ASPECTS OF THE BIOLOGY OF GRUNTS (TELEOSTEI : HAEMULIDAE) FROM NORTH QUEENSLAND WATERS.

Thesis submitted by

Terri Malcolm BADE M.Sc.,Dip.Ed.(Qld)

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for the degree of Doctor of Philosophy in

the Zoology Department, School of Biological Sciences, at

James Cook University Of North Queensland.

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ABSTRACT

Three species of haemulid fishes, *Pomadasys kaakan*, *P. argenteus*, and *P. maculatus*, were sampled from two sites, one inshore and one estuarine, in the Townsville region, northern Queensland. Aspects of their biology, with emphasis on feeding, reproduction, growth, and movements were studied.

It was found that all three species were primarily feeding on decapod crustaceans. However, bivalve molluscs and annelids were also important food items for these species at some times of the year.

All three species spawn over a prolonged breeding season, from about August to March, and individuals most probably spawn more than once during that period. There is a major spawning peak in spring (September - November) and a minor spawning peak in late summer/early autumn (February - March).

Two marks were laid down per year on the scales of individuals of *P. kaakan* and *P. argenteus*, corresponding with the times of the two peak spawning periods, but these are not spawning marks *per se*. The timing of mark formation suggests that it may be related to physiological changes or other events associated with reproductive development, and that one is a 'birthday' mark, laid down at the corresponding time of the year when the fish was spawned, and the second during the other peak spawning period. Individuals of *P. maculatus* larger than 100mm total length (TL) generally had a

high proportion of replacement scales, which were not useful for ageing purposes.

Individuals of each species grew rapidly over the first year, with those of *P. kaakan* and *P. argenteus* attaining average lengths of 157mm and 152mm respectively, and of *P. maculatus* an average length of 120mm. Early spawned fish grow larger than these values, due to a longer period of favourable growth conditions after being spawned, while late spawned fish grow slower and reach a smaller size. After the first year, individuals of *P. kaakan* continue to grow rapidly, approaching an estimated asymptotic length of 756mm, and a weight of 5.2kg, after 10+ years. *P. argenteus* may live to about 10 years old, but only reaches an estimated asymptotic length of 481mm and a weight of 1.6kg. Individuals of *P. maculatus* appear to be short lived, attaining approximately 60% of their growth in the first year and approaching their estimated asymptotic length of 203mm after 4 to 5 years. The weights of *P. maculatus* corresponding with the estimated asymptotic length are 143g for females and 127g for males.

Growth patterns determined from length frequency analysis, scale reading and tagging, were in close agreement, and von Bertalanffy growth equations were determined for each species.

Tagging of *P. kaakan* and *P. argenteus* indicated that most individuals of these fishes in the estuarine situation, at least up to 300mm TL, remained close to the tagging sites, with recoveries over periods as long as 517 days providing no evidence for extensive, or regular, movements.

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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 at 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.

T.M.BADE.

1 June, 1989.

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CHAPTER 1 - INTRODUCTION

1.1 GENERAL INTRODUCTION

The family Haemulidae (encompassing the Pomadasyidae of earlier authors) includes as many as 17 genera and 108 species, which inhabit the coastal waters in tropical and subtropical regions of the Atlantic, Indian and Pacific Oceans. The largest number of genera are known from the Pacific coast of America (13 genera, 41 species), followed by the Atlantic coast of America (7 genera, 29 species). The Atlantic coast of Africa and the Indo-Pacific region each have 4 genera, three of which are common to both areas. However the Indo-Pacific region has 33 species compared with 9 species from the former region (Konchina, 1976).

Within the Haemulidae the largest number of species belong to the genus *Pomadasys*, 25 according to Konchina (1976), and this genus is represented by four species in North Queensland waters. These are *P. kaakan* (Cuvier, 1830), *P. argenteus* (Forskål, 1775), *P. maculatus* (Bloch, 1797), and *P. trifasciatus* (Fowler, 1937). As noted below (page 5), however, there is considerable confusion in the literature concerning the taxonomy and nomenclature of three of these species.

The majority of haemulids are shallow water marine or estuarine fishes, though a few species have been recorded from depths greater than 100m (Konchina, 1978). Most are represented by fish attaining 300mm to 600mm in length and many species are important both to commercial and recreational fisheries. Thus, within the genus *Pomadasys* for example, '*P. hasta*' in India makes up 5-10% of total trawl landings (Deshmukh, 1973); *P. commersoni* is the most important fish taken by anglers in the Swartkops estuary in South Africa, both in terms of mass (83% of all fish caught) and numbers (87%), and is the dominant angling fish in all months of the year (Marais and Baird, 1980); and *P. olivaceum* is the third most important fish in terms of the amateur angling catch in Natal, South Africa (Joubert, 1981). The genus *Haemulon* also provides many commercially and recreationally important species in the Americas (Mochek and Silva, 1975; Huntsman, 1976; Darcy and Gutherz, 1984).

In Australia both *P. kaakan* and *P. argenteus* are important species in the recreational fishery. Together these species provide the greatest mass in the catch of most estuarine fishermen in North Queensland, *P. kaakan* being the more important of the two. These species are also taken incidentally by commercial net fishermen and marketed through local retail outlets, either whole or as fillets, but not in sufficient quantities for records of the commercial catch to be kept for Queensland.

As well as *P. kaakan* and *P. argenteus* being common in estuaries the four *Pomadasys* species occur in shallow inshore areas and bays where the smaller sized fish, and particularly *P. maculatus*, are often caught in large numbers by commercial prawn trawlers.

Until recently most of the published literature from overseas concerning the genus *Pomadasys* has been taxonomic, distributional or descriptive. The most pertinent references are Forskål, 1775; Lacepede, 1802; Cuvier and Valenciennes, 1830; Ruppell, 1837; Cantor, 1849; Gunther, 1859; Playfair and Gunther, 1866; Klunzinger, 1870,1879; Bleeker, 1872; Day, 1878; Fowler, 1904, 1925, 1928, 1929, 1931a, 1931b, 1937; Evermann and Seale, 1906; Smith and Seale, 1906; Jordan and Seale, 1907; Gilchrist and Thompson, 1908; Regan, 1908; Seale, 1910, 1914; Fowler and Bean, 1922; Rendahl, 1922; Barnard, 1926; Weber and de Beaufort, 1936; Smith, 1964; Doriaraj, 1970; Gonzalez, 1972; and Wallace, 1975.

Some of the more recent studies have concentrated on the biology of various species within the genus, for example, those of Deshmukh,1973; Hussain and Abdullah, 1977; Van Der Westhuizen and Marais, 1977; Fursa, 1979; Wallace and Schleyer,1979; Warburton, 1979; Joubert and Hanekom, 1980; Joubert, 1981; Abu-Hakima *et al.*, 1983; and Abu-Hakima, 1984.

Most of the Australian literature concerning the genus *Pomadasys* falls into the category of taxonomic or descriptive, with little or no substantiated biological information (Macleay, 1878; Kent, 1893; Stead, 1906; McCulloch, 1929; Whitley, 1950, 1962; Marshall, 1964; Taylor, 1964; Munro, 1967; Carcasson, 1977; Pollard, 1980; Grant, 1982; Leis and Rennis, 1983; McKay, 1984; Gloerfelt-Tarp and Kailola, 1985; Sainsbury *et al.*, 1985).

Until now there has been no comprehensive Australian study of the biology of any of the *Pomadasys* species occurring in local waters, and only a few studies of these species have been conducted overseas. Hussain and Abdullah (1977) studied *P. argenteus* in Kuwaiti waters, concentrating on the length-weight relationship, spawning and food habits, while Abu-Hakima (1984) studied the reproductive biology of *P. argenteus*, also from Kuwaiti waters.

Deshmukh (1973) has given an account of reproduction, growth and feeding in *P. hasta* from Indian waters. However there is some question whether this study referred to *P. argenteus* (of which *P. hasta* is now considered a synonym), due to the confused taxonomy and notable differences in his data compared with those for this species from the present study. It is possible that the species studied was *P. kaakan* (for which *P. hasta* has sometimes incorrectly been applied), to which his data correspond more closely, although it may have been a different but similar species to *P. kaakan*. Namalwar (1974) also refers to *P. hasta* from Indian waters.

Thus, with the possible exception of Deshmukh (1973) and Namalwar (1974), there has been no published biological study of *P. kaakan*, either from Australia or overseas. Similarly there has been no study of *P. trifasciatus*. The other species, *P. maculatus*, has been briefly studied by Naumov (1968, in Konchina, 1978) in the eastern Indian Ocean and very briefly by Basheerudin and Nayar (1962) in Indian waters.

The present study was undertaken in recognition of a need to provide biological information on *Pomadasys* species, which form a major component of the recreational fishery and a small part of the commercial fishery in coastal areas of North Queensland.

