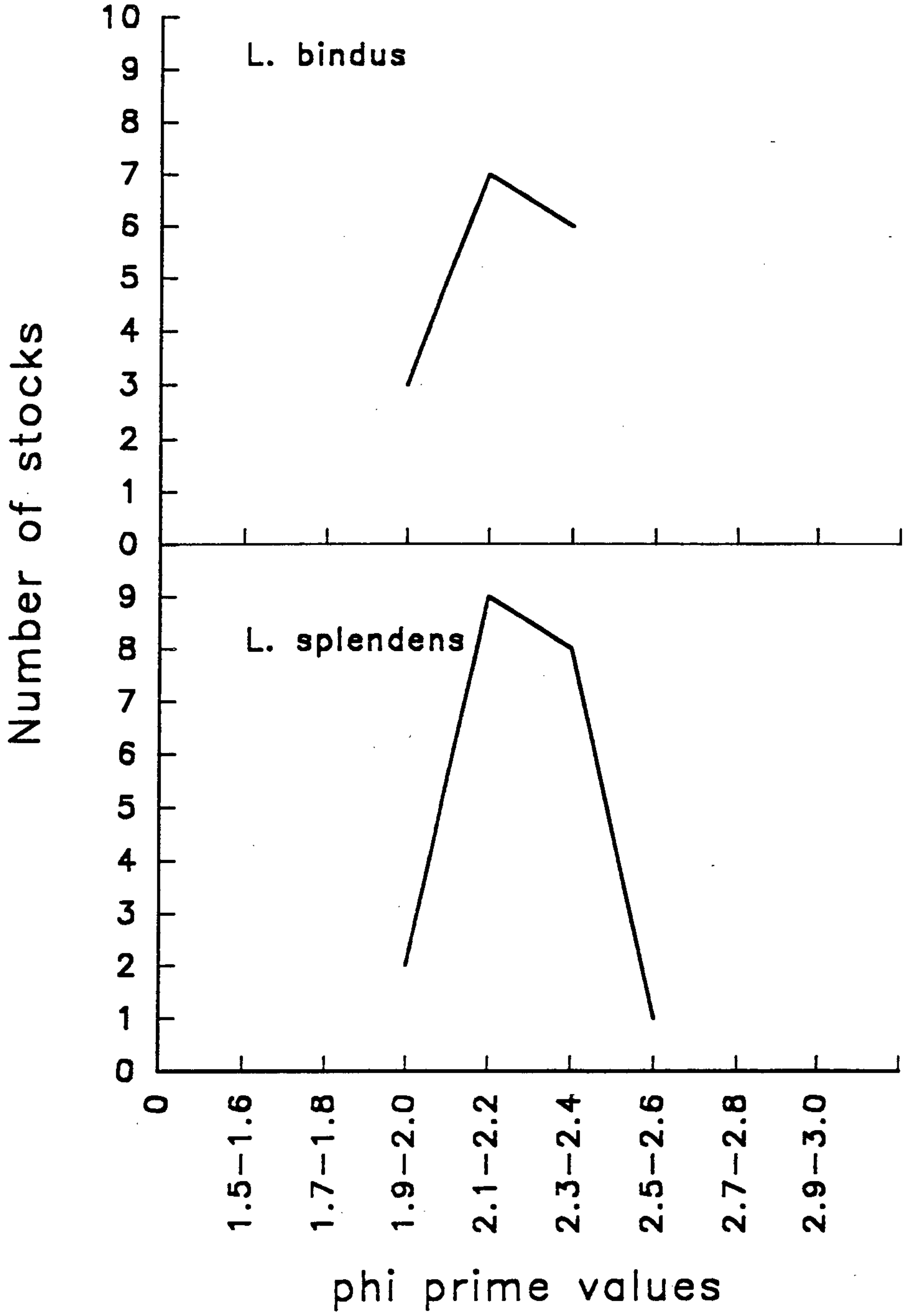

10
9
8
7
6
5
4
3
2
1
0
L. bindus
9
8
7
6
5
4
3
2
1
0
L. splendens
Number of stocks
0
1.5–1.6
1.7–1.8
1.9–2.0
2.1–2.2
2.3–2.4
2.5–2.6
2.7–2.8
2.9–3.0
phi prime values

Table 1. The mathematical expressions of the length-weight relationships of four leiognathid species found in Cleveland Bay, Australia

Species/Sex	Equation	r^2
L. bindus		
female	$W = 0.00005676\ L^{2.834}$	0.984
male	$W = 0.00005008\ L^{2.866}$	0.989
L. decorus		
female	$W = 0.000010064\ L^{3.246}$	0.985
male	$W = 0.00002468\ L^{3.053}$	0.973
L. splendens		
female	$W = 0.00003517\ L^{2.992}$	0.998
male	$W = 0.00002887\ L^{3.304}$	0.995
S. ruconius		
female	$W = 0.0001057\ L^{2.730}$	0.875
male	$W = 0.0001038\ L^{2.734}$	0.855

Table 2. Estimates of growth parameters from length-frequency data and from size at age data and indices of growth performance (ϕ'); SL (standard length), TL (total length); * from Powell-Wetherall method (see text).

Species	Length-frequency data					Size at age data						
	SL L_∞	TL L_∞	K_1	ϕ'	Rn	SL L_∞	K_{2a}	ϕ'	L_∞*	K_{2b}	ϕ'	K_1/K_{2b}
L. bindus	100	129	0.82	2.135	0.304	104.5	0.289	3.50	100	0.284	3.453	2.887
L. decorus	120	151	1.20	2.475	0.439	119	0.526	3.809	120	0.455	3.658	2.637
L. splendens	115	147	1.30	2.417	0.234	110	0.556	3.828	115	0.459	3.662	2.832
S. ruconius	80	103	1.00	2.028	0.411							

Table 3. Summary of estimates of growth parameters of some demersal fishes using various methods: LF - length-frequency data analysis (ELEFAN); MP - modal progression; IM - integrated method

Species	L_∞ (cm)	K (y^{-1})	t_o (year)	lifespan (year)	Method	Location	Source
Family Drepanidae							
Drepane punctata	54.3	0.134	-	-	LF	Senegal	Thiam (1988)
Family Gerreidae							
Pentaprion longimanus	15.5	0.945	-	-	-	North Queensland, Australia	Dolar (1986)

Family Leiognathidae							
Leiognathus bindus	15.84	0.58	-0.024	2.9	MP	Kakinada	Murty (1987)
	12.2	1.3	-	-	MP	Calicut	Balan (1967)
L. splendens	13.00	3.3	-	1.0	?	Indonesia	Pauly (1978)
Secutor insidiator	12.30	1.2	-0.010	-	IM	Kakinada	Murty (in press)
Family Mullidae							
Upeneus sulphureus	19.9	0.875	-	-	LF	Indonesia	Budihardjo (1988)
Family Nemipteridae							
Nemipterus bathybus	19.0			4		Hong Kong	Eggleston (1972)
N. japonicus	30.5	0.3141	-1.1079	-	MP	Andhra-Orissa	Krishnamoorthi (1973, 1978)
	29.0	0.6244	0.1439	-	scale	Visakhapatnam	Rao and Rao (1986)

	31.4	0.7514	-0.1731	-	MP	Kakinada	Murty (1983a, 1984)
	33.9	0.5200	-0.1600	-	IM	Kakinada	Murty (1987)
	30.5	1.0040	0.2254	-	IM	Madras	Vivekanandan and James (1986)
	32.6	0.5100	-	-	LF		Pauly and David (1981)
	31.4	0.5500	-	-	LF	Malaysia	Isa (1988)
	23.1			3	scales	Visakhapatnam	Rao and Rao (1986)
N. mesoprion	21.9	0.8300	-0.2600	-	MP	Kakinada	Murty (1984)
N. virgatus	29.0			6		Hong Kong	Eggleston (1972)

Family Sciaenidae							
Johnius carutta	33.3	0.4400	0	-	IM	Kakinada	Murty (1984, 1986)
Pennabia macropthalmus	34.5	0.4200			LF	Malaysia	Ahmad (1988)

CHAPTER VI

THE BIOLOGY, DISTRIBUTION AND ABUNDANCE OF THE PREDATORY FISHES, *SAURIDA MICROPECTORALIS* AND *SAURIDA UNDOSQUAMIS* (PISCES: SYNODONTIDAE), AND THEIR PREDATION ON LEIOGNATHIDS

Introduction

Perhaps the major density-dependent factor in controlling populations of fish (particularly juvenile phases) is predation (Sissenwine, 1984; Williams, 1986; Shulman and Ogden, 1987; Doherty and Williams, 1988). Natural mortality due to predation and its variability are difficult to estimate (Lassig, 1982; Sissenwine, 1984) while spatial and temporal variabilities in population density *per se* are relatively easier to quantify.

However, information on natural mortality resulting from predation provides a basis for rational conservation and management of resources (Daan, 1973; Sainsbury, 1982, 1988). The complexity of the food web in a community, exemplified by predator-prey interactions, probably determine the capacity of populations to resist or recover from exploitation (Jones, 1982; Paine, 1984). However, there are conflicting results in the literature of whether removal of predators affect the size of immediate prey populations (Shulman and Ogden, 1987; Doherty and Williams, 1988; Russ, 1991) and other prey populations in the community (Beddington, 1984; Paine, 1984). Nevertheless natural mortality, as a result of predation, plays an important part in the theory of exploitation of populations (Sissenwine, 1984); natural mortality is likely to decrease with the reduction, by fishing, of the size of the population of predator. Thus predation, along with competition, were included with economic criteria by Sainsbury (1982; 1988) in the analysis of the mulstispecies fisheries of Northwestern Australia and in subsequent management decisions. Estimates of natural mortality are important in allowing managers to set appropriate levels of fishing effort to maintain a sustainable yield, allowing assessment of the effects of fisheries, and permitting the introduction of appropriate measures for the conservation of stocks (Daan, 1973). Information on gut contents of predators is important in estimating natural mortality.

In tropical demersal ecosystems, the most numerous of predatory fishes are the synodontids, commonly called lizardfishes (Family: Synodontidae; Aprieto and Villoso, 1979; Villoso and Hermosa, 1982; Chan and Liew, 1986; Kulbicki and Wantiez, 1990; Harris and Poiner, 1990; 1982; Cabanban and Russ, MS). Other less important predators in this ecosystem are the paralichthyids and cynoglossids (Rainer and Munro, 1982; Chapter III). Synodontids, paralichthyids, and cynoglossids feed on small (< 20 cm SL) but abundant species such as the gerreids, mullids, and leiognathids (Pauly, 1979). At present, several studies on the diet of predatory species have been made, *e. g.*, *Megalaspis cordyla* (Sreenivasan, 1974), *Psettodes erumei* (Devadoss and M. Pillai, 1973), *Saurida undosquamis* (Hayashi *et al.*, 1960; Bograd-Zismann (1965); Tiews *et al.*, 1972; Sainsbury and Whitelaw, MS), *S. elongata* (Hayashi *et al.*, 1960).

The synodontids are known piscivores (Chan and Liew, 1986; Kulbicki and Wantiez, 1990). *Saurida undosquamis*, in particular, feed on teleosts and invertebrates intermittently throughout day and night. Adult synodontids consume between 23-30 g of food per day which is equivalent to 4.9-6.4 % of their body weight (Hayashi *et al.*, 1960; Sainsbury and Whitelaw, MS). This consumption of food is greater than that for the serranid, *Epinephelus guttatus* (Menzel, 1960), which consumes 4 % of body weight per day, but lower than that of another synodontid found in coral reefs, *Synodus englemanni*, which consumes the equivalent of 12 % of body weight per day (Sweatman, 1984). *Saurida undosquamis* exert natural mortality on nemipterids and lutjanids which is an order of magnitude greater than the fishing mortality caused by trawling in the Northwest Shelf of Australia (Sainsbury and Whitelaw, MS). *S. undosquamis* showed great adaptability when introduced into the eastern Mediterranean and competed successfully for food and space with *S. tumbil* and *Merluccius merluccius* (Family: Gadidae) to the extent of superseding the populations of the native synodontid species, *S. saurus* (Ben-yami and Glaser, 1974). This species and other synodontids have the potential to affect the population dynamics of demersal fishes substantially (Thresher *et al*, 1986; Sainsbury and Whitelaw, MS).

In Cleveland Bay, Townsville, Australia, the most abundant group of small (< 20 cm) demersal fishes are the leiognathids, commonly called slip-mouths or ponyfishes (Chapter III). This family is also abundant in many soft-bottom environments in the tropics (Pauly, 1979; Rainer and Munro, 1982; Villoso and Hermosa, 1982; Harris and Poiner, 1990; Kulbicki and Wantiez, 1990). Many species, including the lizardfishes, are reported to feed on leiognathids (*see* Pauly and Wade-Pauly, 1981). In Cleveland Bay, only two abundant predatory species, *Saurida micropectoralis* and *S. undosquamis*, were trawled in large numbers. The distribution, abundance, growth, reproductive biology, and diet of these two species were investigated in detail so that the possible effects of predation of these fishes on the abudance of leiognathids could be estimated.

Materials and Methods

Sampling and laboratory procedures

Saurida micropectoralis and *S. undosquamis* were collected by trawling in Cleveland Bay, Townsville, Australia at approximately monthly intervals from March to December 1989 as part of the routine sampling of the fish fauna (Chapter II). Preliminary samples were collected in July and October 1988.

In the laboratory, saurids were identified, counted, and measured (standard length, SL) to the nearest mm. Some individuals were weighed to the nearest mg. After measuring the specimens, an abdominal slit was made to expose the gonad and stomach. The sex and gonadal stage were determined macroscopically based on Bagenal (1978). The stomach was slit longitudinally. The fullness of the gut was not determined for speed in processing of so many samples; however, the occurence of empty guts was noted and counted. When guts contained prey, the prey were identified and enumerated. In general, the prey were at various stages of digestion (stages 1- 4, Magnuson, 1969) so that identification was limited to the family level in the case of teleosts and orders in the case of invertebrates. Prey that were in stage 3 and 4 (Magnuson, 1969) were categorized as unidentified. Prey that were larval stages were placed in a separate category (= larva). Leiognathids that occured in the guts of saurids were identified to species when possible and their lengths measured. All the above measurements and observations provided data on abundance, length-frequency, reproductive activity, composition of the diet and frequency of occurence of prey items in the diet of *S. micropectoralis* and *S. undosquamis*.

Analytical procedures

Distribution and abundance -

Variation in abundance of saurids among trawls, sites, locations, and months was analyzed using Analysis of Variance (ANOVA; Underwood, 1981). Locations (Inshore, Offshore) and Months (11) were considered fixed, orthogonal factors. Both Sites and Trawls were nested in combinations of Location and Month. Sites were considered fixed factors and Trawls as random factors. Heterogeneity of variances was tested using Cochran's Test (Underwood, 1981). Pooling of sum of squares was done when F-ratios for Sites and Trawls were not significant at $p = 0.25$. Student-Newman-Keuls tests (Winer, 1971) were performed when a significant location x month interaction was detected.

Gut contents - The percentage of empty guts was calculated for each month. Synodontids were arbitrarily categorized into length-classes (1 - 100, 101 - 200, 201 - 300, 301 - 400 mm SL) and their diet examined to detect whether there were any ontogenetic shifts in prey composition. Homogeneity of the proportion of leiognathids *versus* all other fishes per month was tested using a chi-square test (Zar, 1974).

Dietary overlap was calculated using the Caswell and Futuyma Coefficient (C_{ih}):

$$C_{ih} = 1 - 0.5 \quad (p_{ij} - p_{hj})$$

where p_{ij} and p_{hj} are proportions of diets of species i and h. The coefficient is 0 when species share no prey or 1 when all prey are the same.

Estimation of natural mortality - The impact of predation by *Saurida micropectoralis* and *S. undosquamis* was estimated combining two methods. The first method was based on the predation of synodontids on leiognathids and the second method from the empirical formula of Pauly (1980).

The first method used information on the following:

1. average weight of an individual leiognathid;
2. average number of leiognathids/net;
3. average weight of an individual synodontid;
4. average number of saurids/net;
5. ratio of saurid:leiognathid number;
6. rate of food-consumption of one saurid; and
7. percent occurrence of leiognathids in the diet of saurids.