Ecologically, they constitute an abundant group within the inshore and estuarine fish communities and are of particular interest in relation to the possible impacts of destruction of 'trash fish' during prawn trawling operations, of which they form a substantial part. The information sought in the project, concerning feeding, reproduction, movements and growth, was considered essential for the future management of this fishery resource and, at the same time, achievable within the scope of an individual Ph.D. programme.

1.2 TAXONOMY

The taxonomy of the species of *Pomadasys*, and of the Haemulidae in general, has been confused. This applies especially to the forms occurring in the Indo-West Pacific region. Factors that have contributed to this confusion are the morphological similarity of most of the species and the colour patterns, which, although useful for some species diagnoses in freshly dead specimens, may be variable in intensity and less distinctive in live specimens or lost in preserved ones.

Five species of *Pomadasys* are recorded from Australian waters. These are *P. kaakan* (Plate 1), *P. argenteus* (Plate 2), *P. maculatus* (Plate 3), *P. trifasciatus* (Plate 4), and *P. auritus*. It is very doubtful, however, whether *P. auritus*, recorded from Australia from only one specimen "found floating 'half dead' in Newcastle harbour, early in July 1948" (Whitley, 1950) represents a local species. This species has also been recorded from Thailand, Malaysia and Singapore (McKay, 1984).

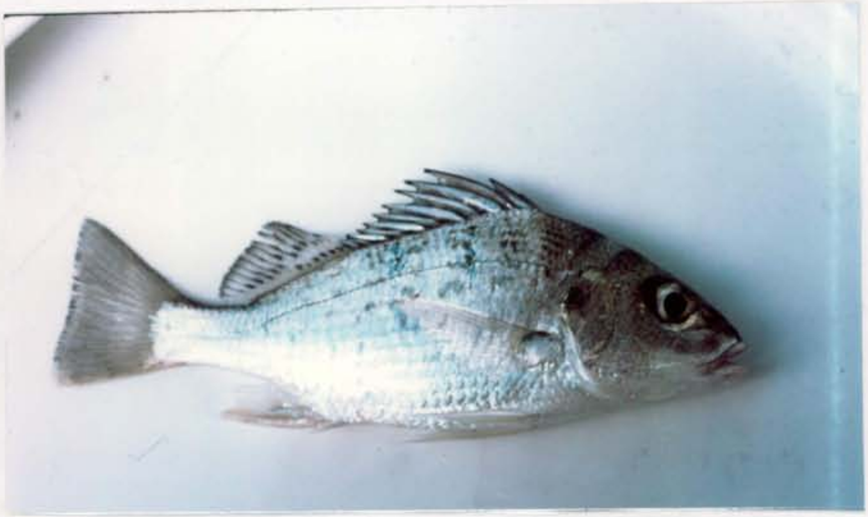

Plate 1. *Pomadasys kaakan* (198mm TL).

Plate 2. *Pomadasys argenteus* (203mm TL).

Plate 3. *Pomadasys maculatus* (160mm TL).

Plate 4. *Pomadasys trifasciatus* (120mm TL).

The four other species recorded from Australia occur in the study area and all are morphologically similar. The main differences between them are in adult size and colour pattern, though these features are even quite similar in the two largest species.

Pomadasys kaakan (Cuvier, 1830) is the largest and most common species in local estuarine and inshore areas. It has approximately 10 vertical bars on the body, each being composed of small blotches of dark pigment about the size of a scale or a little larger.

Pomadasys argenteus (Forskål, 1775) is the other large species. It is characterised by having numerous small spots of pigment, each being smaller than the size of a scale and usually arranged to suggest narrow horizontal lines or a profuse speckling, restricted to the upper two thirds of the body. At times, though, the pattern on live fish of this species may resemble a few broad vertical bars or blotches.

P. argenteus is often referred to locally as the 'golden grunter' because it generally has yellowish pelvic and anal fins and in estuaries often has a golden sheen to the body. However, *P. kaakan* may also have a pale yellow tinge to the anal and lower caudal fin in some specimens, rather than the normal white, and often also has golden colouration around the head in larger specimens from the estuaries. On a few occasions, specimens have been caught which exhibit a mixture of characteristics of these two species. Since both spawn at the same time of the year and in the same place (see Reproduction chapter) it is possible that these fish were natural hybrids.

Much of the taxonomic confusion in the Australian literature relates to the variable use of *P. hasta* and *P. opercularis* for *P. kaakan* and *P. argenteus*. Thus, for example, Macleay (1878), McCulloch (1929), Rendahl (1922), Whitley (1962), Munro (1967), and Pollard (1980) used *P. hasta* for *P. argenteus*, whereas others, such as Marshall (1964), Carcasson (1977), and Grant (1982), have used *P. hasta* for *P. kaakan* and *P. opercularis* for *P. argenteus*.

Neither *P. hasta* nor *P. opercularis* are valid names for Australian fish. *P. hasta* (Bloch) is a junior synonym of *P. argenteus*. *P. opercularis* (Playfair) is a junior synonym of *P. commersoni*, which is found in the western Indian Ocean and differs from *P. argenteus* in having 9½ anal rays instead of 7½ (McKay, 1984), and having spotting on the head and snout as well as on the body.

Pomadasys maculatus (Bloch, 1797), one of the two smaller species occurring in the study area , is readily recognised by the few large dark blotches on the body, and as such has escaped the confusion associated with the larger species, even though this species has a wide distribution throughout the Indo-West Pacific region.

The other small species occurring in North Queensland has been referred to in the Australian literature as *Pomadasys argyreus*, but in a recent revision of the group McKay (1984) indicates that the local species is *Pomadasys trifasciatus* (Fowler, 1937). He notes that *P. trifasciatus* has a pigmented gut lining which distinguishes it from the very similar *P. argyreus* that occurs further to the north around New Guinea. While the local fish does have a pigmented gut lining, fresh specimens often lack the obvious banding indicated by Fowler (1937), and appear uniformly silver below and grey above, with a dark spot on the operculum.

CHAPTER 2 - SAMPLING SITES AND GENERAL METHODS

Two sampling sites were selected for collection of fish and data: (a) Cleveland Bay, a large relatively shallow bay immediately adjacent to Townsville (19° 15'S; 146° 50'E) and partly protected by Magnetic Island; and (b) Barramundi Creek, a moderate sized estuarine system approximately 70km by road south of Townsville (see Figs. 1 and 2).

Site (a) - Cleveland Bay:

This site was chosen for trawl sampling since earlier work (N. Milward, pers. comm.) had shown four species of *Pomadasys* to be available in the area, and also because of its proximity to Townsville and ease of access by the James Cook University's Research Vessel "James Kirby", which is based at Townsville. The R.V. "James Kirby" is a 17 metre steel hull vessel, rigged during this study with a single 6 fathom otter trawl of 30 mm body and cod end mesh size.

Trawl sampling was carried out for one day per month on a regular basis from January 1981 to December 1982. Water depth varied from approximately 3m to 10m in the trawling area and trawls were each of 20 minutes duration. Surface water temperature and salinity were recorded on each sampling trip

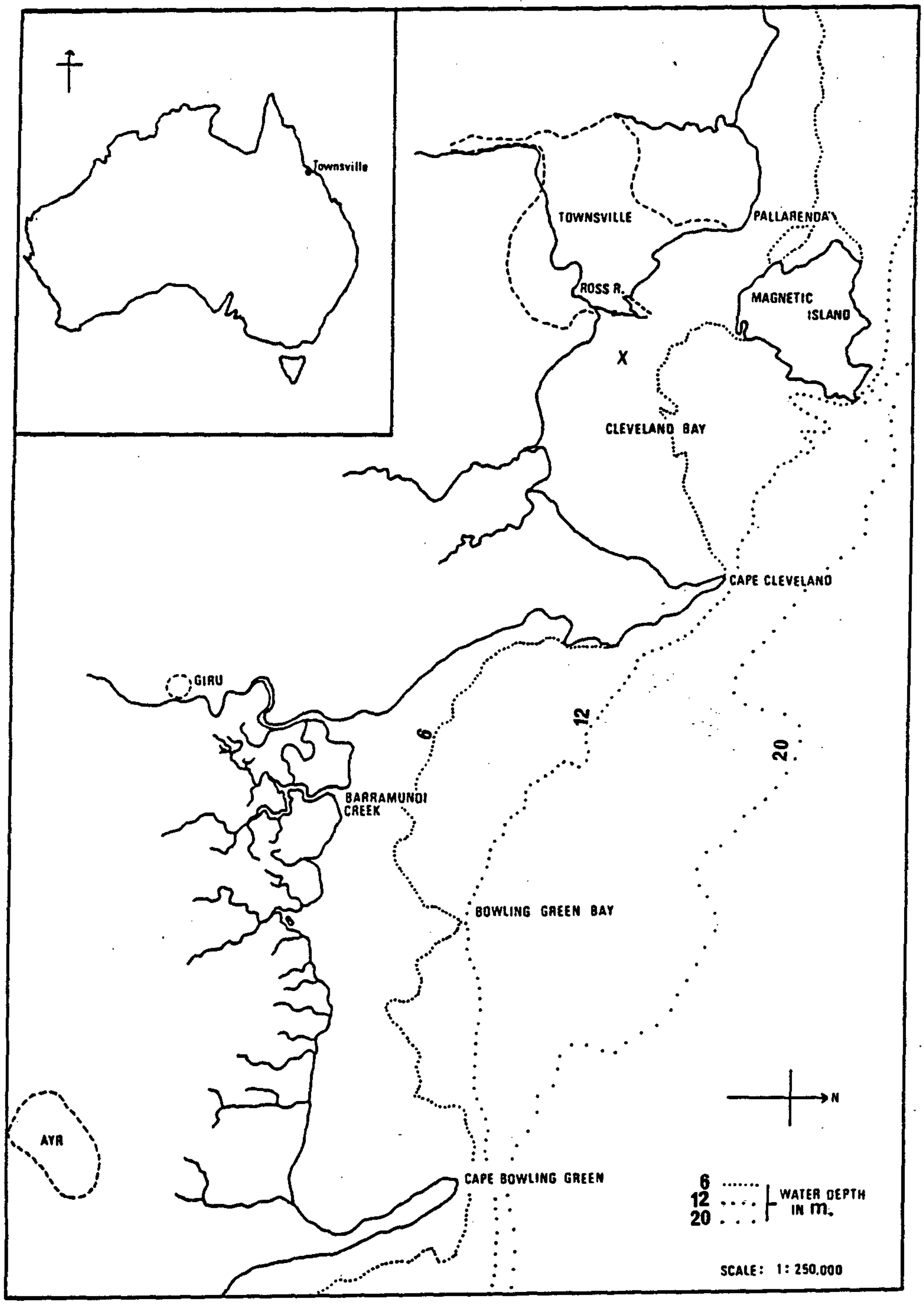

Fig. 1. Map showing the relationship of the study sites, (a) Cleveland Bay and (b) Barramundi Creek, to Townsville. ('x' indicates the position in Cleveland Bay where salinities and temperatures were recorded).

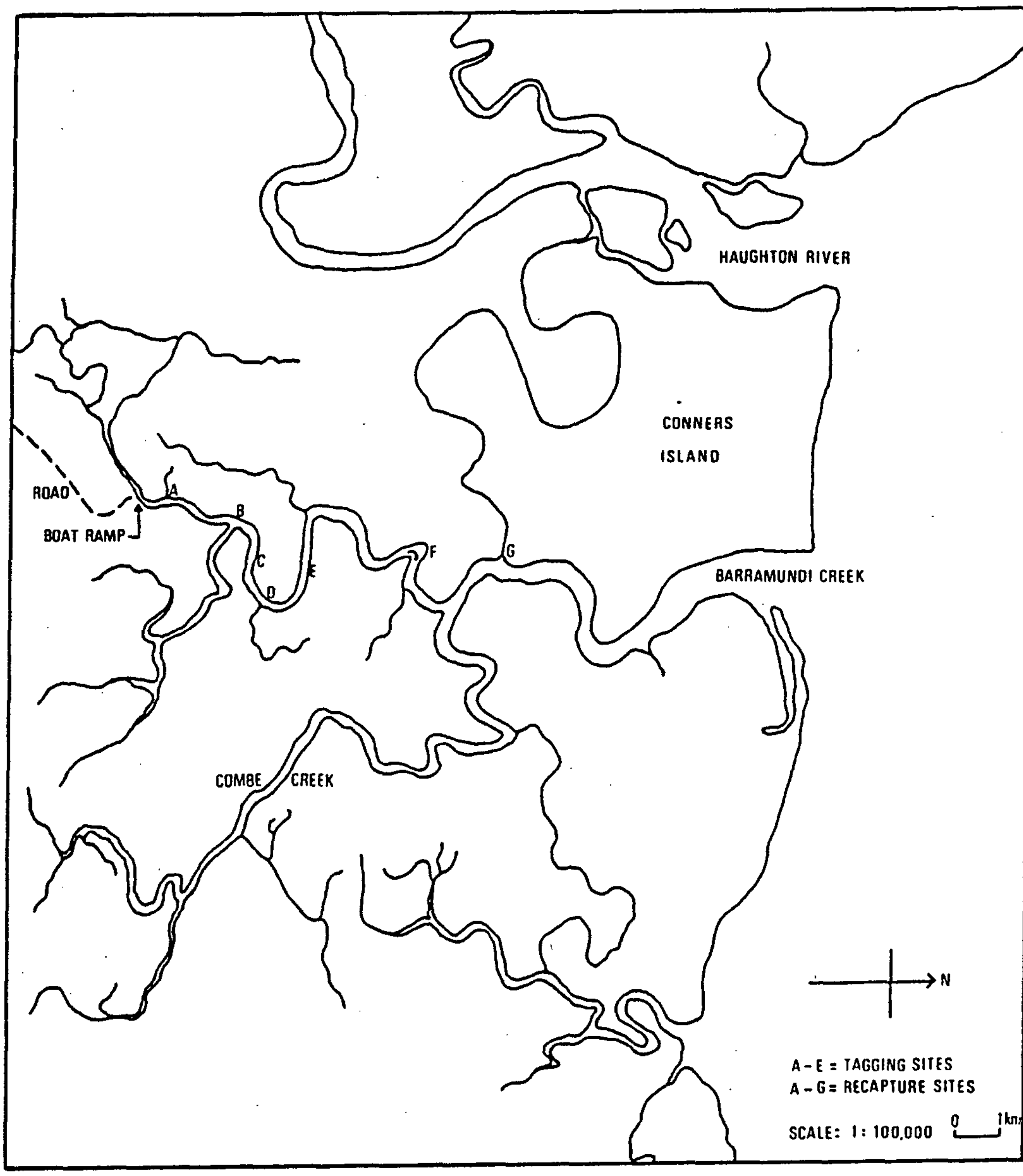

Fig. 2. Map of the Barramundi Creek (site b) sampling area, showing tagging and recapture sites.

After each trawl the catch was sorted and most *Pomadasys* material was immediately stored in freezers on board the vessel. At the end of the day samples were taken back to the laboratory, where each fish was measured in total length, length to the caudal fork, and standard length, using a fish measuring board calibrated in millimetres; then weighed to the nearest gram using a Sartorius model 2200 top pan balance. The abdominal cavity of each fish was opened and the sex and gonad stage were recorded following macroscopic examination. A number of fish from each monthly catch were selected for age studies, and scales and sagittal otoliths were removed from these fish. Scales were mounted between two glass microscope slides which were then bound at the ends with adhesive tape. Otoliths were stored dry in small paper envelopes. Both the scales and otoliths were labelled with the identifying number given to each specimen.

Gut contents were removed from some freshly killed fish of each monthly sample and preserved in 5% formalin for later study. Gonads were also taken from fish of each monthly sample and preserved for later histological examination.

Site(b) - Barramundi Creek:

This site was chosen because of its accessibility for most of the year, presence of only one boat launching ramp (and therefore effectively a single point of access), and because usage of the area by fishermen was moderately high. It was anticipated that the latter would assist with recoveries during the tagging program.

At the Barramundi Creek site, sampling was conducted by line fishing from a 3.6m aluminium dinghy, the method primarily being used to obtain fish in good condition for tagging. Only apparently undamaged fish were tagged and released; any that were obviously injured or stressed during capture were retained. The latter were chilled and taken back to the laboratory where they were measured and weighed and the sex and gonad condition recorded. Scales and otoliths were then removed as for the Cleveland Bay fish. Gonads for histological study, and gut contents, were removed and preserved in the field from a sample of the catch.

Sampling at Barramundi Creek was undertaken bimonthly from June 1981 to December 1984, and on a monthly basis during 1985. Most of the sampling took place in a small section of the estuary, between approximately 1km and 6km downstream from the boat ramp, and usually at particular sites within this area designated site A, site B, etc. (Fig. 2). Occasionally intermediate sites were also sampled if insufficient fish were obtained at the regular sites. Sampling was generally conducted from the last quarter of the ebb tide to the full tide. Plate 5 shows the typical habitat at Barramundi Creek.

Water temperature and salinity were recorded at a site in Cleveland Bay, approximately 1.5km offshore and 2km east of the Ross River mouth, (marked 'x' in Fig. 1), and at site B in Barramundi Creek (Fig. 2). Temperature measurements and water samples for salinity determination were taken from about 0.5m below the water surface (the water at both sites being less than 5m deep and

Plate 5. Typical habitat at Barramundi Creek, sampling site (b).

well mixed). Water temperature was measured using a mercury thermometer; salinity was determined using an optical salinometer.