The average weight of one leiognathid was calculated from the weights of various species of leiognathids weighed in the laboratory. The number of leiognathids/net was acquired by dividing the mean-gross weight of leiognathids/net by the average weight of one leiognathid.

The average weight of one saurid was the quotient of the mean-gross weight of saurids/net (which was weighed on board the research vessel) divided by the number of saurids/net. The average number of saurids/net was calculated per species from the data on numerical abundance. The combined averages of number of saurids/net (for both species) was used in the calculation. The ratio of saurids to leiognathids was calculated simply by dividing the average number of leiognathids by the average number of saurids.

The rate of food-consumption used in the calculation was taken from Sainsbury and Whitelaw (MS). This rate of food consumption was based on the square-root model of gastric evacuation for *Saurida undosquamis* in the Northwest Shelf of Australia. The given range of consumption was 4.9 to 6.4 % of body weight per day. The median of these values (5.6 %) was used to estimate the food consumption of the average synodontid in this study. In this study, the feeding rate during the cooler months (during dry season) was not considered; calculations were based on the assumption that the feeding rate was similar.

The percentage occurence of leiognathids in the diet of synodontids was based on the data acquired from the analysis of gut contents in this study.

Natural mortality (M) was calculated by the following steps:

1. estimate the amount of leiognathids consumed of the total fish-prey in the diet of synodontids;

2. calculate the number of leiognathids consumed by a synodontid/year;

3. calculate the density of both synodontids and leioganthids in the Bay;

4. calculate the synodontid-induced component of natural mortality (from the percentage of standing stock) in numbers of leiognathids removed per year by synodontids.

Each of these steps are explained below.

Step 1. The weight of leiognathids consumed by a saurid was calculated by multiplying the percent occurence of leiognathids in the diet of saurids by the amount of fish- consumption of one saurid in one day.

Step 2. The number of leiognathids consumed per year by one saurid required several calculations. First, the number of days required for one saurid to eat an amount in weight equivalent to one leiognathid was calculated by dividing the mean weight of one leiognathid by the amount of leiognathid consumed by a synodontid (from Step 1). The resulting number was converted to number of leiognathids/year consumed per synodontid.

Step 3. Densities of leiognathids and synodontids were estimated from trawl samples (Chapters III, IV, this chapter).

Step 4. Mortality of leiognathids due to predation by synodontids was calculated by dividing the number of leiognathids consumed by synodontids/year by the ratio of synodontid:leiognathid per unit area. This figure represents the percentage of the leiognathids per unit area which would be consumed by synodontids in one year. This was used as the estimate of survivorship (having not been consumed) of leiognathids over one year. This annual survivorship estimate was converted to an estimate of instantaneous natural mortality from the formula

Survivorship = e^{-M}.

The contribution of *S. micropectoralis* and *S. undosquamis* was split in proportion to the biomass of each species.

The second method of estimating natural mortality of each leiognathid species was based on Pauly's (1980) empirical formula:

$$\log_{10} M = 0.0066 - 0.279 \log_{10} L_{\infty} + 0.6543 \log_{10} K + 0.4634 \log_{10} T$$

where L_{∞} is in terms of TL (cm), K is on an annual basis, and T is the average temperature (°C).

The average temperature used was 25.0 °C.

The mean weighted natural mortality (M) of leiognathids was calculated using their abundance per 6,000 m^2 (Chapter IV).

Estimate of fishing mortality

Fishing mortality (F) was calculated using two methods: a) the swept area method; b) the length-converted-catch-curve method (Pauly, 1984). The swept area method formula is:

$$F = a.\ f.\ x_1/A$$

where a - area swept

f - effort

x_1 - escapement factor

A - total area of Cleveland Bay.

Cleveland Bay has never been trawled on a commercial basis (Duncan, D., pers. comm.). However, the James Cook University of North Queensland vessel *RV James Kirby* has trawled for educational and research purposes since the 1970's (Stark *et al.*, 1975). From 1988-1991, the Bay was subjected to trawling on a monthly basis with 12 10-minute shots/day each month. This is equivalent to 4 net-hours per day or 48 net-hours per year. The total area trawled in one year (1988-1991) was 1.63 km^2/year or 0.76 % of the total area of the Bay, excluding the dumping sites. Thus, fishing mortality is likely to be very low. The escapement factors used were 0.3 (Liu *et al.*, 1985) and 0.5 (South China Sea Project, 1978). The smaller escapement value (0.3) was used in the Northwest Shelf of Australia by Sainsbury and Whitelaw (MS) while the larger one is widely used in trawled areas in Southeast Asia (Pauly, 1984). The total area of the Bay, excluding the dump sites, is 215 km^2.

Estimate of total mortality

The length-converted catch curve for each leiognathid species, based on pooling of per cent samples, were used to estimate total mortality (Z'). The value of Z' was obtained from a steady-state population and the equation:

$$\ln (N/1-\exp(-Z\Delta t)) = a + bt'$$

where N is the number of fully recruited animals of a given relative age (t'), where the slope (b), with sign changed, is equal to Z and Δt is the time needed for the fish to grow through a length class.

The total mortality (Z) was also calculated by adding the estimate of fishing mortality (F) using the swept area method and the estimate of natural mortality (M) using Pauly's formula (1980). This was done for each species of leiognathid.

Estimates of Z' and Z were compared. The difference between these estimates (I) could perhaps be attributed to emigration (*sensu* Pinto, 1986).

Estimate of growth rate and reproductive activity of synodontids

The length-weight relationship for each gender was established separately for *Saurida micropectoralis* and *S. undosquamis* using regression (Pauly, 1984). The relationship was expressed by the following equations

$$W = a.L^b$$

where W is weight (in g) and L is length (in mm).

Growth parameters of the saurids were estimated by the analysis of the length-frequency data using a computer-package, Electronic Length-frequency Analysis (ELEFAN, Pauly and David, 1981; Gayanilo *et al.*, 1989). In addition, percentages of immature (Stages I, II), maturing (Stages III, IV), mature (V, VI), and spent (Stage VII) gonads taken from fish each month were presented graphically to illustrate temporal patterns of reproductive activity.

Results

Distribution and Abundance

A total of 1840 saurids were collected in Cleveland Bay in 1988 and 1989. *Saurida micropectoralis* (n = 1263) was more numerous than *S. undosquamis* (577).

S. micropectoralis varied in abundance between inshore and offshore locations and months of collection (with a significant interaction between location and months), between sites and between trawls (Table 1). The three largest monthly catches of *S. micropectoralis* occurred in March, April and May 1989 while the lowest catches were recorded in December, 1989 (Figure 1). In terms of interannual comparisons of abundance, there were more *S. micropectoralis* in July 1988 than July 1989 but more in October 1989 than in October 1988. The complexities of the significant Location by Month interaction of abundance of *S. micropectoralis* are shown in Table 2. Significant differences in abundance between locations were detected in May, July and August 1989 (Table 2). No significant differences were detected between inshore catches throughout the sampling period. However, significant differences between monthly catches were detected at the offshore sites (Table 2).

Saurida undosquamis displayed significant variation in abundance at the level of Sites only (Table 1).

Estimates of parameters of growth

The growth of *S. micropectoralis* and *S. undosquamis* was isometric. The following equations represent the length-weight relationships:

S. micropectoralis

female: $\log W = -5.202 + 3.103 \log L$; $r^2 = 0.960$

male : $\log W = -4.469 + 3.00 \log L$; $r^2 = 0.927$

S. undosquamis

female: $\log W = -4.936 + 2.994 \log L$; $r^2 = 0.936$

male : $\log W = -5.124 + 3.07 \log L$; $r^2 = 0.937$

The length-weight relationships are illustrated in Figures 2a and 2b.

The estimates of growth parameters of *Saurida micropectoralis* were: $L_{\infty} = 415.0$ mm; $K = 0.401$ ($Rn = 0.328$). The growth curve is shown in Figure 3a.

The estimates of growth parameters of *Saurida undosquamis* were: $L_{\infty} = 298$ mm; $K = 0.500$ ($Rn = 0.333$). The growth curve is shown in Figure 3b.

Composition of Diet

The gut contents of a total of 835 *Saurida micropectoralis* and 549 *S. undosquamis* were examined. About 40 % of these individuals contained prey. The percentage of empty stomachs in both species was high throughout the sampling period (Tables 3, 4). Saurids were opportunistic predators, feeding on a wide selection of teleosts, including some commercially important species, and occasionally on invertebrates: *e. g.*, penaeids, cephalopods, crustacea, and stomatopods (Table 5). The two main categories of prey (fish, invertebrates) were sometimes found at the same time in the gut of saurids. The composition of prey was similar for each species (Table 5) but the composition of teleosts in the prey differed from month to month (Table 6). Although there was taxonomic similarity in the diets of *S. micropectoralis* and *S. undosquamis*, a very neligible dietary overlap was detected (C_{ih} = 0.07015).

A. *Saurida micropectoralis*

Thirty five percent (s. e. = 5.77) of *S. micropectoralis* that were examined had prey in their guts (Table 4). Throughout the sampling period, the percentage of empty stomachs was high (mean = 65.216, s. e. = 5.77) except in June 1989 when 53.85 % of saurids contained prey in their guts.

Teleosts dominated the diet of *S. micropectoralis* (88.53 %) (Tables 5, 6). Most of the prey items (42.06 %) in the guts were in various stages of digestion such that identification to familial level was difficult or impossible. The prey items of *S. micropectoralis* included 16 families of fishes (Table 5). Commercially important groups of fishes in the diet were engraulids, mullids, clupeids, sillaginids, carangids, scombrids, trichiurids, and pomadasyids. The partially digested prey were mostly gobiids, engraulids, and leiognathids. These three groups of fishes occured most frequently in the guts of about 30 % of individuals containing prey (Table 6).

Among the invertebrates, penaeids were the main prey of *S. micropectoralis* (Table 5). Cephalopods (primarily squids), crustaceans, stomatopods, and other invertebrates were also found in the guts.

The predominance of teleosts in the diet of *S. micropectoralis* was consistent for all 4 arbitrary 100 mm length-classes (% of guts containing fish: range = 22 to 74 %; Table 7). The highest occurence of fish prey (as a percentage of all saurid individuals examined) was in the 1-100 mm length-class (74 %, n = 19). However, where the sample size was bigger, in the size range 101-200 mm (n = 528) and 201-300 mm (n = 359), the frequency of occurrence of fish in the guts was 26 % and 23 %, respectively (Table 7). In the size range 301-400 mm, 25 % of the individuals examined (n = 3) had fish in their stomach. This piscivorous diet did not change through the sampling period but the composition of the species of prey differed per month (Table 6).

The three most numerous fishes that were identified in the guts were the gobiids (mean = 21 %, s. e. = 6.111), engraulids (mean = 17 %, s. e. = 6.910), and leiognathids (mean = 13 %, s. e. = 3.732) (Tables 5, 6). The proportion of leiognathids in the fish-prey was the same throughout the sampling period (overall chi-squared = 10.98, p = 0.359, d.f. = 10).

Saurida micropectoralis feed on larval, juvenile, and adult fish (Table 5, 6). Recruits (< 30 mm SL) of leiognathids were found in their diet (Table 8). Seventeen individuals contained larval stages of fishes but most prey were either juveniles or adults. Cannibalism occured also (9 occurrences).

B. *Saurida undosquamis*

Thirty eight percent (s. e. = 4.87) of *Saurida undosquamis* that were examined had prey in their guts. The percentage of empty stomachs was high throughout the sampling period (mean = 62.02, s. e. = 4.87; Table 4). About one third (37 %) of the prey of *Saurida undosquamis* contained unidentifiable groups of fishes in various stages of digestion (Table 5). Fourteen families of fishes were recorded in the diet. However, only two families were dominant in their diet [eleotrids, primarily *Oxymetopon* sp. (undescribed species, P. Arnold, pers. comm.) and gobiids]. Commercially important groups such as lethrinids, sillaginids, scombrids, carangids, trichiurids, pomadasyids, engraulids, and clupeids also were found in the diet. Leiognathids were found in 3 *S. undosquamis* (Table 8). This saurid was ocassionally cannibalistic; saurids were found in five individuals.

Another one third (30 %, n = 72) of the *S. undosquamis* containing prey contained invertebrates (Table 5). Penaeids, stomatopods, and squids composed the invertebrate diet. Crustaceans (including crabs), octopus, and other invertebrates occured also in the guts of *S. undosquamis.*

Saurida undosquamis fed mainly on fishes. Fish dominated the gut contents of all size ranges of *S. undosquamis* (Table 7). 28 % of the guts of *S. undosquamis* 100-200 mm in length contained fishes and 14 % of guts of such fish contained invertebrates (Table 7). Eleotrids were the most numerous of the identifiable fish prey (21 % of total fish prey; n = 37) followed by gobiids (17 %, n = 30), and engraulids (8 %, n = 13) while leiognathids composed 1 % of the total fish prey (Tables 5, 6).

Fishes were the primary diet from month to month. However, the composition of fishes differed among monthly samples (Table 6). Of those identifiable teleosts, the eleotrids were dominant or co-dominant in 4 of the 9 months, gobiids were dominant or co-dominant in 6 of the 9 months, and engraulids dominant or co-dominant in 3 of the 9 months. The leiognathids were not dominant in the diet in any month and their proportion relative to other fishes in the guts of this saurid remained the same throughout the sampling period (overall chi-squared = 13.97, p = 0.7312, d.f. 10).

Estimate of dietary overlap between the two species

The Caswell and Futuyma Coefficient (C) was 0.0701. There was little overlap in the diet of *S. micropectoralis* and *S. undosquamis* in Cleveland Bay.

Estimate of natural mortality

The information used in estimating natural mortality was:

1. mean weight of leiognathid - 15.0541 g
2. number of leiognathids/net - 174.238 (= per 6,000 m^2)
3. mean weight of saurid - 144 g
4. number of saurids/net - 4.750 (*S. micropectoralis*) plus 2.189 (*S. undosquamis*) = 6.939 (= per 6,000 m^2)
6. ratio of saurid to leiognathid - 1:25.110 (= relative density per unit area)
7. rate of fish prey consumed by one saurid - 8.22 g/day; and
8. occurrence of leiognathid in the diet of saurids - 4.17 % of teleost-prey.

Thus, the amount of leiognathids present in the fish-prey of one saurid was 0.339 g/day. It took 44.407 days for a saurid to consume the equivalent weight of one leiognathid. At this rate, 8.219 leiognathids were eaten by one saurid each year and this represented a mortality due to predation by synodontids of 32.73 % of the leiognathid population per year. The instantaneous rate of predation mortality (M) due to synodontids was 0.396. Of this estimate, *S. micropectoralis*, the more abundant synodontid, imposed a slightly higher predation mortality (M = 0.215) than *S. undosquamis* [M = 0.181; (Table 9)].

The mean weighted natural mortality (using Pauly's empirical formula) was 2.3 $year^{-1}$. The estimates for each leiognathid species are in listed in Table 10. This weighted natural mortality estimate can be assumed to include all mortality due to predation by synodontids and other fishes. Thus, the percentage contribution of predation by *S. micropectoralis* to natural mortality (weighted M = 2.3) was 9.3 % while that of *S. undosquamis* was 7.9 % (Table 9).

Estimate of fishing mortality

Fishing mortality (F) estimates when escapement was set at 0.5 and 0.3 were F = 0.004 and 0.002 $year^{-1}$, respectively. Fishing mortality was equivalent to 0.57 - 1.01 % of M.

Estimate of total mortality

Estimates of total mortality based on length-converted catch curves (Figures 4a-d) were almost 50 % higher than those calculated from the sums of fishing mortality (F) and natural mortality (M; Tables 10, 11). Emigration (I) was possibly high and was higher than fishing mortality (F = 0.004).

Reproductive activity

Saurida micropectoralis matured at about 200 mm (SL). A total of 615 individuals were examined with more than 20 individuals examined each sampling month (Table 12). There were slightly more males than females except in August, October, and November 1989 (Table 12). The spawning pattern was not distinct. The high percentage of mature and spent individuals in September-October indicate a peak in spawning activity (Fig. 5a). Spawning may occur throughout the year, as indicated by the presence of mature and spent individuals and the high percentages of immature individuals at all sampling times.