Three of the four species of *Pomadasys* occurring in the study area, *P. kaakan*, *P. argenteus*, and *P. maculatus*, were examined in detail in the present study. The fourth species *P. trifasciatus*, which mainly occurs further offshore, was only sampled occasionally and in small numbers from Cleveland Bay and not at all from Barramundi Creek, and was, therefore, not included in the study.

CHAPTER 3 - GENERAL RESULTS

Water temperature and salinity values recorded monthly for Cleveland Bay over 24 months (1981 and 1982) are presented in Figs. 3 and 4 respectively, while water temperature and salinity values recorded monthly for Barramundi Creek over 24 months (1984 and 1985) are presented in Figs. 5 and 6 respectively.

Marked seasonal changes in water temperature occurred in Cleveland Bay (Fig.3), with the highest temperatures (approximately 29°C to 34°C) occurring from December to March and the lowest (approximately 19°C to 22°C) from June to August. The patterns of change were similar in the two years sampled, with little variability (mostly less than 2°C) between corresponding months in each year. The annual temperature range was approximately 12°C in both years. Similarly, in Barramundi Creek (Fig.5), the highest water temperatures occurred from December to March (approx. 30°C to 34°C) and the lowest water temperatures occurred from June to July (approximately 18°C to 19°C). Again there was little difference in the temperatures for the same months in the two years, but the annual range was slightly greater compared with Cleveland Bay in 1981 and 1982, being 13°C in 1984 and 15°C in 1985.

The salinity of the water in Cleveland Bay (Fig. 4) remained much more constant over a 12 month period than that at Barramundi Creek, as might be expected. In Cleveland Bay the salinity ranged from a low of 24°/oo in January 1981 (during the wet season) to a high of 38°/oo in September 1981 (the end of the dry season). In

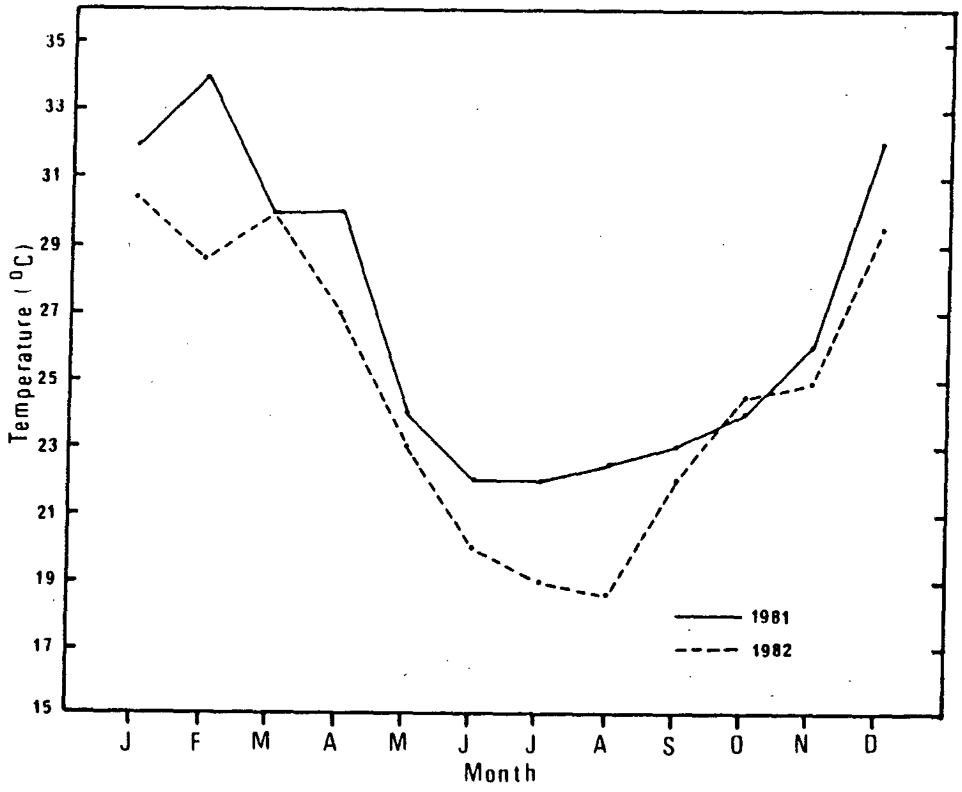

Fig. 3. Temperature of near surface water for Cleveland Bay over 24 months (1981 and 1982).

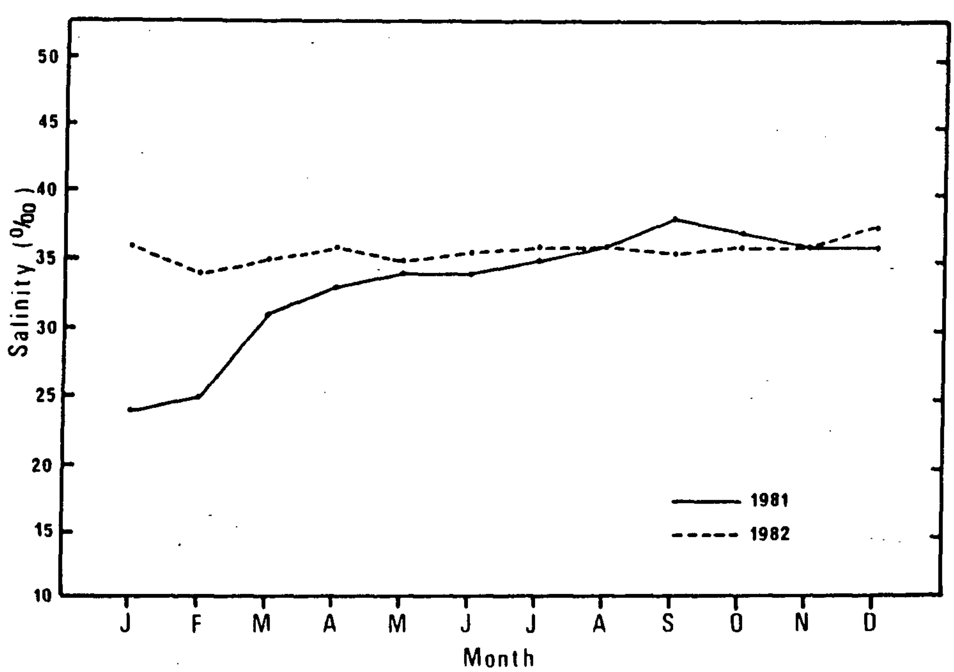

Fig. 4. Salinity of near surface water for Cleveland Bay over 24 months (1981 and 1982).

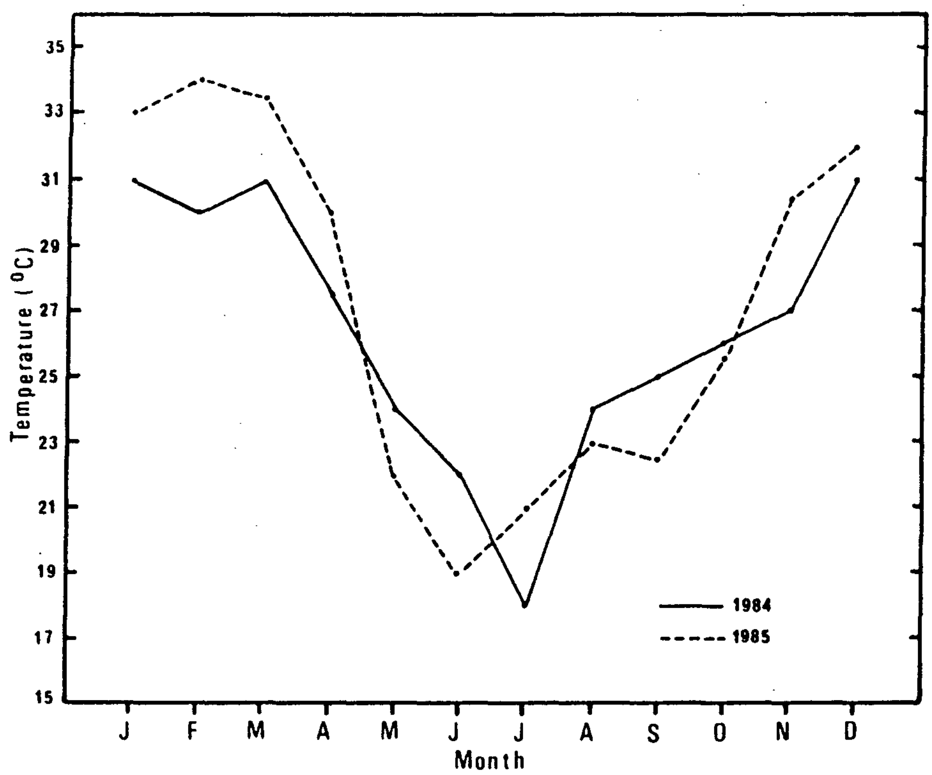

Fig. 5. Temperature of near surface water for Barramundi Creek over 24 months (1984 and 1985).

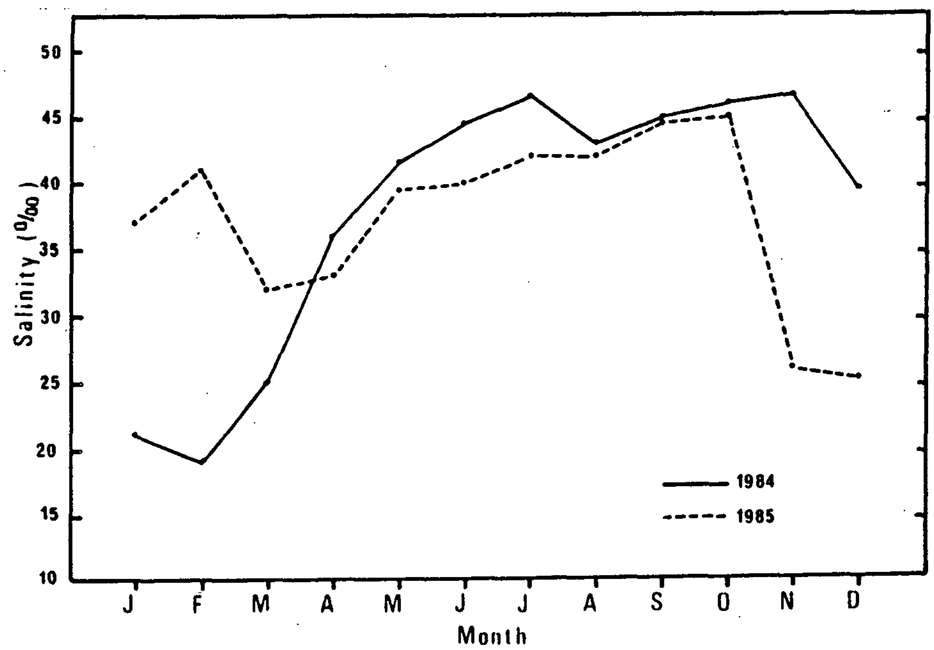

Fig. 6. Salinity of near surface water for Barramundi Creek over 24 months (1984 and 1985).

1982 the salinity remained close to 35°/₀₀ throughout the year due to failure of a marked wet season.

For Barramundi Creek (Fig. 6), seasonal variation in salinity was much greater, with a low of 19°/₀₀ in February 1984, and a high of 47°/₀₀ in both July and November 1984. During the dry months (May to October/November), salinities were consistently above 40°/₀₀. It should be noted, however, that records taken in Barramundi Creek coincided with two years of relative drought, with poor wet seasons. In years of heavier rainfall and flood conditions, the salinity would be expected to fall much lower than the recorded 19°/₀₀ during the summer months.

The habitat of the Barramundi Creek sampling sites consisted of muddy banks lined with mangroves, primarily *Avicennia marina* (see Plate 5). As the water in the creek at these sites was typically quite turbid, there was no gross underwater vegetation apart from mangrove pneumatophores covered at high tide. The intertidal muddy banks were often covered with a thin layer of ephemeral green algae during the winter and spring months.

The Cleveland Bay sampling sites included a variety of habitat types, though predominantly the bottom was muddy with patches of shell rubble, isolated stands of the gorgonian *Solenocaulon grandis*, and sea grass beds.

CHAPTER 4 - FOOD AND FEEDING

4.1 INTRODUCTION

Most species of Haemulidae are zoophages, though at least seven species are euryphages with algae forming some part of the diet (Konchina, 1978). In most *Pomadasys* species, it has been noted that crustaceans form the commonest food item (Venkataraman, 1961; Deshmukh, 1973; Hussain and Abdullah, 1977; Van Der Westhuizen and Marais, 1977; Blaber, 1980; Joubert and Hanekom, 1980). Many of these reports also noted the high percentage of empty stomachs in sampled specimens. Deshmukh concluded that the high percentage of empty stomachs may be attributed to intermittent feeding by the fish. However it was noted that the intestine often contained recognisable food items. He found that adult *'P.hasta'* (? = *P.kaakan* - see Taxonomy section) larger than 180mm fed mainly on *Squilla*, prawns and crabs, but also on teleosts. Fish less than 180mm fed mainly on amphipods and small *Squilla*.

Of 163 stomachs of *P.argenteus* examined by Hussain and Abdullah (1977), 124 were empty and of the remainder, 59% contained crabs, 20.5% contained shrimps and 20.5% contained fish. It was concluded that *P.argenteus* feeds mainly on benthic crustaceans in Kuwaiti waters.

Van Der Westhuizen and Marais (1977) examined the stomach contents of *P.commersoni* by the occurrence method in South Africa. In 92 stomachs examined containing food they found crustaceans to be the most important food item, occurring in 94% of the stomachs, while molluscs occurred in 28% and annelids occurred in 22% of stomachs. No differences were found in the diets of fish of different size ranges. Blaber (1984) found that *P. commersoni* fed mainly in the morning and at dusk in South African waters and that there was resource partitioning between *P. commersoni* and the sparid *Rhabdosargus sarba*, which had a similar diet and inhabited the same area.

In a study of *P. olivaceum* in South Africa, Joubert and Hanekom (1980) examined 54 stomachs of juveniles of that species and found 74.4% to be empty. No marked seasonal variation in food consumed was observed and, as with other studies, crustaceans formed the bulk of the food items. In the adults, crustaceans comprised 75.7% of the diet with stomatopods being dominant.

A high frequency of empty stomachs was noted by Kimura (1981) in his study of the haemulid *Parapristipoma trilineatum* in Japanese waters and it was noted that empty stomachs occurred more frequently in samples collected by line fishing than in samples collected by set net.

In the present study the gut contents of *P. kaakan*, *P. argenteus* and *P. maculatus* were examined to determine the frequency of occurrence of various contained food items, in order to ascertain usage of particular food types in the local area. The dentition of these fish suggested that they could be generalist feeders capable of handling a variety of foods.

4.2 METHODS

Samples of larger fish (>150mm TL for *P. kaakan* and *P. argenteus*, and >100mm TL for *P. maculatus*) for gut content analysis were collected monthly from Cleveland Bay by trawling and from Barramundi Creek by line fishing. Smaller fish (50 - 100mm TL for *P. kaakan* and *P. argenteus*, and 25 - 75mm TL for *P. maculatus*) were collected by beach seine at Pallarenda, on the north-western shore of Cleveland Bay. The procedures followed were logistically designed to most adequately provide both live and preserved samples for the various requirements of the study. They also avoided the use of nets in enclosed estuarine waters, partly in order to maintain the goodwill of recreational fishermen in the belief (not vindicated) that their assistance would be essential for the success of the tagging programme.

Gut contents, both from the stomach and intestine, were removed in the field and preserved in 5% formalin. A high proportion of guts examined were almost totally empty, so only guts with obvious contents were collected. The gut contents of other species collected from the area were also examined whenever feasible, but this was not possible on a routein or comprehensive basis.

The gut contents were examined in the laboratory using an Olympus SZ stereo dissecting microscope. For each gut examined, the occurrence of particular food types, as well as an approximate proportion of the volume of contents determined visually, was recorded. Food items were identified to the lowest taxon possible but since most food items were well processed by the pharyngeal teeth pads of the fish, few items could be identified to species level and most were identified to class, order or sub-order level for the purpose of this study.

4.3 RESULTS

Table 1(a) shows the percentages of guts of larger fish containing particular food items for each of the species studied. For *P. kaakan*, 120 gut samples were examined from Cleveland Bay fish and 56 from Barramundi Creek fish. For *P. argenteus*, 80 gut samples were examined from Cleveland Bay fish and 36 from Barramundi Creek fish. *P. maculatus* was only caught in Cleveland Bay and 106 gut samples from larger fish of this species were examined. Table 1(b) shows the percentage of guts containing particular food items for 30 smaller fish of each species. These were all collected from Cleveland Bay, as fish smaller than 100mm TL were rarely caught by line fishing at Barramundi Creek.