Saurida undosquamis matured at about 160 mm (SL). 414 individuals were examined. The number of individuals examined per sampling month depended on available specimens (Table 12). There were generally more males than females. There was insufficient data to determine the spawning pattern (Fig. 5b). However, the highest recorded percentage of mature individuals was in August 1989 . Immature individuals were abundant throughout the sampling period.

Discussion

Natural mortality of leiognathids due to predation

The high rate of predation of *Saurida micropectoralis* and *S. undosquamis* on leiognathids suggests strongly that predation could control the size of leiognathid populations in a diverse, tropical demersal environment like Cleveland Bay (*e. g.*, Munro, 1974; Sissenwine, 1984; Overholtz and Tyler, 1986; Shulman and Ogden, 1987; Doherty and Williams, 1988; Chapter III). In particular, synodontids appear to have significant influence upon the abundance of adult leiognathids (Chapter III, IV) by preying on the pool of larvae and recruits of these species (Tables 6, 8).

Furthermore, the varied piscivorous diet of synodontids in Cleveland Bay (Table 5) illustrated that the predator-prey interactions in this diverse tropical demersal ichthyofauna (Chapter III) are complex and flexible. *S. micropectoralis* and *S. undosquamis* prey on clupeids, engraulids, gobiids, eleotrids, and leiognathids (Table 5). The juvenile and adult leiognathids are also preyed on by other piscivorous species: juveniles were eaten by medium-sized piscivores (<50 cm) while adults are consumed by large-sized piscivores [> 50 cm; *e. g.*, sharks (Simpendorfer, pers. comm.) and scombrids; Table 13)]. Thus, this estimate of natural mortality on leiognathids due to predation was an underestimation of the reduction of the size of their populations. The synodontid-imposed mortality contributed only 7.9 to 9.3 % of the natural mortality.

This study of piscivory by synodontids in Cleveland Bay has shown that predator-prey interactions result in complex community interactions. Many models of multispecies fisheries assume that predator-prey interactions are strong (Beddington and May, 1982; Beddington, 1984) and predict that such fisheries are more vulnerable to perturbations, *e. g.*, removal of predators by fishing. Removal of predators was proposed to result in changes in the overall abundance and relative abundances of prey (Beddington and May, 1982; Beddington, 1984; Grigg *et al.*, 1984). However, when a variety of predators feed on a prey population, it is likely that some predators will benefit from the reduction or elimination of a competitor (more prey will be available). On the contrary, removal of prey populations are likely to cause the decline of predatory populations but not *vice versa* (Pielou, 1969). In the tropics, it is possible that when a prey population declines, opportunistic or generalist piscivorous predators feed on any other abundant prey (Table 5). Any available food at each trophic level is possibly utilized (Jones, 1982). However, there is a paucity of empirical information on biological interactions in multispecies ecosystems making it difficult to establish generalizations (Munro and Williams, 1985).

In Cleveland Bay, an unexploited demersal community, the estimate of natural mortality (M = 0.396) of leiognathids due to predation by *S. micropectoralis* and *S. undosquamis* in Cleveland Bay was higher than the fishing mortality (F = 0.002, 0.004) caused by trawling for ecological studies. Likewise, in the Northwest Shelf, Australia, natural mortality of nemipterids and synodontids as a result of predation by *S. undosquamis* was higher than fishing mortality (Sainsbury and Whitelaw, MS). The consumption of nemipterids and synodontids by *S. undosquamis* was an order of magnitude larger than the fishery catch (Sainsbury and Whitelaw, MS).

Similarly, in the Eastern Mediterranean, predation and competition have been demonstrated to have a greater effect than exploitation on the population of leiognathids. The enormous increase in abundance of *S. undosquamis* reduced the density of *Leiognathus klunzingeri* (Ben-Tuvia, 1973). As a result of competition for prey, the catch of *M. merluccius* decreased as the catch of *S. undosquamis* increased (Ben-Tuvia, 1973).

This empirical evidence stresses that predation is an important component of models of communities (Sainsbury, 1982; 1988). Secondly, when natural mortality is higher than fishing mortality, the surplus biomass-production that will be available for sustained exploitation may certainly be limited. Thus, estimates of natural mortality due to predation can assist in managing exploited populations (Daan, 1973) and can be used successfully in models in combination with economic and managerial considerations (Sainsbury, 1982; 1984). Thirdly, the result suggests that compensatory density-dependent processes, such as an increase in the rate of growth or a decrease in the rate of natural mortality, may be important mechanisms permitting populations to recover from fishing (Sissenwine, 1984). However, density-dependent responses of fish populations to fishing pressure are often obscured by variability in recruitment, presumably due to the density-independent effect of environmental factors (Sissenwine, 1984) or density-dependent effect of predation (Overholtz and Tyler, 1986; Shulman and Ogden, 1987; Doherty and Williams, 1988; Sainsbury and Whitelaw, MS).

Natural mortality, emigration, and total mortality

Estimates of apparent total mortality (Z') from length-converted catch curves could be overestimations of true total mortality (Z = M + F) because these could include loss of individuals in the population due to emigration (I) of fish out of the sample area (Pinto, 1986). This is supported by the results of this study where the difference between the calculated Z was lower than Z' (Table 11).

Natural mortality (M, Table 10), however, was found to be higher than emigration (I) of leiognathids from Cleveland Bay (Table 11). This supports indirectly the variability of abundances of leiognathids (Chapter IV) which could be due to migration. In addition, this finding implies that predation could have a greater impact than migration in relatively unexploited populations.

Trophic position of the saurids

The two species of *Saurida* that were most abundant in Cleveland Bay, *Saurida micropectoralis* and *Saurida undosquamis* were primarily piscivorous (Tables 5-8). They employ the sit-and-wait strategy of catching prey (Hayashi, 1983; Sweatman, 1984) but are also capable of roaming in search of food.

There were several lines of evidence regarding the piscivorous habit of the two most abundant synodontids in Cleveland Bay. These were the dominance of fish in the diet, constancy of the presence of fish in the guts of young and old synodontids throughout the sampling period, and the occurrence of cannibalism. All of this information provides ample evidence that the synodontids were opportunistic, piscivorous fishes. This finding is in agreement with the results of other studies in tropical waters (Hayashi *et al.*, 1960; Hayashi, 1983; Sainsbury and Whitelaw, MS).

A wide variety of species of teleosts, including commercially important species, were present in the diet of *S. micropectoralis* and *S. undosquamis* (Table 5). This dietary pattern indicates a generalist diet. In different localities, *S. elongata*, *S. undosquamis*, and *Synodus variegata* were reported to prey on a variety of fishes (Hayashi *et al.*, 1960; Tiews *et al.*, 1972; Ben-Tuvia, 1973; Ben-yami and Glaser, 1974; Hayashi, 1983; Sweatman, 1984; Sainsbury and Whitelaw, MS). A large variety of teleosts in the diet has been demonstrated in other small- to medium-sized piscivores such as *Megalaspis cordyla* (Sreenivasan, 1974) and *Psettodes erumei* (Devadoss and M. Pillai, 1973). Marcotte and Browman (1986) suggested that the variability of prey composition and prey size may be related to the sometimes poor or slow perception and cognition of fish, particularly in turbid environments such as the bottom of bays. The overall result is predatory strikes at a very wide range of potential prey.

Synodontids in Cleveland Bay were mainly piscivorous throughout the year and throughout their life. However, monthly changes in the composition and proportion of various teleosts were recorded. From the point of view of this study, an important feature is that various stages of leiognathids remained a significant proportion of their diet throughout the year (Tables 5-8). Sainsbury and Whitelaw (MS) observed a seasonal shift in prey; there were more nemipterids and mullids in June than November while bothids and synodontids were more abundant in the diet in November than June. It was suggested that the availability of appropriate sizes (recruits) of nemipterids, synodontids, and lutjanids resulted in the change of diet. This is a likely explanation for the variable composition of the fishes in the guts of the saurids in Cleveland Bay.

This piscivorous role of synodontids has been reported in New Caledonia (Kulbicki and Wantiez, 1990), Malaysia (Chan and Liew, 1986), Thailand (Pauly, 1979), the Northwest Shelf of Australia (Sainsbury and Whitelaw, MS), the Philippines (Tiews *et al.*, 1972), and Japan (Hayashi *et al*, 1960). Besides feeding on fishes, saurids feed on cephalopods, crustaceans, and stomatopods [Tables 5-7; Hayashi *et al.*, 1960; Sainsbury and Whitelaw, MS). *Saurida micropectoralis* and *S. undosquamis* in Cleveland Bay are high-level consumers in the community. This finding agrees with that of Hayashi *et al.* (1960) who found that *S. undosquamis*, *S. elongata*, and *S. tumbil* were high level consumers in the trophic structure of a community of tropical demersal fishes in the Inland Sea of Japan.

However, the composition of fishes preyed upon by the two saurids in Cleveland Bay differed from that found in previous studies in the Indo-Pacific region. *Saurida undosquamis* in Cleveland Bay preyed mainly on eleotrids (Tables 5, 6) while the same species in Northwest Australia preyed on clupeids, nemipterids, carangids, mullids, bothids, and synodontids (Sainsbury and Whitelaw, MS). In the Eastern Meditteranean Sea, a large proportion of the diet of *S. undosquamis* was composed of *Dusumiera acuta* (Clupeidae), *Leiognathus klunzingeri* (Leiognathidae), *Upeneus moluccensis*, and *U. asymmetricus* (Mullidae) (Bograd-Zismann, 1965). In Japan, *S. elongata* fed primarily on *Engraulis japonica* (Engraulidae) and gobiids (Hayashi *et al.*, 1960) but the proportion of all prey items differed between the individuals coming from three locations in the Inland Sea and the adjacent region of the Pacific Ocean.

Cannibalism was another aspect of the predatory nature of *S.*

micropectoralis and *S. undosquamis* in Cleveland Bay (Table 5). This behaviour has been observed in other locations also, *e. g.*, in the Northwest Shelf, Australia (Sainsbury and Whitelaw, MS) and Japan (Hayashi *et al.*, 1960). Recruits of saurids were preyed upon and this may affect the subsequent size of the adult population.

The high percentage of empty stomachs of synodontids does not necessarily mean that food is unavailable but rather reflects the required frequency of feeding of the predator (Table 4). Prey species (*e. g.*, engraulids, clupeids, mullids, leiognathids) are abundant in Cleveland Bay (Chapter III, IV) and are of high caloric content (Longhurst, 1957). Simulations by Hayashi (1983) for *S. undosquamis* in Japan showed that the ratio of the benefit (r) to the abundance of prey (R) is low when food is abundant and interpreted this to mean that predators exploit the food resource at a relatively low level and can afford to spend time searching for desirable prey because the probability of encountering prey is high. This finding and the high caloric content of fish-prey may explain the high percentage of empty stomachs in the synodontids in Cleveland Bay.

High percentages of empty stomachs is common in synodontids (Table 4). The proportion of *S. micropectoralis* with empty stomachs was 65.22 % (s. e. = 5.77) over 12 months while for *S. undosquamis* it was 62.03 (s. e. = 4.87). These figures were comparable with that for *S. undosquamis* in the North West Shelf, Australia (Sainsbury and Whitelaw, MS), India (Rao, 1984), and for *S. tumbil* in the China Sea (Yamada *et al.*, 1986). The occurrence of empty stomachs was also high in a tropical species, *M. cordyla* (Sreenivasan, 1974). These proportions are much higher than those reported for *Gadus morhua* in the

North Sea at 8 % (Daan, 1973).

S. micropectoralis and *S. undosquamis* in Cleveland Bay may be considered efficient predators similar to *S. undosquamis* in the Inland Sea of Japan (Hayashi, 1983). Efficiency was achieved by *S. undosquamis* (Hayashi, 1983) by changing the strategy of capturing prey with the amount of available food in the environment. *S. undosquamis* actively search for prey when prey is abundant or sit-and-wait when prey is not abundant (to conserve energy). However, abundant prey may confuse predators (*e.g.*, Williams, 1964; Neill, 1972) and thus they may opt for areas of intermediate prey density permitting them to 'select' prey and not necessarily optimize energetic returns (Marcotte and Browman, 1986).

Although the most profitable prey was not identified and optimal foraging not estimated, *S. micropectoralis* and *S. undosquamis* were apparently adaptable predators, feeding on a wide array of teleosts and invertebrates (Table 5). This agrees with the prediction, based on optimal foraging theory, that generalizing is the best strategy when profitable prey are scarce (Werner and Hall, 1974; Pulliam, 1974; Pyke, 1984).

Saurida micropectoralis and *S. undosquamis* prey on similar food resources, however the proportions of specific items eaten differ (Table 5). There was little dietary overlap or competition for food resources (C_{ih} = 0.0701). The most abundant fishes that were found in the guts of *Saurida micropectoralis* were gobiids, engraulids, and leiognathids while the most abundant fishes in the guts of *S. undosquamis* were eleotrids, gobiids, and engraulids. This is a likely strategem which may permit coexistence.

Synodontids have the potential to out-compete related species or other predatory species. *S. undosquamis* invaded from the Indo-west Pacific biological province of the Red Sea to the eastern Mediterranean Sea as a result of the construction of the Suez Canal (Ben-Tuvia, 1973; Ben-yami and Glaser, 1974). This species became the only abundant species of synodontid in the Gulf of Suez and the Levant Basin, out-competing the native *S. saurus* and the Atlantic-Mediterranean lizardfish, *S. tumbil* (Ben-yami and Glaser, 1974). It was observed also that catches of *Merluccius merluccius*, the Atlanto-Mediterranean hake, decreased when catches of *S. undosquamis* increased (Ben-Tuvia, 1973).

Spatial and temporal patterns of abundance

The difference in the patterns of distribution and abundance of *S. micropectoralis* and *S. undosquamis* suggest spatial partitioning between these two congeners. This suggests the possibility of competition for resources although it is unlikely that food was a limiting factor. Prey species such as the leiognathids were abundant throughout the Bay and throughout the year (Chapter IV).

S. micropectoralis and *S. undosquamis* were numerous and more abundant than some of the other piscivorous species in the ichthyofaunal community of Cleveland Bay, *e. g.*, *Pseudorhombus arsius* and *P. elevatus* (Chapter III). However, their abundances were variable in space and time (Figure 1; Table 1). Spatial variability indicates that these species were mobile and moving in schools (*see* Results; abundances significantly different among sites). Temporal variability was not due to seasonality but reflected unexplained natural fluctuations in population density.

Short-term and long-term studies of the distribution and abundance of both *S. micropectoralis* and *S. undosquamis* provided different results. Significant variations in abundance of these saurids were detected between inshore and offshore locations in a short-term (days) study (Chapter III). This indicated that saurids probably migrated locally within the Bay. Long-term (months) studies have shown significant temporal (month) and spatial (sites) variations in abundance (Tables 1, 2). However, both short- and long-term studies consistently reflect the schooling behaviour of synodontids as indicated by the significant differences in abundance among Sites (Tables 1, 2). Ethological studies (*e. g.*, schooling behaviour) on the synodontids are necessary to complete the understanding of their ecology.

Growth and reproductive activity

The estimates of length-infinity for *S. micropectoralis* and *S. undosquamis* based on ELEFAN (Pauly and David, 1981; Gayanilo *et al.*, 1989; *see* Figures 3a and 3b) were likely to be underestimated because large individuals were not collected. The maximum recorded size of related species range from 657-794 mm FL for *S. tumbil* [in China Sea (Yeh *et al.*, 1977); India (Rao, 1984)] and 535 mm FL for *S. undosquamis* [in the Northwest Shelf, Australia (Thresher *et al.*, 1986)]. These large individuals were sampled only in waters deeper than 20 m (*e. g.*, Yeh *et al.*, 1977; Rao, 1984; Thresher *et al.*, 1986).