From these tables it can be seen that all three species eat a relatively wide range of foods, but crustaceans, molluscs and annelids make up the most important food groups. However, the proportions of the various food items varied for the different species and at different sites. Also, while proportions of various food groups were similar for larger and smaller fish they differed in make-up of items, as might be expected, with smaller fish

Table 1(a): Gut contents of *Pomadasys kaakan* and *P. argenteus* (larger than 150mm TL) from two sites and *P. maculatus* (larger than 100mm TL) from one site, expressed as percentage of guts containing particular food items. (Classification of invertebrate food items after George and George, 1979)

Taxon of food item	*P. kaakan* Cleve	*P. kaakan* Barra	*P. argenteus* Cleve	*P. argenteus* Barra	*P. maculatus* Cleve
Ph. SARCODINA					
Cl. Rhizopodea					
O. Foraminiferida	1	-	2	-	4
Ph. PORIFERA	1	-	-	-	-
Ph. SIPUNCULA	7	6	2	-	1
Ph. ANNELIDA					
Cl. Polychaeta	18	12	50	6	62
Ph. CRUSTACEA	96	87	61	50	64
Cl. Ostracoda	-	-	4	-	2
Cl. Cirripedia	1	2	-	-	-
Cl. Malacostraca					
O. Stomatopoda	28	4	3	-	4
O. Mysidacea	3	1	1	-	8
O. Tanaidacea	-	-	-	-	1
O. Isopoda	1	-	1	-	-
O. Amphipoda	2	1	6	11	35
O. Euphausiacea	1	-	-	-	-
O. Decapoda					
S.O. Natantia	58	69	26	39	18
S.O. Reptantia	73	40	45	14	31
Ph. MOLLUSCA					
Cl. Gastropoda	2	2	-	3	-
Cl. Bivalvia	6	21	45	81	39
Cl. Cephalopoda	-	-	1	-	5
Ph. ECHINODERMATA					
Cl. Holothuroidea	-	-	-	-	2
Cl. Stelleroidea					
S.Cl. Ophiuroidea	1	-	2	-	13
Ph. CHORDATA					
Cl. Osteichthyes	15	19	15	6	13
Cl. Reptilia	-	-	-	-	1
DETRITUS AND SAND	3	4	32	6	83
UNIDENTIFIED REMAINS	6	21	10	8	12

Cleve = Cleveland Bay (site a)
Barra = Barramundi Creek (site b)

Table 1(b): Gut contents of *Pomadasys kaakan* and *P. argenteus* between 50mm TL and 100mm TL, and *P. maculatus* between 25mm TL and 75mm TL from Cleveland Bay, expressed as percentage of guts containing particular food items. (Classification of invertebrate food items after George and George, 1979)

Taxon of food item	*P. kaakan*	*P. argenteus*	*P. maculatus*
Ph. SARCODINA			
Cl. Rhizopodea			
O. Foraminiferida	10	13	17
Ph. ANNELIDA			
Cl. Polychaeta	20	37	57
Ph. CRUSTACEA	90	70	63
Cl. Malacostraca			
O. Mysidacea	7	7	17
O. Isopoda	10	10	17
O. Amphipoda	30	33	50
O. Euphausiacea	27	27	33
O. Decapoda			
S.O. Natantia	47	37	20
S.O. Reptantia	13	17	13
Ph. MOLLUSCA			
Cl. Gastropoda	7	3	3
Cl. Bivalvia	7	17	20
Ph. CHORDATA			
Cl. Osteichthyes	10	10	7
DETRITUS AND SAND	13	30	33
UNIDENTIFIED REMAINS	13	13	17

feeding on smaller food items. Thus, while crustaceans made up the major item in the diets of both smaller and larger fish, the larger fish were feeding mainly on crabs, thalassinids and larger shrimps, while the smaller fish were feeding mainly on amphipods, sergestids (*Acetes* sp.) and very small shrimps.

The most commonly occurring food items for *P. kaakan* larger than 150mm TL from Cleveland Bay were reptant decapods (*eg.* crabs), these being found in 73% of guts, followed by natant decapods (*eg.* shrimps and yabbies) in 58% of guts, and stomatopods in 28% of guts. From Barramundi Creek the most commonly occurring food items in *P. kaakan* larger than 150mm were again crustaceans but here the natant decapods were a more important item in the diet, occurring in 69% of guts, while reptant decapods occurred in 40% of guts. Bivalve molluscs occurred in 21% of *P. kaakan* guts from Barramundi Creek but were relatively unimportant as a food item from Cleveland Bay fish, occurring in only 6% of *P. kaakan* guts from that site.

For *P. argenteus* larger than 150mm, polychaetes were a common item in the diet of fish from Cleveland Bay, occurring in 50% of guts, while both reptant decapods and bivalves occurred in 45% of guts. A relatively high percentage of guts (32%) also contained 'detritus' (unidentified vegetable matter and fine sediment) and sand in this species. At Barramundi Creek, bivalves were very important in the diet of *P. argenteus* larger than 150 mm, occurring in 81% of guts, and in many cases crushed bivalve shell formed 100% of the gut contents. This was particularly the case for the months from October to January. (This was also noted for the sparids

Acanthopagrus berda and *A. australis*, which were co-occurring in the sampling area of Barramundi Creek and were caught along with the *Pomadasys* species on most sampling trips.) Similarly to *P. kaakan*, natant decapods were also a common food item, occurring in 39% of *P. argenteus* guts. Polychaetes were only found in 6% of guts of *P. argenteus* from Barramundi Creek.

Pomadasys maculatus larger than 100mm TL in Cleveland Bay fed on a wide range of food items. The most common were polychaetes, found in 62% of guts examined and also often making up the greatest volume of the food items in the guts. Bivalve molluscs were found in 39% of guts, amphipods in 35%, and reptant decapods in 31%. Many guts (83%) contained 'detritus' and sand in significant quantities. The broad range of food items consumed by this species is evident from the 13% of guts containing the arms of brittle stars (Ophiuroidea) and the presence in one gut of some sea snake skin. Smaller *P. maculatus* also fed heavily on polychaetes (found in 57% of guts), though small crustaceans such as amphipods (found in 50% of guts) and natant decapods, including the sergestid *Acetes* sp. and small penaeids (found in 47% of guts) were obviously important items in the diet. In the smaller fish a lower percentage of guts (33%) contained 'detritus' and sand in significant quantities compared with the larger fish, suggesting that smaller fish may be more selective in capture of food items.

Fish, either in the form of whole animals, scales, lenses or otoliths, occurred in approximately 15% of the guts of larger fish, and 7 - 10% of smaller fish, of each species studied. This suggests that teleosts form a small but significant part of the diet of these species. In smaller fish, prey were primarily a postlarval anchovy (*Stolephorus* sp.).

Comparisons between species show considerable overlap in the broad categories of dietary items but there is some evidence of food resource partitioning in the different percentage compositions of the diet. For example, bivalves are a more important item in the diet of *P. argenteus* than *P. kaakan* from Barramundi Creek (χ^2 = 35.29, df = 1, P < 0.001)), though this item is available to, and used by, both species. Similarly, in Cleveland Bay, polychaetes are more common in the diet of *P. argenteus* than *P. kaakan* (χ^2 = 15.05, df = 1, P < 0.001), though both species are using the resource.

Of the natant decapods found in the guts of larger fish from Cleveland Bay, alpheids were most common, followed by thalassinids and penaeids. The most common reptant decapods were ocypodid crabs, then portunid, grapsid and porcellanid crabs in that order. Reptant decapods were much less frequent in the guts of smaller fish (P < 0.001 for *P. kaakan* and *P. argenteus* and 0.005 < P < 0.01 for *P. maculatus*). From Barramundi Creek the natant decapod item was almost entirely composed of thalassinids of the genus *Upogebia*; reptant decapods were mainly grapsid crabs, with a few portunids and ocypodids, the latter including a species of *Mictyris*. The bivalve mollusc item consisted of more than one species of small bivalve which could not be identified at this time.

Overall, for larger fish from Cleveland Bay, crustacean remains of some sort were present in 96% of *P. kaakan* guts, 61% of

P. argenteus guts, and 64% of *P. maculatus* guts. For smaller fish, crustaceans occurred in 90% of *P. kaakan* guts, 70% of *P. argenteus* guts and 63% of *P. maculatus* guts. For fish from Barramundi Creek, crustaceans occurred in the guts of 87% of *P. kaakan* and 50% of *P. argenteus*.

4.4 DISCUSSION

While a number of methods can be used to determine the diet of fish (Hynes, 1950; Pillay, 1953; Windell and Bowen, 1978), difficulties in interpretation of data may occur with any of them and the method chosen should recognise the goals of the study and the nature of the food to be analysed (Windell and Bowen, 1978). The frequency of occurrence method was chosen in this study since it gave the best indication of the variety of food items in the diets of the species studied. While the approximate proportions by volume were also determined for food items in the gut, this method did not always give a true indication of the importance of various food items since many of the remains were well digested, broken up, or consisted of hard parts of the prey. For example, in some cases teleost remains were determined from otoliths or lenses so it was not possible to accurately determine the volume of the prey these came from, yet by their frequency it is obvious that teleosts are important in the diet. It must be recognised, however, that if these hard parts remain in the gut for longer periods than other items, this could have the effect of increasing the relative frequency of their occurrence. Another factor considered was the fact that the most frequent items in the diets, except for bivalves, were relatively large, eg. thallassinids, crabs, penaeids etc., and made up the largest volume of contents in individual guts in most cases. When bivalves were present they usually made up a very considerable volume of the gut contents, more often than not close to 100%. Thus, while the frequency of occurrence method tends to over-emphasise items in the diet that are of small size or have hard parts resistant to digestion, in this case it gave the most meaningful results when considered against the inadequacies of the other methods and the range of dietary items.