The estimates of growth parameters of *S. micropectoralis* and *S. undosquamis* based on ELEFAN (Pauly and David, 1981; Gayanilo *et al.*, 1989) were high (Figures 3a and 3b) compared with *S. tumbil* in India which had L_∞

= 637 mm, K = 0.249 (Rao, 1984). Rao's estimates were based on length-frequency data and analyzed using the Petersen method. Yeh *et al.* (1977) found that age and growth of *S. tumbil* differed between the sexes and between regions. They estimated the age of fishes by examination of annual rings which were formed in scales during the spawning season. In the East China Sea, the growth parameters of the von Bertalanffy equation for this species were: male, L_{∞} = 689.9 mm, K = 0.1177, t_o = -1.3953; female, L_{∞} = 724.4 mm, K = 0.1043, t_o = -1.4160; and in the Gulf of Tonkin they were: male, L_{∞} = 782.9 mm, K = 0.0790, t_o = -1.7934; female, L_{∞} = 794.6 mm, K = 0.0965, t_o = -1.5430. Rao (1984) reported that *S. micropectoralis* could live to 5-6 years while *S. undosquamis* could live to 3 years based on the Petersen method. The maximum length measured for *S. undosquamis* of 340 mm in India was 70 mm greater than that recorded for the same species in Cleveland Bay. Justifiable comparisons of growth of these species are precluded primarily by the fact that different methods were used to estimate the growth parameters and that specific, gender-related and regional differences occur.

The spawning pattern of saurids in the Bay was not distinct (Figures 5a, 5b) and cannot be determined unequivocally because of the low percentage of mature individuals in the samples. A low percentage of mature individuals in the population was observed also by Rao (1984) for *S. undosquamis*. Nevertheless, the presence of some mature individuals and the high numbers of immature individuals throughout the year suggest that spawning may be protracted. *S. tumbil* in India spawn 5-6 broods per spawning season while *S. undosquamis* spawn throughout the year (Rao, 1984). In Cleveland Bay, 1-4 modes were noted in the length-frequency data for *S. micropectoralis*. In constrast with Rao's (1984) finding for the same species, *S. undosquamis* had only 2-3 modes in the length-frequency data from Cleveland Bay.

In the waters of China, Chiang and Shean-ya (1974) found that the spawning activity of *S. tumbil* was asynchronous between the southern part of the East China Sea-Taiwan Strait and the northern part of the South China Sea-Gulf of Tonkin. In the East China Sea and the Taiwan Strait, spawning occurred from March to June while in the northern part of the South China Sea and the Gulf of Tonkin, the spawning season was from February to May. The sex ratio changes as fish become larger, with more females found as size increases. Chiang and Shean-ya (1974) explained that the slower growth rate of the males resulted in the predominance of females among the larger fish. In Cleveland Bay, there were generally more males than females except for *S. micropectoralis* in August, October, and November.

Based on the reproductive studies on *S. tumbil* in the East China Sea, reproductive-curves were found to be density-dependent (Saishu and Ikemoto, 1970; Murphy, 1982) - the relationship between the number of spawners and the number of recruits produced each year (stock-recruitment curve) was very good.

Conclusion

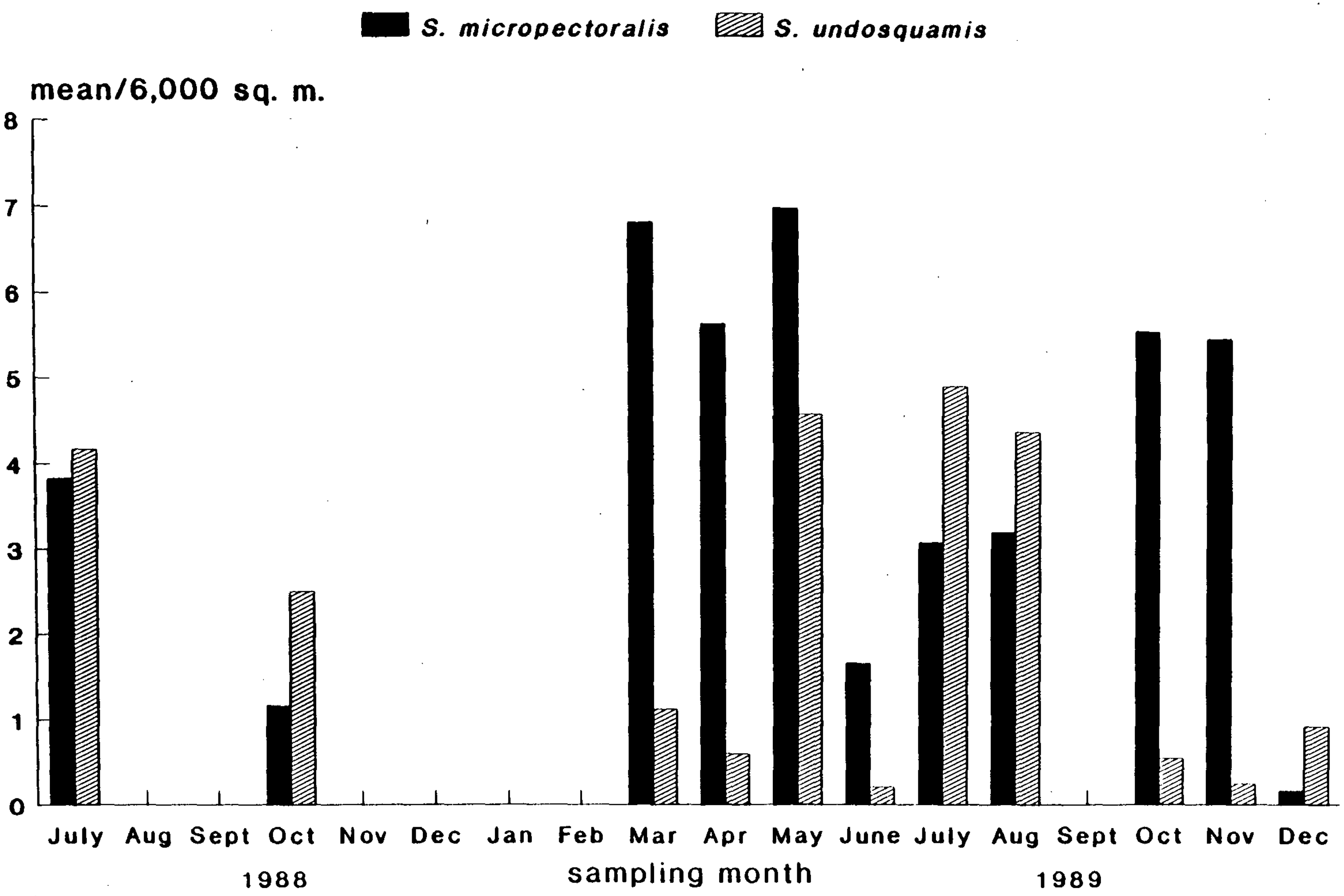
One mechanism by which the size of populations of small prey species in the demersal environment could be controlled is by predation of piscivores on the recruits of these prey species. The synodontids imposed a higher natural mortality on the populations of the most abundant family of demersal fishes in

Cleveland Bay (Leiognathidae) than that imposed by fishing. This implies that interspecific interactions, in particular predation, are likely to be important components in the assessment of size and variability of exploited populations.

Synodontids were the most abundant of the medium-sized predators in Cleveland Bay (Chapter III) but their abundance, at the scale sampled (depth range < 20 m; 225 km^2) was highly variable in space and time. The abundance of synodontids may be attributed to several pulses of spawning within one year, relatively fast growth, and its varied diet.

Further studies on the feeding behaviour of synodontids can be pursued (from this study). The detailed studies of Hayashi *et al.* (1960) and Sainsbury and Whitelaw (MS) may be replicated to arrive at biological and ecological generalizations. Caloric values of the prey taken can answer the question as to whether synodontids are feeding optimally. In addition, ethological studies on whether the synodontids form schools in feeding are also important in understanding their distribution (ecology) and their predatory impact on other fishes. More studies on predation by carnivorous species in Cleveland Bay should be conducted to understand the ecology of fishes within the bay while it is unpolluted.

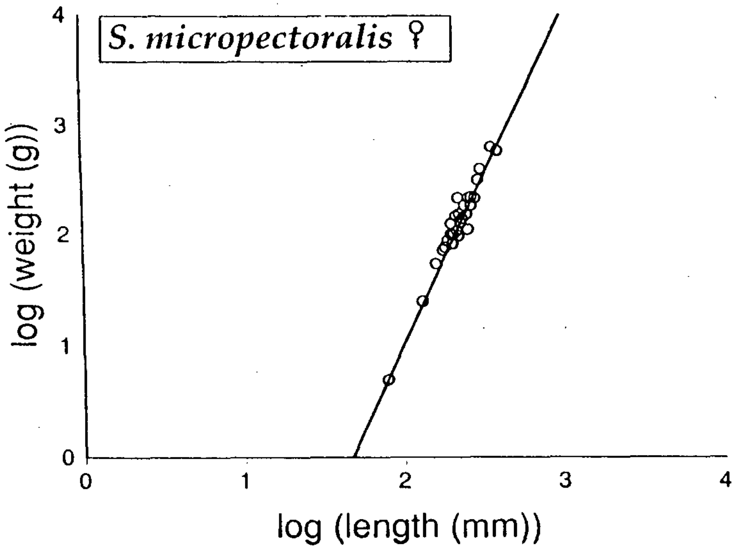
Figure 1. Abundance of *Saurida micropectoralis* and *S. undosquamis* per month. Note that samples were collected in 1988 only during July and October.



S. micropectoralis
S. undosquamis
mean/6,000 sq. m.
8
7
6
5
4
3
2
1
0
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
1988
sampling month
1989

Figure 2a. Length-weight relationship of *Saurida micropectoralis*.

Shaded symbols = female; Open symbols = male.


S. micropectoralis ♀
log (weight (g))
log (length (mm))
0
1
2
3
4
0
1
2
3
4

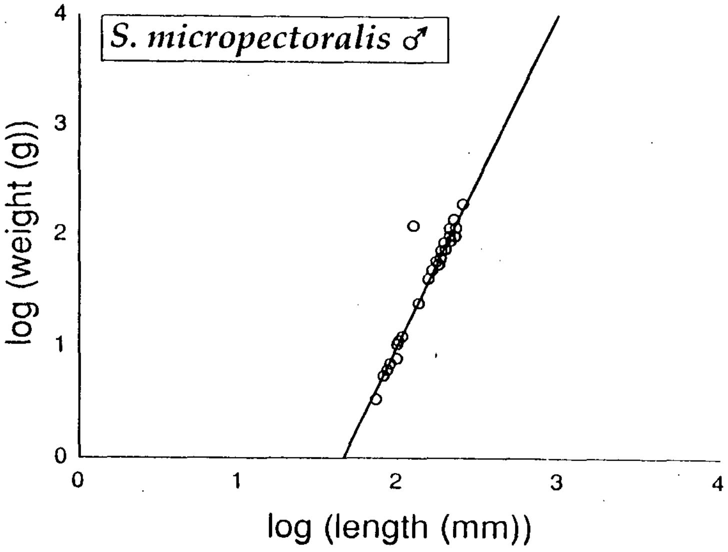
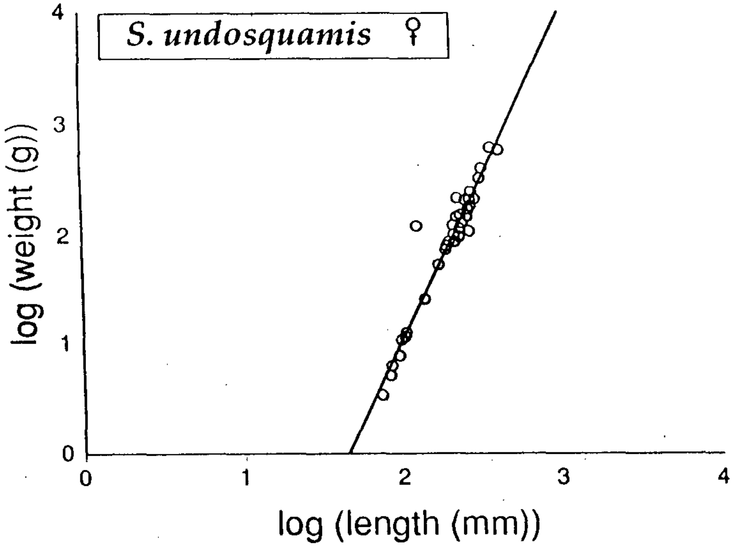

S. micropectoralis ♂
log (weight (g))
log (length (mm))
0
1
2
3
4
0
1
2
3
4

Figure 2b. Length-weight relationship of *Saurida undosquamis*.

Shaded symbols = female; Open symbols = male.


S. undosquamis ♀
log (weight (g))
0
1
2
3
4
log (length (mm))
0
1
2
3
4

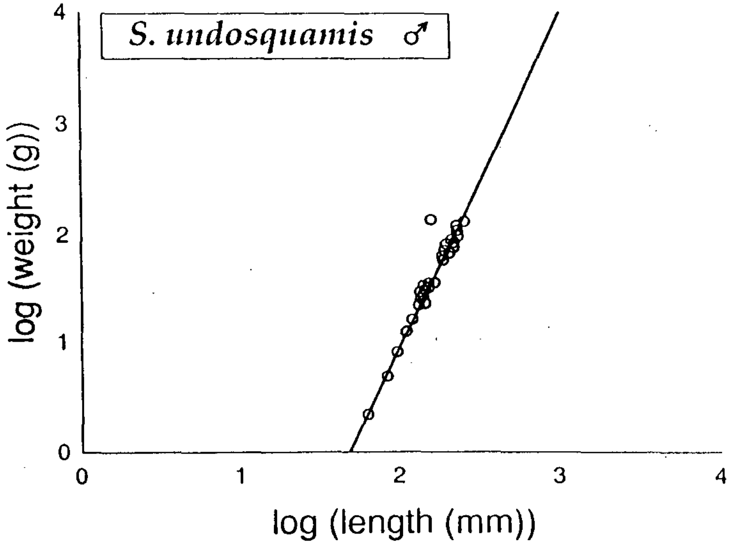
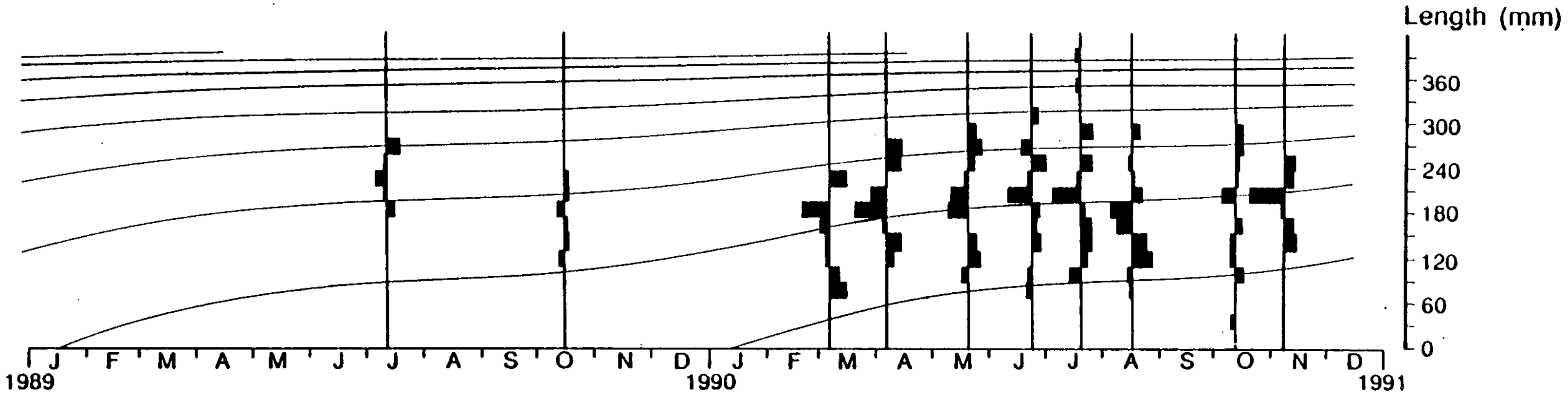
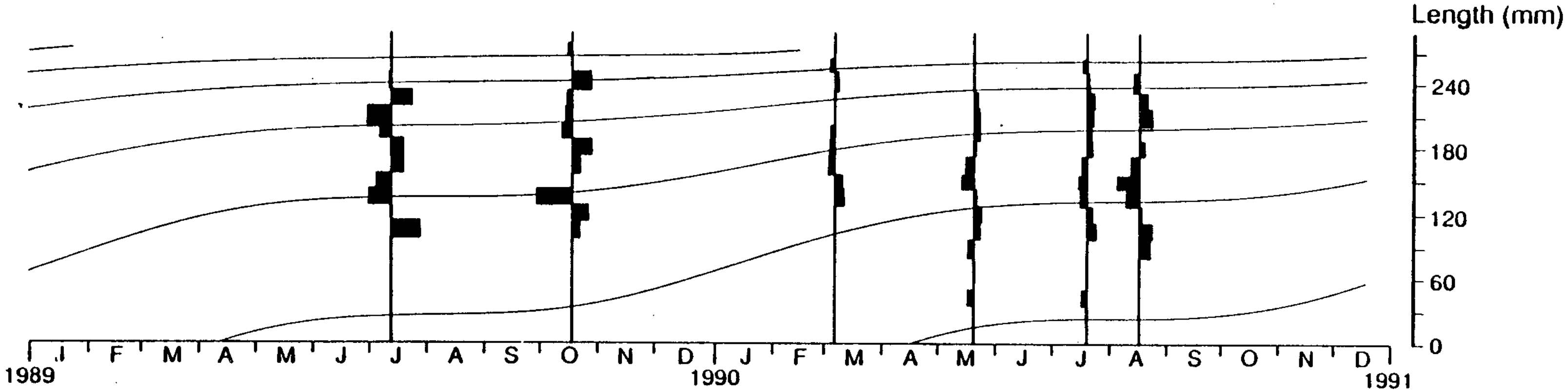

S. undosquamis ♂
log (weight (g))
0
1
2
3
4
log (length (mm))
0
1
2
3
4

Figure 3a. Growth curve of *Saurida micropectoralis* derived using ELEFAN (L_∞ = 415 mm, K = 0.401, Rn = 0.328).



Saurida micropectoralis

Figure 3b. Growth curve of *Saurida undosquamis* derived using ELEFAN (L_{∞} = 298 mm, K = 0.500, Rn = 0.333).



Saurida undosquamis

Figure 4a. Estimate of total mortality (Z') from length-converted catch curve for *L. bindus* [Z' = 2.84 (CI = 2.43-3.25)]; filled circles were points used

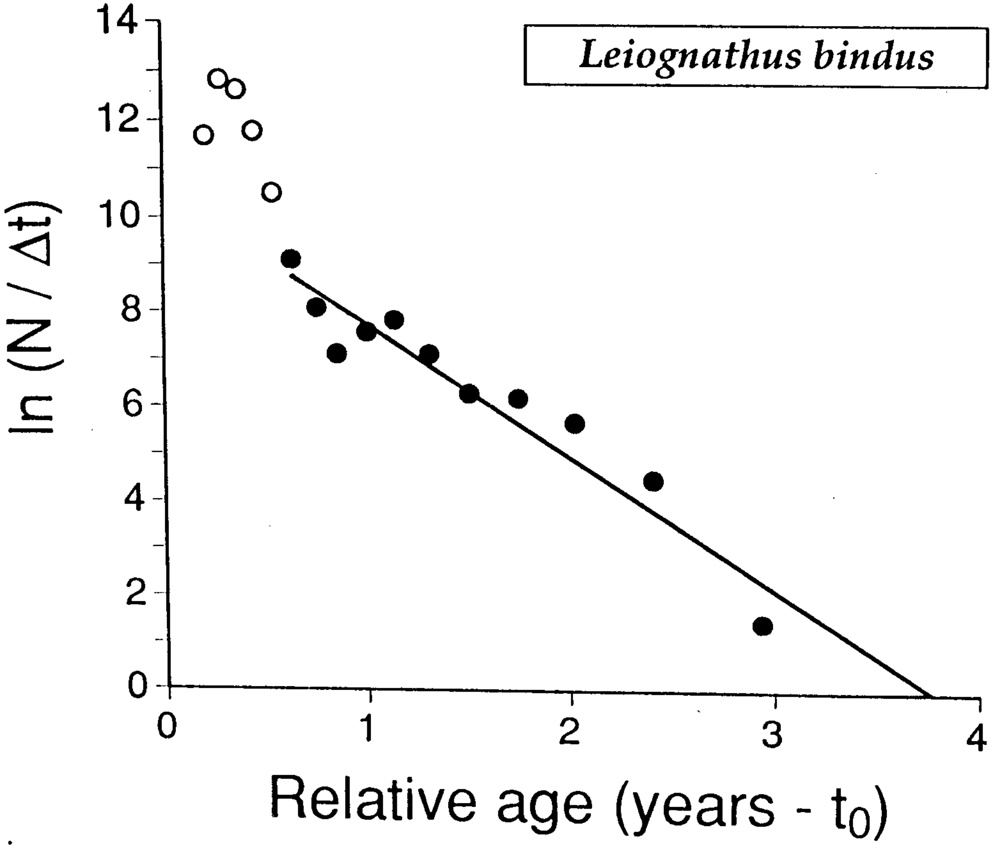

Leiognathus bindus
ln (N / Δt)
14
12
10
8
6
4
2
0
0
1
2
3
4
Relative age (years - t0)

Figure 4b. Estimate of total mortality (Z') from length-converted catch curve for *L. decorus* [Z' = 5.23 (CI = 3.99-6.47)]; filled circles were points used

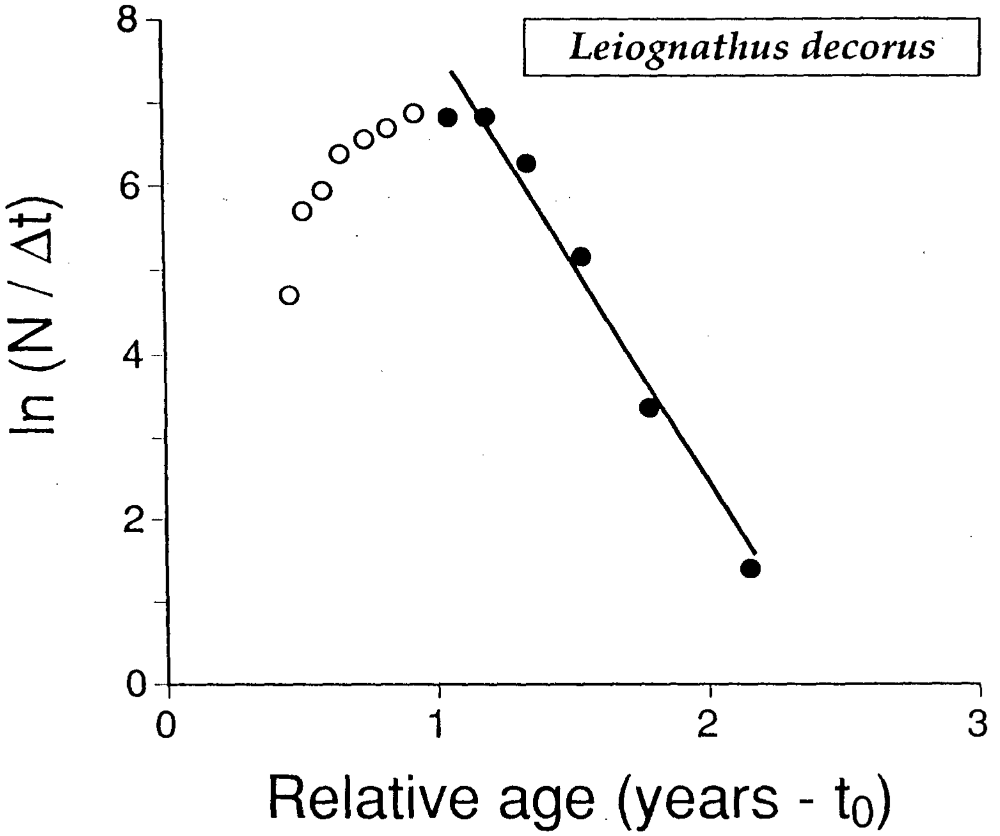

Leiognathus decorus
ln (N / Δt)
8
6
4
2
0
0
1
2
3
Relative age (years - t0)

Figure 4c. Estimate of total mortality (Z') from length-converted catch curve for *L. splendens* [Z' = 3.88 (CI = 3.23-4.53)]; filled circles were points used

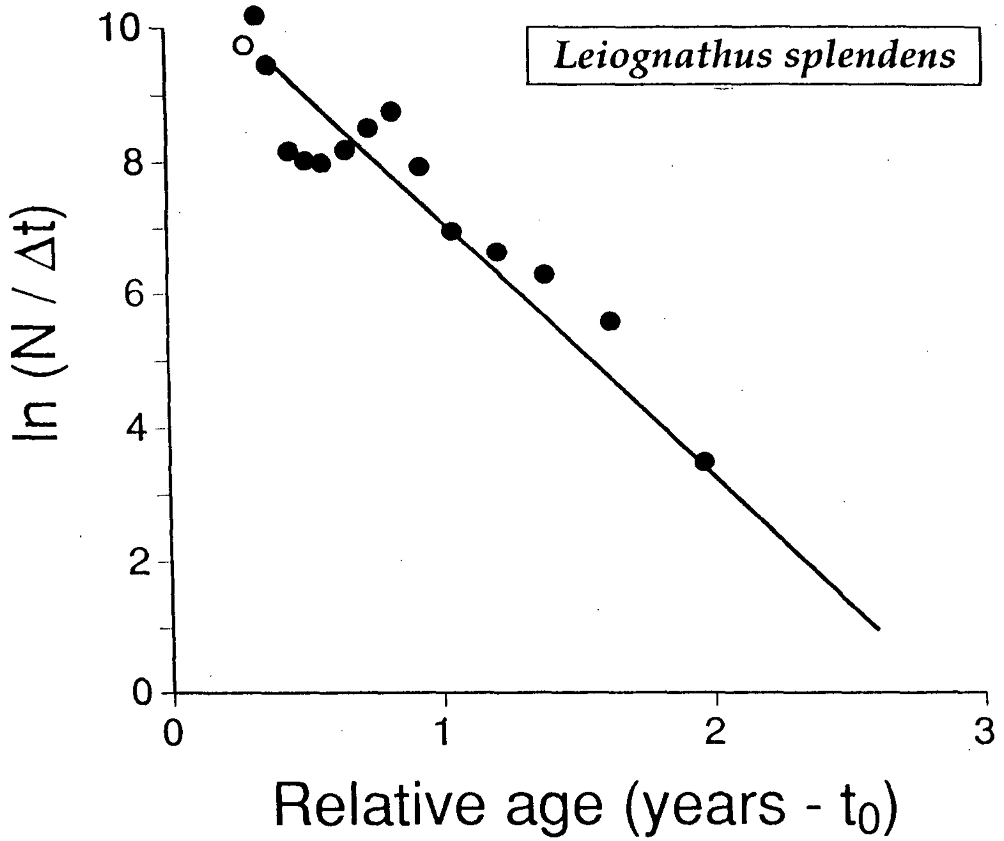

Leiognathus splendens
ln (N / Δt)
10
8
6
4
2
0
0
1
2
3
Relative age (years - t_0)

Figure 4d. Estimate of total mortality (Z') from length-converted catch curve for *S. ruconius* [Z' = 3.67 (CI = 2.81-4.52)]; filled circles were points used

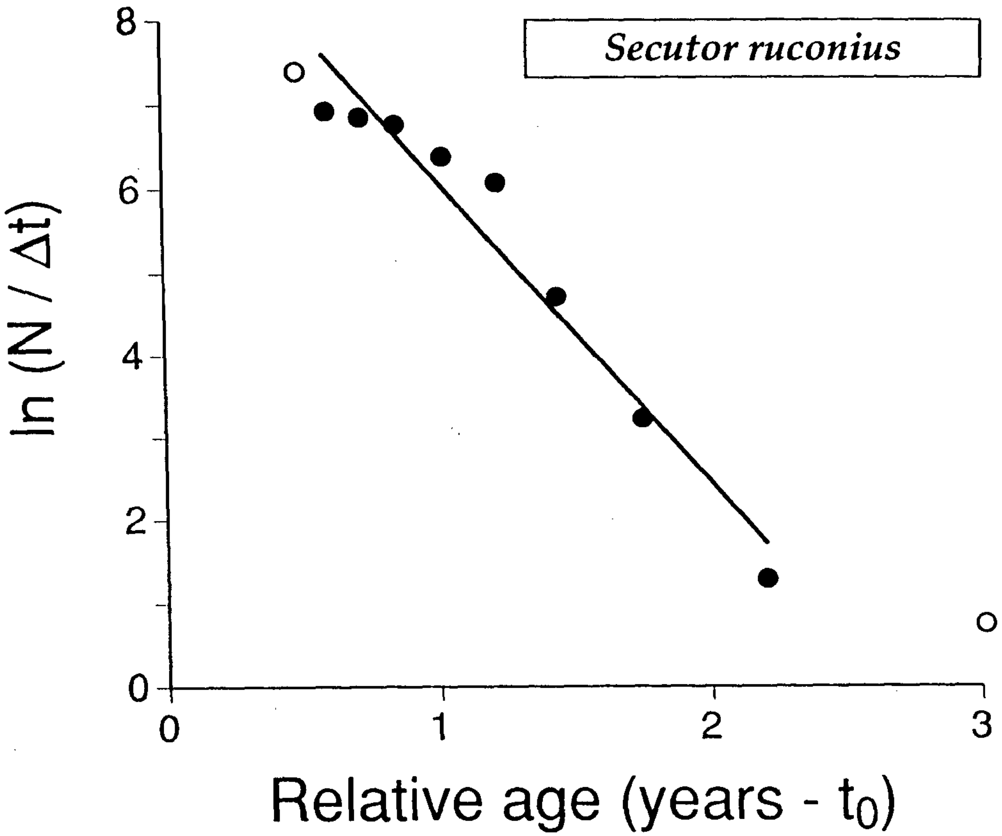

Secutor ruconius
ln (N / Δt)
8
6
4
2
0
0
1
2
3
Relative age (years - t0)

Figure 5a. Percentage distribution of gonadal stages of *Saurida micropectoralis* over time.

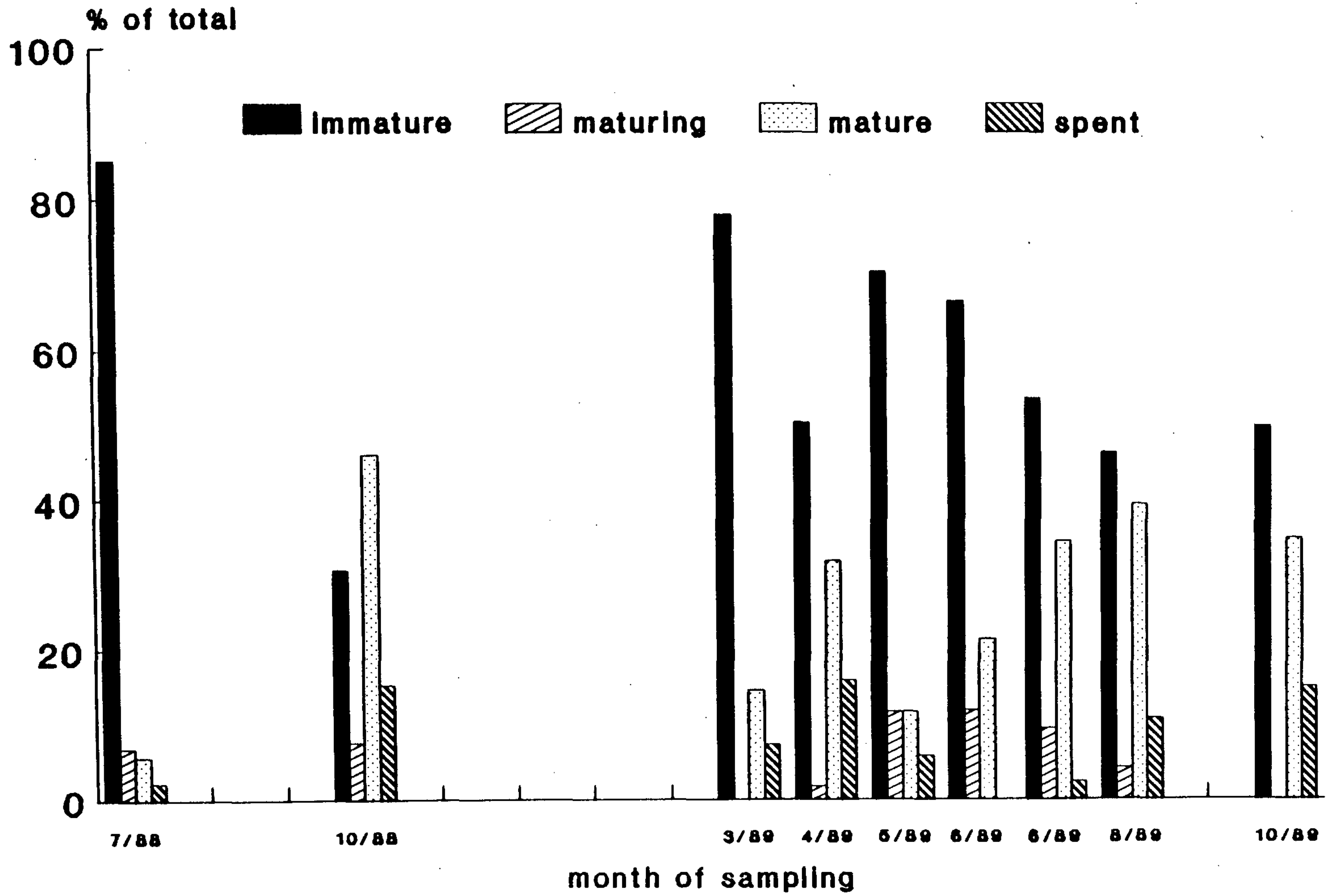

% of total
100
80
60
40
20
0
immature
maturing
mature
spent
7/88
10/88
3/89
4/89
5/89
6/89
6/89
8/89
10/89
month of sampling

Figure 5b. Percentage distribution of gonadal stages of *Saurida undosquamis* over time.