As noted in most other published reports on the food of *Pomadasys* species, crustaceans formed the major taxonomic group in the diets of the local species studied, but annelids and molluscs were also important food items. These fish are well suited to processing this diet, having large and sturdy pharyngeal teeth pads for crushing the exoskeleton of crustaceans and the shell of bivalves.

While crustaceans are the most common taxonomic group in the diet, there is an obvious difference in the components of this item for different species, for different sites and for different sizes. This would be expected since there may be different availability of prey species in the two areas, one being inshore and the other estuarine, and small fish would not be able to utilize large prey that may be available to larger fish. For example, reptant decapods are the commonest crustacean component in the diets of larger fish from Cleveland Bay while natant decapods, and particularly thalassinids, are the commonest component in the diets of larger fish from Barramundi Creek. In smaller fish, amphipods and natant decapods are more important, the latter being *Acetes* sp. and penaeids rather than alpheids or thallassinids. The lack of reptant decapods in the diets of smaller pomadasyids is most probably related to the hardness of the carapace of crabs which would make them more difficult to consume for small fish. Bivalve molluscs, on the other hand, are a more important item in the diets of *Pomadasys*, both in terms of frequency of occurrence and bulk, from Barramundi Creek than from Cleveland Bay. Conversely, few guts from Barramundi Creek fish contained polychaetes.

While these differences may be a consequence of the availability of the different food items in the two areas, there are also differences between the species studied which must be a function of food preference rather than availability. For example, bivalve molluscs are more common in the diets of larger *P. argenteus* than *P. kaakan* at both sites yet the two species were caught in the same areas at the same time, and therefore the food should have been equally available to both species.

It has been noted earlier that bivalve molluscs form a major food resource for *P. argenteus* from Barramundi Creek. In many cases the entire gut was gorged with crushed bivalve shells, particularly in the months from October to January. It was noted that some other species caught regularly during the course of this study, for example the sparids *Acanthopagrus berda* and *A. australis*, fed heavily on these bivalves throughout the year, so *P. argenteus*, and to a lesser extent *P. kaakan*, are only using this resource at a high level for part of the time that it is available. This may be another example of opportunistic taking or of selection of other items which may be more accessible or preferred. Molluscs were not reported as an important part of the diet of *P. argenteus* in Kuwait (Hussain and Abdullah, 1977), but were important in the diet of the closely related *P. commersoni* in South Africa (Van Der Westhuizen and Marais, 1977).

The few guts of *Pomadasys* species from Barramundi Creek containing polychaetes also reflects the opportunistic feeding of these species in relation to availability of prey in the area. Most of the guts containing polychaetes were collected in April and May, and these contained the reproductive heteronereid stage which was abundant and swam freely at this time. Many other species of fish caught at Barramundi Creek at this time of the year were also feeding heavily on these polychaetes as could be easily noted by the dark green colour of the gut contents and faeces. Polychaetes were rare in the guts of fish from Barramundi Creek at other times of the year, though some polychaetes did occur throughout the year in the gut contents of *Pomadasys* species from Cleveland Bay, particularly of *P. maculatus* and *P. argenteus*.

The fact that teleost remains occurred in the guts of all species in small but fairly consistent percentages of guts examined, again suggests that these may be taken opportunistically rather than being regularly, actively sought. The *Stolephorus* species found in the guts of the small pomadasyids of the three species from Cleveland Bay were caught in large numbers in the same seine hauls as the pomadasyids. The latter were obviously making use of an available food resource.

Rainer and Munro (1982) drew attention to the overlap in distribution of species having similar patterns of resource utilization in the Gulf of Carpentaria and noted that overlap in resource utilization may be expected in tropical regions where there is a high species diversity. There appears to be considerable overlap, but also some partitioning, of food resources used by local *Pomadasys* species.

Unlike the '*P. hasta*' studied by Deshmukh (1973) and *P. olivaceum* studied by Joubert and Hanekom (1980), stomatopods generally formed a small component in the diets of North Queensland pomadasyids, with only *P. kaakan* from Cleveland Bay using this resource to any extent (28% of guts). Also, while species in Cleveland Bay were feeding mainly on reptant decapods, in Trinity Inlet (approximately 400km north of Townsville) Blaber (1980) noted that prawns were the main food item of pomadasyids of all sizes and related this to the abundance of this food resource in the area.

Thus the results support the hypothesis that local pomadasyids are generalist, opportunistic feeders taking a wide variety of foods but will select particular food items in preference to others if both are available. Undoubtedly there is an ever changing relationship between nutritional requirements, availability of prey and food preference. For example, within the size constraints of the prey there may be other limiting factors such as hardness of the prey, behaviour of the prey, etc. The fact that these species can utilize a variety of food types should increase the stability of their populations and no doubt is a contributing factor to the abundance of pomadasyids wherever they occur.

All three species primarily consume benthic animals and would therefore feed on or close to the bottom. For *P. maculatus* the high percentage of guts containing significant amounts of 'detritus' and sand and the importance of polychaetes in the diet of this species suggest that this fish may feed by grubbing along the bottom and snatching at whatever is edible. The other species appear to be more specific in their prey capture techniques.

Another factor in relation to feeding behaviour was the high proportion of empty stomachs encountered when taking gut content samples. This suggests specific feeding times for these species. Similar results have been noted for haemulids from other parts of the world by other workers (Hussain and Abdullah, 1977; Joubert, 1980; Kimura, 1981).

In summary then, it can be seen that crustaceans, bivalve molluscs and annelids were the most common food items in the guts of the three *Pomadasys* species studied. The importance of each item varied for the different species and at different sites. This suggests that the fishes are opportunistic and rather generalist feeders, taking a wide variety of food items. The importance of any one item depended on its availability, in relation to other potential food items. While there was some evidence of food resource partitioning, as might be expected when similar species are feeding in the same area, it is obvious that there was also considerable overlap in the diets of the species studied.

CHAPTER 5 - REPRODUCTION

5.1 INTRODUCTION

Most reports of reproduction in the genus *Pomadasys* have indicated an extended spawning season, usually in spring and summer (Shuntov, 1971; Deshmukh, 1973; Hussain and Abdullah, 1977; Venkataramanujam and Ramamoothi, 1977; Konchina, 1978; Wallace, 1979; Joubert, 1981; Lasiak, 1983; Abu-Hakima, 1984), with some noting two peaks of spawning activity during the year (Konchina, 1978; Joubert, 1981; Abu-Hakima, 1984). Whitfield (1980) suggested that the extended spawning season is a buffer against failure of survival of the young due to short term adverse environmental conditions, since it prolongs the period of juvenile recruitment.

In Indian waters, Deshmukh (1973) recorded a high percentage of mature '*P. hasta*' (? = *P. kaakan* - see Taxonomy section 1.2) during August and September with spent and recovering fish common from October to December. He suggested probable spawning from September to December. This was supported by young specimens approximately 85mm in length occurring in large numbers inshore during January and February (Deshmukh, 1973). Deshmukh, however, also gave a minimum size at maturity for '*P. hasta*' of 410mm, which is large compared with determinations from other studies. Venkataramanujam and Ramamoothi (1977) concluded that '*P. hasta*' spawned during the summer off Porto Novo as larvae were recorded from the plankton in October, November and December. They also noted that low rainfall during a year correlated with higher larval fish abundance and a longer spawning period.

In South Africa, Wallace (1975) found that *P. commersoni* also spawned in the spring and early summer, from September to December. Spawning occurred at sea in the shallow inshore zone, although partially spawned fish penetrated short distances into estuaries, and on rare occasions running-ripe specimens also strayed into estuaries. This author noted, however, that '*P. hasta*' (= *P. kaakan*) remains reproductively inactive in the estuarine system and spawns during the winter months offshore in 30-40m of water. An extended spawning season of four to eight months was indicated. Joubert (1981) records *P. olivaceum* in South Africa also having a prolonged spawning period but with two peaks, August to December and March to May.

Melville-Smith and Baird (1980) concluded that larvae of *Pomadasys* species are rare in the plankton of the Swartkops Estuary in South Africa, but some were recorded in the months of November, February, March and April.

Hussain and Abdullah (1977) noted that for *P. argenteus* in Kuwait, gonads began developing from December, with peak maturation from March through May, but with a sharp decline in the numbers of mature gonads in June. Similarly, Abu-Hakima (1984) reported a seasonal maturation of gonads in his study of *P. argenteus* from Kuwait, with spawning occurring in spring and early summer (April to June). The gonads developed during late winter, with the gonado-somatic index of female fish reaching a maximum in March and decreasing with spawning in the following months. There was also a minor peak in gonadosomatic index in October, suggesting a second spawning, though, as was noted, this was based on a small sample of fish in this month.