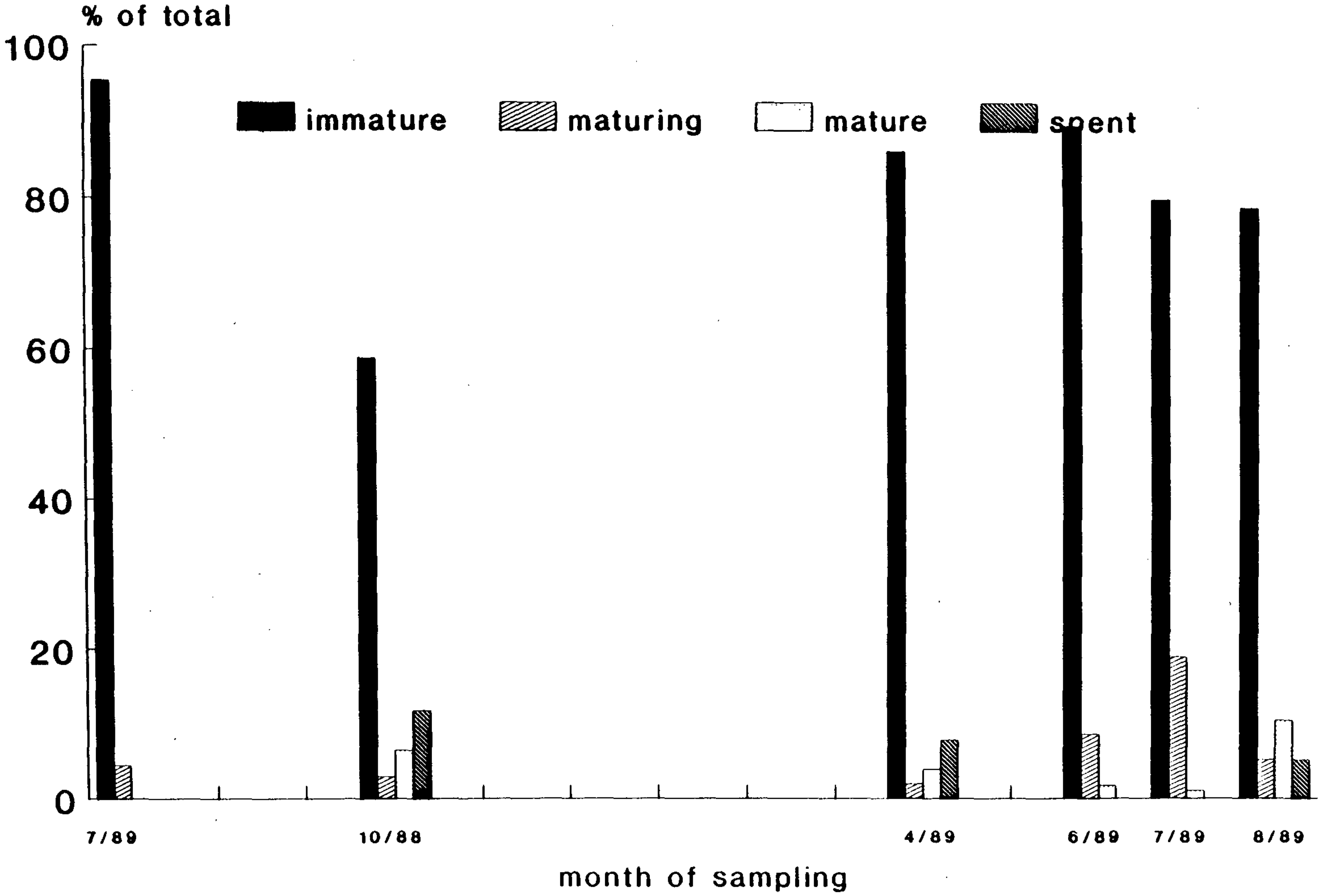

% of total
100
80
60
40
20
0
immature
maturing
mature
spent
7/89
10/88
4/89
6/89
7/89
8/89
month of sampling

Table 1. Results of analyses of variance of the abundance of *Saurida micropectoralis* and *S. undosquamis*; sums of squares were pooled when 'site' and 'trawl' F-ratios were not significant at p = 0.25; subsequent d.f. and F-ratios are underscored; * - significant at p = 0.05.

	A. *S. micropectoralis*			B. *S. undosquamis*		
factor	d.f. of F-ratio	mean square	F-ratio	d.f. of F-ratio	mean square	F-ratio
location	1, 237	180.020	9.035*	1, 39	1622.400	3.288
month	10, 237	127.780	6.413*	9, 39	611.711	1.240
loc. and month	10, 237	931.070	46.728*	9, 39	626.811	1.270
site	43, 194	21.345	1.088*	39, 176	493.433	2.413*
trawl	64, 130	20.758	1.090	58, 118	74.664	0.278
residual	130	19.044		118	268.254	

Table 2. Summary of the significant results of the Student-Newman-Keul's test ($p = 0.05$) for the significant interaction of 'location and month' for *S. micropectoralis*.

A. Significant differences between inshore and offshore locations per month

1. Offshore May 1989 > Inshore May 1989
2. Offshore July 1989 > Inshore July 1989
3. Offshore August 1989 > Inshore August 1989

B. Significant difference between months at the offshore location

1. July 1989 > July 1988
2. July 1989 > October 1988
3. July 1989 > March 1989
4. July 1989 > April 1989
5. July 1989 > May 1989
6. July 1989 > June 1989
7. July 1989 > October 1989
8. July 1989 > November 1989
9. July 1989 > December 1989
10. August 1989 > July 1988
11. August 1989 > October 1988
12. August 1989 > March 1989
13. August 1989 > April 1989
14. August 1989 > June 1989
15. August 1989 > October 1989
16. August 1989 > November 1989
17. August 1989 > December 1989
18. May 1989 > October 1988
19. May 1989 > March 1989
20. May 1989 > April 1989
21. May 1989 > June 1989
22. May 1989 > October 1989
23. May 1989 > November 1989
24. May 1989 > December 1989
25. July 1988 > April 1989
26. July 1988 > June 1989
27. July 1988 > October 1989
28. July 1988 > November 1989
29. July 1988 > December 1989
30. July 1988 > March 1989
31. July 1988 > May 1989

Table 3. Results of the two-factor analysis of variance comparing the percentage of empty stomachs between *S. micropectoralis* and *S. undosquamis* over time (* - significant at p = 0.05).

Factor	d.f. of F-ratio	mean square	F-ratio
month	10, 506	121.000	3.19*
species	1, 506	865.480	22.80*
month x species	10, 406	204.530	5.39*
net	506, 527	37.954	
residual	527		

Table 4. Percentage of empty stomachs (ES) and stomachs with prey (NE) throughout the sampling period. *S. micropectoralis* (left), *S. undosquamis* (right).

	S. micropectoralis			*S. undosquamis*		
Date	ES	NE	n	ES	NE	n
07/12/88	68.13	31.87	91	68.00	32.00	100
10/17/88	67.86	32.14	28	50.00	50.00	60
03/06/89	78.13	21.88	160	77.78	22.22	27
04/06/89	79.59	20.41	98	70.00	30.00	10
05/20/89	73.13	25.88	160	63.21	36.79	106
06/23/89	46.15	53.85	39	80.00	20.00	5
07/20/89	60.29	39.71	68	49.15	50.85	118
08/17/89	73.97	26.03	73	51.85	48.15	108
10/12/89	95.12	4.88	82	76.92	23.08	13
11/08/89	50.00	50.00	32	33.33	66.67	3
12/19/89	25.00	75.00	4	0	0	0
mean	65.22	34.78		62.03	37.98	
s. e.	5.77	5.77		4.87	4.87	
total			835			550

Table 5. Species composition and percentage (in brackets) of prey found in the guts of *S. micropectoralis* and *S. undosquamis*.

Prey item	***S. micropectoralis***	***S. undosquamis***
A. teleost		
1. UID	106 (42.92)	61 (35.26)
2. engraulid	31 (12.96)	13 (7.51)
3. gobiid	24 (9.72)	30 (17.34)
4. leiognathid	19 (7.69)	2 (1.16)
5. larva	17 (6.89)	12 (6.94)
6. eleotrid	10 (4.05)	37 (21.39)
7. saurid	9 (3.64)	6 (3.47)
8. mullid	6 (2.43)	1 (0.01)
9. carangid	5 (2.20)	2 (1.16)
10. clupeid	5 (2.20)	1 (0.01)
11. callionymid	4 (1.62)	0
12. sillaginid	2 (0.01)	1 (0.01)
13. apogonid	2 (0.01)	0
14. cynoglossid	2 (0.01)	3 (1.73)
15. trichiurid	1 (0.01)	0
16. scombrid	2 (0.01)	0
17. pomadasyid	1 (0.01)	0
18. gerreid	0	1 (0.01)
19. lethrinid	0	1 (0.01)
20. uranoscopid	0	1 (0.01)
21. anguillid	0	1 (0.01)
B. invertebrate		
1. penaeid	15 (46.88)	32 (44.44)
2. stomatopod	6 (18.75)	12 (16.67)
3. cephalopod (squid)	5 (15.63)	12 (16.67)
4. cephalopod (octopus)	0	1 (1.39)
5. crab & other crustacea	0	3 (4.17)
6. others	6 (18.75)	12 (16.67)

Table 6. Composition of fish prey found in the guts of *Saurida micropectoralis* and *S. undosquamis* and its percentage of the diet (UID - Unidentifiable prey; n - number of guts containing prey per month per species).

A. *S. micropectoralis* B. *S. undosquamis*

Month (n)	Prey Composition	Percentage of teleost prey	Prey Composition	Percentage of teleost prey
July 1988	gobiid	37.50	eleotrid	21.43
(n = 16, 28)	carangid	18.75	gobiid	28.57
	leiognathid	16.25	leiognathid	3.57
October 1988	no dom. group		no dom. group	
(n = 7, 13)				
March 1989	engraulid	38.89	no dom. group	
(n = 18, 4)	leiognathid	27.78	leiognathid	25.00
April 1989	engraulid	68.75	no dom. group	
(n = 16, 2)	leiognathid	18.75	eleotrid	40.00
May 1989	clupeid	20.00	saurid	30.00
(n = 15, 10)	leiognathid	13.33		
June 1989	gobiid	57.14	no dom. group	
(n = 6, 1)	leiognathid	14.29		
July 1989	saurid	27.27	eleotrid	59.09
(n = 11, 22)			gobiid	27.27
August 1989	no dom. group		eleotrid	44.44
(n = 7, 27)			gobiid	44.44
October 1989	gobiid	45.00	no dom. group	
(n = 20, 2)	leiognathid	20.00		
November 1989	saurid	50.00	no dom. group	
(N = 10, 1)	leiognathid	20.00		
December 1989	no dom. group			
(n = 3, 0)	leiognathid	33.33		

Table 7. Type of prey found in *Saurida micropectoralis* and *S. undosquamis*. Numbers represent percent of diet by length class of *Saurida*.

A. *S. micropectoralis*

type of prey	length class mm			
	1 - 100	101 - 200	201 - 300	301 - 400
fish	73.68	26.33	22.28	25.00
invert	0	3.60	2.51	0
fish & invert	68.42	0.01	0.01	0
unidentified prey	0	0.01	1.67	0
empty stomach	26.32	68.94	73.26	75.00
total guts examined	19	528	359	3.00

B. *S. undosquamis*

fish	44.44	28.40	22.41
invert	5.56	13.99	0.72
fish & invert	0	1.23	0
unidentified food	0	0	0
empty stomach	50.00	56.38	75.86
total guts examined	18	486	

Table 8. Species composition and size of leiognathids found in the guts of *Saurida micropectoralis* and *S. undosquamis* (uid - unidentifiable leiognathid).

A. *S. micropectoralis*

Date	Length of Saurid	Leiognathid Species	Length of Leiognathid
12/07/88	233.00	*L. bindus*	4.39
06/03/89	103.50	uid	postlarva
06/03/89	204.00	*L. splendens*	48.00
06/03/89	165.00	uid	-
06/03/89	193.00	*L. bindus*	35.00
06/03/89	159.00	*L. bindus*	43.00
06/04/89	186.00	uid	46.00
06/04/89	228.00	uid	52.00
06/04/89	222.50	uid	-
20/05/89	200.00	*L. bindus*	51.00
20/05/89	164.00	*L. bindus*	43.00
20/05/89	182.00	*L. bindus*	47.00
12/10/89	239.00	*L. bindus*	62.00
12/10/89	242.00	*L. splendens*	67.00
12/10/89	252.00	*L. splendens*	60.00
12/10/89	27.00	uid	-
08/11/89	201.00	uid	23.00
08/11/89	197.00	*Secutor* sp. +	37.00
		uid	33.00
19/12/89	-	uid	-

B. *S. undosquamis*

06/03/89	162.00	*L. bindus*	38.50
12.07/88	163.00	*L. moretoniensis*	45.00

Table 9. Contribution of two lizardfish species to the natural mortality of leiognathids in Cleveland Bay

Item	*S. micropectoralis*	*S. undosquamis*
% fraction of synodontid biomass	54.3 %	45.7 %
distribution of synodontid-induced M[a]	0.215	0.181
% of overall natural mortality of leiognathid[b]	9.3 %	7.9 %

a) fraction of 0.396 year^{-1}

b) overall estimate = 2.3 year^{-1}

Table 10. Estimates of natural mortality M_l using Pauly's empirical formula (1980) for each species of leiognathid and estimation of biomass-weighted mean M for leiognathids in Cleveland Bay, Townsville, Australia

Species	M_l	Relative biomass[a]
L. bindus	1.9	41
L. decorus	3.3	5
L. splendens	2.4	105
S. ruconius	2.3	7
	2.3 - weighted mean	

a) number per 6,000 m^2, from Chapter III

Table 11. Estimates of total mortality (Z') for leiognathid species, sums (Z) of fishing mortality (F) and natural mortality (M) from Pauly's formula, and estimates of loss due possibly to emigration (I)

Species	Z'	Z	I
L. bindus	2.84	1.904	0.936
L. decorus	5.23	3.304	1.926
L. splendens	3.88	2.404	1.476
S. ruconius	3.67	2.304	1.370

Table 12. Sex ratios of *S. micropectoralis* and *S. undosquamis* over the sampling period.

Date	micro	n	undos	n
07/12/88	0.704:1	75	0.846:1	96
10/17/88	0.474:1	28	0.385:1	54
06/03/89	0.667:1	85		
05/20/89	0.418:1	139	0.590:1	62
06/23/89	0.700:1	334		
07/20/89	0.579:1	60	0.446:1	107
08/17/89	1.345:1	68	0.727:1	95
10/12/89	1.366:1	97		
11/08/89	1.231:1	29		
total		615		414

Table 13. List of predators of leiognathids reported in the literature and in unpublished data.

Species (Family)	Leiognathid-prey	Reference
C. tilstoni (Carcharhinidae)	leiognathids *L. splendens* (?)	Simpfendorfer, pers. comm.
R. acutus	as above	as above
R. taylori	as above	as above
Gymnura poecilura (Gymnuridae)	*Leiognathus*	James, 1966
S. undosquamis (Synodontidae)	*L. klunzingeri*	Vermeij, 1978
S. tumbil	*L. bindus* and *S. insidiator*	Tiews et al., 1972
F. petimba (Fistularidae)	-	Druzhinin, 1977
L. lactarius (Lactaridae)	*Leiognathus* spp.	Apparao, 1966 Venkataraman, 1960
M. cordyla (Carangidae)	*Leiognathus* spp. *G. minuta*	Sreenivasan, 1974
N. macropterus	*Leiognathus*	Ronquillo, 1954 Nakamura, 1936
E. affinis affinis	*Leiognathus* sp.	Ogilvie et al., 1954
P. saltatrix	*S. insidiator* *L. equulus*	Van der Elst, 1976
N. japonicus (Nemipteridae)	*Leiognathus* spp.	Kuthalingam, 1965
P. diacanthus (Sciaenidae)	*Leiognathus* sp.	Suseelan & Nair, 1969
sciaenids	leiognathids	Yap, 1990
U. vittatus (Mullidae)	*Leiognathus* sp.	Thomas, 1969
Trichiurus spp. (Trichiuridae)	*Leiognathus* spp.	Jakob, 1950 James, 1967
T. haemula	*Leiognathus* spp.	Prabhu, 1955
P. erumei (Psettodidae)	*Leiognathus* spp.	Venkataraman, 1944 Devadoss and Pillai, 1973
T. brevirostris (Triacanthidae)	*Leiognathus* sp.	Kuthalingam, 1959

CHAPTER VII

GENERAL DISCUSSION

THE DYNAMICS OF CLEVELAND BAY,
IMPLICATIONS TO MODELLING DEMERSAL ICHTHYOFAUNA AND FISHERIES,
AND SOME DIRECTIONS FOR RESEARCH IN THE FUTURE

I. Major findings

The demersal faunal community of Cleveland Bay, tropical Australia was dominated by teleosts in terms of biomass (Chapter III). The ichthyofauna, at the small spatial scale examined (depth range of study <20 m), was a diverse assemblage of fishes (Chapter III). The most abundant family of fishes was the Leiognathidae, comprising 20 - 46 % of the biomass or 47 % of the numbers of demersal fishes (Chapter III, IV).

The maintenance of a high numrical abundance and biomass of leiognathids in Cleveland Bay, despite the high estimate of mortality due to predation by synodontids (Pisces: Synodontidae; Chapter VI) may be explained by the biological characteristics of these organisms (Chapter IV, V). Leiognathids were found to be short-lived, fast-growing, iteroparous, and fecund (Chapter V; Jayabalan, 1986). In addition, leiognathids reproduce at the time when nutrients are likely to be at the highest levels in the environment (Walter and O'Donnell, 1981; Alongi, 1989). These biological characteristics and the timing of reproduction are some of the factors that contribute to the high numerical abundance and biomass of these organisms.

The fish biomass and leiognathid biomass and density were variable in space (Site, Location) and time (Day, Month; Chapter III, IV). The spatial and temporal variability of leiognathids in Cleveland Bay may be due to their schooling behaviour, local migrations, and variations in the intensity of recruitment and subsequent survivorship of these recruits.

Long-term variability in recruitment could be affected significantly by the predation by synodontids on the recruits of leiognathids (Chapter VI). The reduction in abundance of recruits by predation may influence the size of the adult population substantially. In addition, the cannibalistic behaviour of synodontids could indirectly affect the size of the adult population of leiognathids: the greater the cannibalism on synodontid recruits the smaller the population of adult synodontids preying on leiognathids.

II. The physical environment of Cleveland Bay

The typical habitat of leiognathids is soft-bottom, muddy environments. The terrigenous content of the sediment in Cleveland Bay is about 60-80 % (Maxwell, 1968). The post-glacial rise in sea level 5,500-6,000 years B. P. (Chappell *et al.*, 1983) caused high sedimentation over the Holocene base (beach sand; 6,500 years B. P.) of Cleveland Bay (Carter and Johnson, 1987). However, the origins and quantities of sediment inputs to Cleveland Bay are unclear. The main source of sediments was Ross River with a sediment input of

0.33×10^6 tonnes-y^{-1} (Belperio, 1983). During the mid-Holocene period, Cape Cleveland was probably an island which facilitated the high deposition of sediments from the Burdekin River to the south by long-shore drift and advection up until about 2-3,000 years ago (Carter and Johnson, 1987).

III. Disturbance in and state of Cleveland Bay

The present Cleveland Bay is a typical example of a constantly disturbed environment that is subjected to varied environmental and climatic conditions. Currents from wind-waves generated by afternoon breezes stir sediments on the bottom of the Bay (Dight, 1985). Monsoonal winds intensify this process (Walker and O'Donnell, 1981), particularly the southeasterlies during spring and summer (Alongi, 1989). During the wet-season sedimentation increases due to greater discharges of rivers. Variation in rainfall patterns also determine the annual rate of sedimentation in Cleveland Bay. Flooding as a result of high rainfall has occurred regularly over the last century (Isdale, 1984). In addition, cyclones that bring high rainfall and wave-action occur every 1.36 years during the wet-seasons (Oliver, 1978).

The productivity of Cleveland Bay arises from these natural processes. Nutrients are released into the Bay in terrigenous material by riverine discharges. These nutrients are stored in the bottom sediments. One of the processes by which these nutrients are released is through the constant stirring of the substratum (Dight, 1985; Walker and O'Donnell, 1981). Nutrients are released to the water column in greater amounts during the strong southeasterlies as more nutrients are deposited into the Bay by greater riverine flows. The nutrients (nitrates, phosphates) are used rapidly by microorganisms (Alongi, 1989).

Parallel to these natural processes of disturbance are man-made activities: dredging and trawling. The Platypus Channel for maritime shipping was dredged about 100 years ago. Every year, the Channel was dredged and the sludge dumped into Cleveland Bay. Trawling for research purposes commenced in the 1970's (Stark *et al.*, 1975).

Knowledge of the effects of trawling, or dredging, is limited (Sainsbury and Poiner, 1989). However, excessive trawling in tropical, multispecies demersal environments in Southeast Asia, the North West Shelf (Australia), and the Gulf of Carpentaria (Australia) has been correlated with the alteration of the structure of the bottom and disturbance of the epifaunal communities (Pauly, 1979; Birtles and Arnold, 1988; Sainsbury, 1988; Harris and Poiner, 1990). It can be assumed that trawling would dislocate and resuspend sediment and smother epibiota (Alongi, 1989).

Trawling (and dredging) may enhance release of nutrients for primary production by mechanically scouring the bottom sediments (Alongi, 1989; Hill and Wassenburg, 1990). In addition, there are indications that nutrients may be released from the by-catch (Hill and Wassenburg, 1990). Assuming this is true, the occassional trawling (12 single day trips per year) and dredging (once per year) in Cleveland Bay may have minimal detrimental effect on the substratum and biota.

Thus, the concept of ecological stability in a tropical demersal ecosystem such as Cleveland Bay should be examined closely. The structure of the susbstratum and biota of this demersal ecosystem are constantly being disturbed.

The system is not static (*see* above) but persists within stochastically defined bounds (*sensu* Connell and Sousa, 1983). These disturbances may cause or maintain diversity and abundance of demersal fauna in Cleveland Bay (*sensu* Connell, 1978).

IV. Diversity, Structure, and Biomass of demersal ichthyofauna of Cleveland Bay

The emergent properties of the ichthyofaunal community of Cleveland Bay and comparisons of these properties with other tropical demersal ichthyofauna suggest a stable, unexploited community. (Stability or equilibrium does not preclude variations that occur regularly like climatic factors mentioned above.) Assuming that the demersal communities of Cleveland Bay have reached the stage of equilibrium (if a climax community is naturally achievable at all; Begon and Mortimer, 1986), the characteristics of the community of fishes in the Bay indicate strongly that it is an unexploited community. Diversity of fishes is high (Chapter III) and dominance is partitioned among many species. Many of these dominant species are members of the Family Leiognathidae (Chapter III). The trophic structure is dominated by small zoobenthic feeders and planktivores (Chapter III). Predatory fishes, were relatively low in abundance, but exert a high natural mortality on abundant species (Chapter VI). In addition, the biomass of the community was highly variable in space and time (Chapter III).

Comparison of the ichthyofauna of Cleveland Bay with characteristics of unexploited and exploited tropical demersal fish communities provide further support to the finding that Cleveland Bay is underexploited. Among the characteristics of communities that were found useful in comparing demersal communities in the tropics were dominance, relative abundance, and trophic structure; diversity often appears similar in unexploited and exploited communities. Kulbicki and Wantiez (1990) have shown that density of each trophic group and not species richness was a sensitive measure of change in ichthyofaunal communities. Therefore, comparisons of Cleveland Bay with unexploited and exploited demersal communities will be limited to such characteristics as dominance, relative abundance, and trophic structure.

Unexploited tropical demersal communities are described to be species rich and dominated by *r*-specialists: small fish with short life-span, high reproductive output, and high rates of natural mortality. Meiobenthic feeders (=zoobenthic feeders; including leiognathids) contribute 50-60 % of trawlable biomass (*e. g.*, Warfel and Manacop, 1950; Tiews and Caces-Borja, 1965; Pauly, 1979; Rainer and Munro, 1982; Rainer, 1984). Leiognathids, in particular, could compose 42 % of the biomass or 82 % of the numbers of demersal fishes in an unexploited environment (Kulbicki and Wantiez, 1990).

On the other hand, tropical demersal communities which are highly exploited, *e. g.*, the Gulf of Thailand, San Miguel Bay (Philippines), Malaysia, Samar Sea (Philippines) may still be species-rich but lack certain characteristics of unexploited communities. Species richness was the parameter least sensitive to detection of change in communities (Kulbicki and Wantiez, 1990). A dominant component of the fauna in exploited demersal communities is the cephalopods, consisting of 7-8.2 % of the biomass (Villoso and Hermosa, 1982; McManus, 1986). In the Gulf of Thailand, which was highly exploited, cephalopods dominated the demersal ecosystem (Pauly, 1979). The trophic structure of the ichthyofauna in this Gulf has been characterized by a reduction in abundance of benthic feeders; small prey-species such as leiognathids declined drastically in abundance over a 10-15 year period (Pauly, 1979; Chan and Liew, 1986). In addition, large predatory fishes disappeared and were replaced by small, generalist intermediate predators (*sensu* Pauly, 1979; Villoso and Hermosa, 1982).

The fauna of Cleveland Bay exhibits the characteristics of an unexploited community. The ichthyofauna of Cleveland Bay was species rich and dominated by small prey-species that feed on zoobenthos and plankton associated closely with the bottom (Chapter III). Eight species of leiognathids (Chapter III, IV) dominated this trophic group. Large and intermediate predatory species are common (Chapter VI; Simpendorfer, pers. comm.). The total biomass of the ichthyofauna was high (Chapter III).

It is apparent that the productivity in Cleveland Bay is driven by inputs of nutrients from the terrestrial environment. Leiognathids are capable of availing of this productivity via two pathways: resuspension of nutrients (which leads to phytoplankton production then zooplankton production that leiognathids feed on); or recycled materials (which lead to microbial activity, primary production by filamentous green algae, then to secondary consumers such as benthic and planktonic copepods that leiognathids consume). Furthermore, it can be argued that because leiognathids are the most abundant of the small prey species and can exhibit drastic reduction in densities in exploited, demersal ichthyofaunal communities, they may be useful as an "indicator species" [*e. g*. Gulf of Thailand (Pauly, 1979), Malaysia (Chan and Liew, 1986), Manila Bay (Pauly, 1984), San

Miguel Bay (Pauly, 1982)]. In addition, studies on leiognathids may contribute to elucidating the biology and ecology of a group of abundant and tropical *r*-selected species.

V. Implications of findings to modelling demersal systems and demersal fisheries

There are two approaches in studying biological systems (Gulland and Garcia, 1984). Firstly, to look at individual species and derive generalizations for the whole system (**bottom-up** approach). Secondly, to look at the whole system in terms of trophic levels and energy flow (**holistic** approach; Sainsbury, 1988). The first approach is criticized for being insensitive to species interactions (Gulland and Garcia, 1984). The approach is inherently not aimed at investigating interspecific interactions. However, knowledge of individual species, especially **key-stone** species, is fundamental to the initial understanding of the niche of individual species and to understanding their consequent interspecific interactions.

On the other hand, holistic approaches emphasize properties of the community as a whole. The holistic (cybernetic and trophic level) approaches likewise have limitations in a multispecies system (see review of Sainsbury, 1988). Sainsbury (1988) concluded that "inclusion of spatial and temporal variability, together with competition and predation, in models of communities is a step toward greater biological realism".

This project on the community of fishes and the population dynamics of the most abundant family of fishes in Cleveland Bay has, to a certain extent, employed both approaches to provide a composite view of an unexploited tropical, demersal community. The composition and diversity of the community was studied and then the temporal and spatial variability of the community and its most abundant species. In addition, the population dynamics of species of the most abundant family were investigated. Furthermore, predation on species of this abundant family was investigated, providing information on one interspecific interaction important in the demersal ichthyofauna of Cleveland Bay. This gamut of approaches has provided an empirical basis, albeit incomplete, for the understanding of a tropical multispecies ecosystem.

In addition to the characteristics of the community of fishes in Cleveland Bay, there was high variability in total biomass, leiognathid biomass, and leiognathid densities (Chapter III, IV) at very small spatial and temporal scales (at the level of Site, Location, Month, Day; depth range of study < 20 m). These findings provide additional information that can be used as the basis for managing multispecies fisheries (Sainsbury, 1988). Spatial and temporal variability at different scales are factors known to affect fisheries (Steele, 1984).

Patterns and processes of variability in tropical demersal fish populations have not been well studied (Steele, 1984; Sainsbury, 1988). The total fish and leiognathid biomasses were highly variable, based on systematic sampling at a small scale (daily, site level; Chapter III, IV) such that ecological surveys (*e. g.*, Dredge, 1989a, b; Watson and Goeden, 1989) may have undersampled areas in an effort to describe populations and communities on a large scale. The extremely local variability recorded in the present study implies that ecological surveys which will be the bases of fisheries development and management should be done more rigorously, taking care to replicate adequately at both small and large spatial scales.

Furthermore, estimates of natural mortality of leiognathid populations due to predation (Chapter VI) indicate that predator-prey interactions are an important process that may contribute to variability in the abundances of populations. This finding provides empirical evidence that in unexploited systems, predation may have a strong controlling effect upon the size of prey populations. Thus, in modelling the demersal fish community, studies of distribution and abundance and predator-prey interactions will be necessary to provide a biologically realistic basis for assessing the status of a multispecies fishery (Sainsbury, 1988).

The approach taken in this project has provided data on growth, reproduction, recruitment, biomass (and numerical abundance), and mortality of the most abundant family of fishes in Cleveland Bay. These are the rudimentary data with which the system may be modelled in the future. Thus, this approach taken in this thesis has relevance to modelling and management of exploited populations.

VI. Directions for future reseach

For fisheries science to improve, it has to become more experimental to be able to provide a solid basis for managerial decisions (Larkin, 1978). Secondly, basic research must be conducted by both ecologists and fisheries biologists on the aspects of biology (age determination, growth) and ecology (abundance and variability, interspecific interactions) that are required to manage exploited populations adequately. It was realized a decade ago that ecologists have been slow to investigate these topics (Sale, 1982). In the past decade, there has been a closer association of the two "disciplines" (ecology and fishery biology) on researching vexing questions, especially those pertaining to tropical multispecies fisheries (Sainsbury, 1982; 1984). This association can only improve the science of managing exploited populations by the joining of the strengths of each "discipline" (*e. g.*, sampling and experimental techniques of ecologists, solid demographic research and modelling of fishery biologists).

Many questions can be investigated at the levels of the community, the population, and the individual organism. In addition, several fisheries-related questions can be addressed. The relatively unexploited state of Cleveland Bay, Australia presents a rare opportunity to carry out research on these varied topics.

The tropical demersal ichthyofauna is composed of a diverse assemblage of fishes. It is unknown how this diversity is maintained in an environment that is frequently disturbed naturally or otherwise. Complex interactions of species (competition, predation) are hypothesized to maintain diversity in these multispecific communities (Jones, 1982).

Thus, studies on the diet of demersal ichthyofauna are fundamental to the elucidation of trophic structure and energy flow in the system. At present, knowledge of the food webs of demersal ichthyofaunal communities is sketchy (*e. g.*, Jones, 1982) and at times erroneous, possibly leading to inaccurate interpretation of the trophodynamics of the communities. For instance, leiognathids (an important link in the food chain, being close to primary producers and being prey of piscivores) are believed to feed on detrital material but actually feed on a whole range of benthic and planktonic copepods (in Cleveland Bay; Cabanban, unpub. data).

Many of the processes that determine the niche of demersal organisms are still poorly known. For instance, how do leiognathids feed selectively on epibenthic copepods (mainly cyclopoids, some harpacticoids) in a turbid environment? Do leiognathids have a specialized vision or do they rely heavily on the light produced by the circumesophageal organ? [Preliminary results on the development of the light organ suggest that the latter may be the case because of the development of the light organ at the larval stage (Cabanban and McFall-Ngai, unpub. data)].

The effects of trawling for penaeids and teleosts of commercial importance on the community structure of demersal fishes is poorly known. Pauly (1979) suggested that a shift in the dominance of species occurred caused by the alteration of predator-prey interactions. Sainsbury (1982) proposed that disturbance of the substratum alters the balance of the ecosystem. However, Hill and Wassenburg (1990) speculated that trawling may assist in the release of nutrients by stirring the sediments and via the return of by-catch. If so, perhaps the appropriate question to raise is: At what extent does trawling become detrimental to the community ?

Variability in abundance appears to be a characteristic feature of many species (*e. g.*, leiognathids, synodontids) in the relatively unexploited demersal community of Cleveland Bay. Causes of spatial and temporal variation in abundance of populations still remain unclear (Beddington, 1984). In exploited populations, do changes in the environmental factors or the alteration of interspecific interactions (brought about by the non-selectivity of trawls) contribute more to this variability?

Information on the aspects of biology (growth, mortality, reproduction) which fishery biologists require for managing of multispecific tropical demersal fisheries properly is limited (Sale, 1982). This information, along with data on recruitment, is important in modelling the ecosystem. In particular, it is necessary to gather data on age-structure of fishes in conjunction with length-frequency analysis for a better understanding of growth and mortality. In addition, there is little information on the schooling and migratory behaviour of demersal fishes and how this affects the distribution and abundance of exploited populations.

In tropical soft-substratum ecosystems, benthic and planktonic food chains are closely linked (Alongi, 1989). Nutrient fluxes are low near the substratum which is possibly because of the rapid utilization of these nutrients by benthic microbiota which are in turn eaten by pelagic invertebrate meiofauna and vertebrate macrofauna (Alongi, 1989). It is unknown how trawling could affect the benthic-pelagic coupling of food chains in tropical demersal ecosystems.

Many of these topics appear ecologically oriented. However, information on these topics is fundamental to a biologically realistic management of multispecies fisheries (Sainsbury, 1988).

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Appendix 1. A taxonomic list of species of fishes found in Cleveland Bay on 11 and 12 of March 1989

I. Family Charcharinidae - sharks

1. *Rhizoprionodon acutus* (Rüppell)

II. Family Hemigaleidae - fossil sharks, weasel shark

2. *Hemigaleus microstoma* Bleeker

III. Family Rhynchobatidae - shovel-nosed rays, shark rays

3. *Rhynchobatus djiddensis* (Forsskål)

IV. Family Gymnuridae - butterfly ray, rat-tailed rays

4. *Gymnura australis* (Ramsay and Ogilby)

V. Family Dasyatidae - stingrays

5. *Dasyatis* sp.

VI. Family Clupeidae

6. *Anodotostomata chacunda* (Hamilton-Buchanan)
7. *Dussumiera elopsoides* Bleeker
8. *Herklotsickthys koningsbergeri* (Weber and de Beaufort)
9. *H. lippa* (Whitley)
10. *Sardinella albella* (Valenciennes)
11. *Pellona dayi* Wongratana

VII. Family Engraulidae

12. *Thryssa setirostris* (Broussonet)
13. *T. hamiltoni* (Gray)
14. *Stolephorus indicus* (van Hasselt)
15. *S. nelsoni*
16. *S. devisi*

VIII. Family Chirocentridae - wolf herrings

17. *Chirocentrus dorab* (Forsskål)

IX. Family Synodontidae

18. *Saurida* sp. 2
19. *S. micropectoralis* Shindo and Yamada
20. *S. undosquamis* (Richardson)
21. *S. tumbil* (Bloch)

X. Family Ariidae - catfishes

22. *Arsius thalassinus* (?) (Rüppell)
23. *A. maculatus* (?)

XI. Family
Plotosidae - eel-tailed catfish

24. *Euristhmus nudiceps* (?) (Günther)
25. *Cnigloglanis macrocephalus* (?)

XII. Family Fistulariidae - flutemouths

26. *Fistularia commersonii* Rüppell

XIII. Family Mugilidae - mullets

27. *Mugil cephalus* (?) Linnaeus

XIV. Family Centriscidae - razorfishes or shrimpfishes

28. *Centriscus scutatus* Linnaeus

XV. Family Scorpaenidae - scorpion fishes

29. *Apistops caloundra* (de Vis)
30. *Dendrochirus zebra* (Quoy and Gaimard)

XVI. Family Triglidae - gurnards

31. *Lepidotrigla argus* Ogilby

XVII. Family Platycephalidae - flatheads

32. *Elates ransonetti* (Steindachner)
33. *Platycephalus endrachtensis* Quoy and Gaimard
34. *Suggrundus harrisii* (?) (McCulloch)
35. *S. isacanthus* (?) (Cuvier)
36. *S.* sp. 2

XVIII. Family Serranidae - trouts

37. *Epinephelus sexfasciatus* (Valenciennes)

XIX. Family Teraponidae - Therapon perch, grunters

38. *Terapon jarbua* (Forsskål)
39. *T. puta*
40. *T. theraps* (Cuvier)
41. *Pelates sexlineatus* (Quoy and Gaimard)
42. *P. quadrilineatus* (Bloch)

XX. Family Priacanthidae - bigeyes

43. *Priacanthus hamrur* (Forsskål)
44. *P. tayenus* Richardson

XXI. Family Apogonidae - cardinal fishes

45. *Apogon quadrifasciatus* Cuvier
46. *A. poecilopterus* Cuvier
47. *A. septemstriatus* Günther

XXII. Family Latidae - barramundi perch, sea-bass

48. *Lates calcarifer* (Bloch)

XXIII. Family Sillaginidae - whitings

49. *Sillago sihama* (Forsskål)
50. *S. maculatum burra* Quoy and Gaimard

XXIV. Family Pempheridae - beach-salmon, sweepers

51. *Leptobrama mulleri* Steindachner

XXV. Family Lactariidae - false trevallies

52. *Lactarius lactarius* (Bloch and Schneider)

XXVI. Family Carangidae - trevallies

53. *Carangoides chrysophrys* (Cuvier)
54. *C. humerosus* (McCulloch)
55. C. *buccelentus* Alleyne and Macleay
56. *C. malabaricus* (Bloch and Schneider)
57. *C. talamparoides* (Bleeker)
58. *C. hedlandensis* (Whitley)
59. "*Caranx*" *para* (Cuvier)
60. *Alectis indicus* (Rüppell)
61. *A. ciliaris* (Bloch)
62. *Alepes djedaba* (Forsskål)
63. *Scomberoides commercianus* Lacepede
64. *S. tol* (Cuvier)
65. *Selaroides leptolepis*
66. *Selar crumenophthalmus*
67. *Ulua aurochs* Ogilby
68. *Megalaspis cordyla* Linnaeus

XXVII. Family Formionidae - eyebrow fishes

69. *Apolectus niger* (Bloch)
(= *Parastomateus niger*)

XXVIII. Family Leiognathidae - ponyfishes, slip-mouths

70. *Leiognathus bindus* (Valenciennes)
71. *L. decorus* (de Vis)
72. *L. moretoniensis* (Ogilby)
73. *L. splendens* Cuvier
74. *L. equulus* (Forsskål)

75. *Gazza achlamys*
76. *G. minuta* (Bloch)
77. *Secutor insidiator* (Bloch)
78. *S. ruconius* (Hamilton-Buchanan)

XXIX. Family Lutjanidae - snappers

79. *Lutjanus erythropterus* (Bloch)
80. *L. malabaricus* (Bloch and Schneider)

XXX. Family Nemipteridae - threadfin bream

81. *Nemipterus peronii* ? (Valenciennes)
82. *N. hexodon* (Quoy and Gaimard)
83. *N. mesoprion* (Bleeker)

XXXI. Family Gerreidae - silver biddies

84. *Gerres filamentosus* Cuvier
85. *Pentaprion longimanus* (Cantor)

XXXII. Family Pomadasyidae - grunters

86. *Pomadasys argenteus* (Forsskal)
87. *P. maculatum* (Bloch)
88. *P. kaakan* (Cuvier)

XXXIII. Family Scianidae - jewfishes

89. *Johnius vogleri* (Bleeker)
90. *J. amblycephalus* (Bleeker)
91. *Otolithes ruber*
92. *Nibea semifasciata*

XXXIV. Family Mullidae - goatfishes

93. *Upeneus sulphureus* (Cuvier)
94. *U. sundaicus* (Bleeker)

95. *U. bensasi* (Temminck and Schlegel)
96. *U. luzonius* (Jordan and Seale)
97. *U. moluccencis* (Bleeker)

XXXV. Family Drepanidae - spotted batfishes
(=Ephipphidae, Ephipphididae)

98. *Drepane punctata* (Linnaeus)
99. *D. longimana*

XXXVI. Family Sphyraenidae - barracudas

100. *Sphyraena putnamiae* Jordan and Seale

XXXVII. Family Polynemidae - threadfins

101. *Polydactylus multiradiatus* (Günther)

XXXVIII. Family Callionymidae - dragonets

102. *Callionymus superbus*
103. *Dactylopus dactylopus* (Valenciennes)

XXXIX. Family Siganidae - rabbitfishes

104. *Siganus fuscescens* (Houttuyn)

XL. Family Trichiuridae - hairtails

105. *Trichiurus lepturus* Linnaeus

XLI. Family Scombridae - mackerels

106. *Scomberomorus commerson* (Lacepede)
107. *S. queenslandicus* Munro
108. *Rastrelliger brachysoma* (Bleeker)

XLII. Family Psettodidae - halibuts

109. *Psettodes erumei* (Bloch and Schneider)

XLIII. Family Bothidae - left-eyed flounders

110. *Engyprosopon grandisquama* (Temminck and Schnegel)

111. *Pseudorhombus spinosus* McCulloch
112. *P. arsius* (Hamilton)
113. *P. elevatus* (Ogilby)
114. *P. jenynsii* (Bleeker)

XLIV. Family Soleidae - soles

115. *Dexillichthys muelleri* (Steindachner)

XLV. Family Cynoglossidae - tongue soles

116. *Cynoglossus macrophthalmus* Norman
117. *C. bilineata* (Bloch)

XLVI. Family Triacanthidae - tripod fishes

118. *Pseudotriacanthus strigilifer*
119. *Triacanthus nieuhofi*
120. *Trixiphichthys weveri* (Chaudhuri)

XLVII. Family Monacanthidae - leather jackets

121. *Paramonacanthus filicauda* (Günther)
122. *Monacanthus chinensis* (Osbeck)

XLVIII. Family Tetraodontidae - toadfishes, pufferfishes

123. *Lagocephalus spadiceus* (Richardson)
124. *L. scleratus* (Gmelin)
125. *Torquigener pallimaculatus* Hardy
126. *T. whitleyi* (Paradice)
127. *Chelonodon patoca* (Hamilton-Buchanan)

Appendix 2. Results of the analysis of variance on the biomass of leiognathids collected from July 1988 to April 1990 in Cleveland Bay, Townsville; df - degree of freedom, * - significant at p = 0.05, ** - significant at p = 0.01.

Variate	**df**	**MS**	**F-ratio**	**Result**
Month (M)	12	1.650	16.215	**
Location (L)	1	1.017	9.994	**
M x L	12	0.512	5.037	**
Site	4	0.573	5.630	**
M x S	24	0.198	1.946	**
Trawl	78	0.102	1.837	*
Error	180			

Appendix 3a-h. Results of the analysis of variance on the distribution and abundance of a) *Gazza achlamys*, b) *Leiognathus bindus*, c) *L. decorus*, d) *L. equulus*, e) *L. moretoniensis*, f) *L. splendens*, g) *S. insidiator*, h) *S. ruconius*.

a) *Gazza achlamys*

Variate	**df**	**MS**	**F-ratio**	**Result**
Month (M)	13	6.338	10.238	**
Location (L)	1	2.620	4.231	**
M x L	13	2.660	4.295	**
Site (S)	4	8.868	14.323	**
M x S	52	1.408	2.274	**
Error	80	0.619		

b) *Leiognathus bindus*

Variate	**df**	**MS**	**F-ratio**	**Result**
Month (M)	13	42.246	0.405	ns
Location (L)	1	5.161	0.050	ns
M x L	13	9.526	0.091	ns
Site (S)	4	12.752	0.122	ns
M x S	52	5.453	0.052	ns
Error	80	104.240		

Appendix 3 (continued)

c) *L. decorus*

Variate	**df**	**MS**	**F-ratio**	**Result**
Month (M)	13	9.9	10.833	**
Location (L)	1	14.319	15.668	**
M x L	13	10.211	11.174	**
Site (S)	4	14.352	15.705	**
M x S	52	3.169	3.468	**
Error	81	0.914		

d) *L. equulus*

Variate	**df**	**MS**	**F-ratio**	**Result**
Month (M)	13	5.833	11.094	**
Location (L)	1	0.058	0.110	ns
M x L	13	1.049	1.996	*
Site (S)	4	2.390	4.545	**
M x S	52	0.791	1.504	ns
Error	80	0.526		

Appendix 3 (continued)

e) *L. moretoniensis*

Variate	**df**	**MS**	**F-ratio**	**Result**
Month (M)	13	6.033	9.226	**
Location (L)	1	7.565	11.569	**
M x L	13	4.680	7.157	**
Site (S)	4	2.504	3.830	**
M x S	52	1.018	1.556	ns
Error	81	0.654		

f) *L. splendens*

Variate	**df**	**MS**	**F-ratio**	**Result**
Month (M)	13	21.445	17.218	**
Location (L)	1	2.837	2.278	**
M x L	13	8.061	6.472	**
Site (S)	4	13.368	10.733	**
M x S	52	2.984	2.395	**
Error	80			

Appendix 3 (continued)

g) *S. insidiator*

Variate	**df**	**MS**	**F-ratio**	**Result**
Month (M)	13	3.380	7.004	**
Location (L)	1	0.040	0.078	ns
M x L	13	1.960	4.062	**
Site	4	1.150	2.383	ns
M x S	52	1.143	2.369	**
Error	80	0.483		

h) *S. ruconius*

Variate	**df**	**MS**	**F-ratio**	**Result**
Month (M)	13	17.395	16.535	**
Location (L)	1	0.974	0.092	ns
M x L	13	6.607	6.280	**
Site (S)	4	9.384	8.920	**
M x S	52	2.280	2.167	**
Error	80	1.052		