Fursa (1979) recorded intensive spawning of '*P. hasta*' (? = *P. argenteus*) in the eastern Arabian Sea during the winter monsoon from August to March. He also recorded *P. maculatus* spawning from January to March in the same area.

In the only report of *Pomadasys* reproduction in Australian waters, Shuntov (1971) noted that *P. maculatus*, as with the bulk of the shelf species in the Arafura Sea, spawned throughout the year with the lowest intensity during winter and the highest intensity in spring and summer, from October to March.

Studies of fecundity in *Pomadasys* species are poorly documented in the literature and no such studies have been undertaken in Australian waters to date. Abu-Hakima (1984) estimated the range of fecundity of *P. argenteus* in Kuwaiti waters to be from 625,848 in a 329mm fish to 2,424,846 in a 521mm fish, though he stated that these numbers may be overestimates as they included maturing oocytes which are not shed. Deshmukh (1973) estimated the fecundity of one '*P. hasta*' in Indian waters, but the value, as published, is ambiguous (see Discussion section 5.4).

5.2 METHODS

Specimens of *Pomadasys* species collected from Cleveland Bay by trawling from the R.V. "James Kirby", and those caught by line but unsuitable for tagging purposes from Barramundi Creek, were measured, sexed, and visually allocated to one of 7 recognisable gonad stages. The gonads were categorised according to the following scheme:

Stage 0: (Immature) - Gonads small. Ovaries flat or cylindrical, transparent, pale pink to pale orange colour, with no ova visible to the naked eye. Testes flat, a thin strand of tissue.

Stage 1: (Early developing) - Ovaries cylindrical, pale red-orange colour, some small developing ova visible to the naked eye giving the ovary a speckled appearance. Testes slightly thickened, creamy colour toward posterior, no milt obvious in vas deferens.

Stage 2: (Late developing/Early mature) - Ovaries about half the length of the body cavity, many developing ova obvious but not all of the ovary filled with opaque ova; colour pink-red to pale yellow. Testes creamy coloured, thickened, with some milt obvious in the lower vas deferens.

Stage 3: (Mature) - Ovaries large, approximately half the length of the body cavity or larger, packed with opaque ova and pale yellow in colour. Testes approximately half the length of the body cavity or larger, creamy or white colour, milt along most of the vas deferens and can be squeezed out with slight pressure.

Stage 4: (Spawning condition) - Ovaries large, usually greater than half the body cavity and pink to pale red colour, most ova transparent and expelled from the vent by slight pressure on the body cavity wall. Testes were not distinguished from stage 3.

Stage 5: (Spent) - Ovaries flaccid, bloodshot, with some ova retained. Testes bloodshot, smaller than stage 3 condition but still off-white colour.

Stage 6: (Recovering spent/Resting) - Ovaries with dark red patches giving a mottled appearance, somewhat flaccid and having few recognisable opaque ova. Testes off-white colour and reddened, particularly at the posterior end.

At least ten gonad samples, for confirmation of the stages described above and for further sectional study, were collected monthly for each species where possible. These were taken from freshly killed fish and stored in a solution of formalin, calcium chloride and acetic acid in concentrations of 10%, 1%, and 5% respectively. Samples for histological study were processed using a Shandon Duplex automatic tissue processor. The fixed tissue was dehydrated in six changes of alcohol (70% → 100%) over five hours, then passed through three changes of toluene (each for forty-five minutes) and finally wax embedded using the Tissue Tek system. Sections were cut at 6-8μm using a rotary microtome, stained with Mayer's Haemalum and Young's Eosin, and mounted on microscope slides. Slides were examined with an Olympus EC binocular microscope to confirm the gonadal stages determined by macroscopic means.

For fecundity estimates, mature ovaries were removed from freshly killed fish in the field and immediately preserved in 5% formalin. In the laboratory the ovaries were dried with absorbent paper towel, and weighed to the nearest 0.001g on a Sartorius electronic balance (Model 1405 MP8). A sample from mid way along one ovary, corresponding to approximately 1% of the total weight of both gonads, was taken using a sharp scalpel to cut a thick section of ovary. This sample was then weighed to the nearest 0.001g, placed in a small Petrie dish and thoroughly teased apart in a small ammount of water to separate the ova from the connective tissue. The ova were spread on microscope slides using a Pasteur pipette and those larger than 0.075mm in diameter were counted manually with the aid of an Olympus SZ stereo dissecting microscope. Estimates of fecundity were made by multiplying the number of ova counted in the sample by the total weight of the gonads and dividing the product by the weight of the sample.

From one preserved mature ovary of each species, 1,000 randomly selected ova were measured to the nearest 0.025mm in diameter using an eyepiece micrometer. The ovaries selected for ova measurement were all from fish collected in September, at the beginning of the spawning season.

5.3 RESULTS

Gonads of fish less than 100mm TL for *P.kaakan* and *P.argenteus*, and less than 50mm TL for *P.maculatus*, were all immature (Stage 0). The data from these, therefore, have not been included in the following results.

5.3.1 Sex Ratio:

Table 2 shows the sex ratio for each of the three species studied, in various size groups.

P.kaakan had a significant male biased sex ratio for fish between 101mm and 200mm (χ^2 = 216.8, P < 0.001), both from Cleveland Bay and Barramundi Creek. The sex ratio in the 201mm to 300mm size group was about equal or slightly female biased for both sites, but in general became increasingly female biased in larger size groups.

For *P.argenteus* the results were quite different for Cleveland Bay and Barramundi Creek. In Cleveland Bay there is a marked male bias, at least in fish less than 300mm, (χ^2 = 627.5 for the 101mm to 200mm size group and χ^2 = 303.3 for the 201mm to 300mm size group. P < 0.001 in both cases). Only one fish of this species larger than 300mm was caught in Cleveland Bay and this was a female. At Barramundi Creek the sex ratio of *P.argenteus* is about equal for fish of 101mm to 200mm (χ^2 = 0.18, P > 0.1), but becomes heavily female biased in larger size groups (χ^2 = 74.9 for the 201mm to 300mm size group and χ^2 = 56.6 for the 301mm to 400mm size

Table 2: Percentage of males and females of *P. kaakan*, *P. argenteus*, and *P. maculatus* in samples from Cleveland Bay and Barramundi Creek.

Species	Total Length (mm)	Cleveland Bay				Barramundi Creek			
		N°	%M	%F	χ^2	N°	%M	%F	χ^2
P. kaakan	101-200	1355	70	30	216	246	77	23	72
	201-300	966	49	51	0.4	337	45	55	3.4
	301-400	2	0	100	2	131	18	82	352
	401-500	0	-	-	0	36	17	83	16
	501-600	0	-	-	0	6	50	50	0
	601-700	0	-	-	0	1	0	100	-
P. argenteus	101-200	1146	87	13	627	110	52	48	0.2
	201-300	585	86	14	303	277	24	76	75
	301-400	1	0	100	-	64	3	97	57
	401-500	0	-	-	-	5	0	100	20
P. maculatus	51-100	152	46	54	1	-	-	-	-
	101-150	1247	45	55	13	-	-	-	-
	151-200	1180	35	65	106	-	-	-	-
	201-250	0	-	-	-	-	-	-	-

%M = percentage of males

%F = percentage of females

N° = number of fish in size range

χ^2 = chi-square value

group. $P < 0.001$ in both cases). All *P.argenteus* caught in this study which were larger than 400mm were female.

P.maculatus up to 100mm long from Cleveland Bay have an approximately equal sex ratio, though, as with the other species, the sex ratio becomes significantly female biased in the larger size groups ($\chi^2 = 12.5$ for the 101mm to 150mm size group and $\chi^2 = 106.2$ for the 151mm to 200mm size group. $P < 0.001$ in both cases).

5.3.2 Length at Maturity:

Sexually mature fish are classified as those with a gonad condition corresponding to stage 3 or greater. Thus, in this context fish are also classed as 'mature' if they are in spawning condition (stage 4), spent (stage 5) or recovering (stage 6).

Figure 7 shows the proportion of mature fish in each 10mm size group. From this figure it can be seen that both *P.kaakan* and *P.argenteus* mature at a smaller size in Cleveland Bay than in Barramundi Creek. Males also mature at a smaller size than females at both sites. For *P.kaakan* the smallest mature male was 165mm from Cleveland Bay and 206mm from Barramundi Creek. The smallest mature female was 173mm from Cleveland Bay and 251mm from Barramundi Creek. For *P.argenteus* the smallest mature male was 155mm from Cleveland Bay and 193mm from Barramundi Creek, while the smallest mature female was 180mm from Cleveland Bay and 226mm from Barramundi Creek. The minimum size at maturity for *P.maculatus* was 114mm for males and 118mm for females.

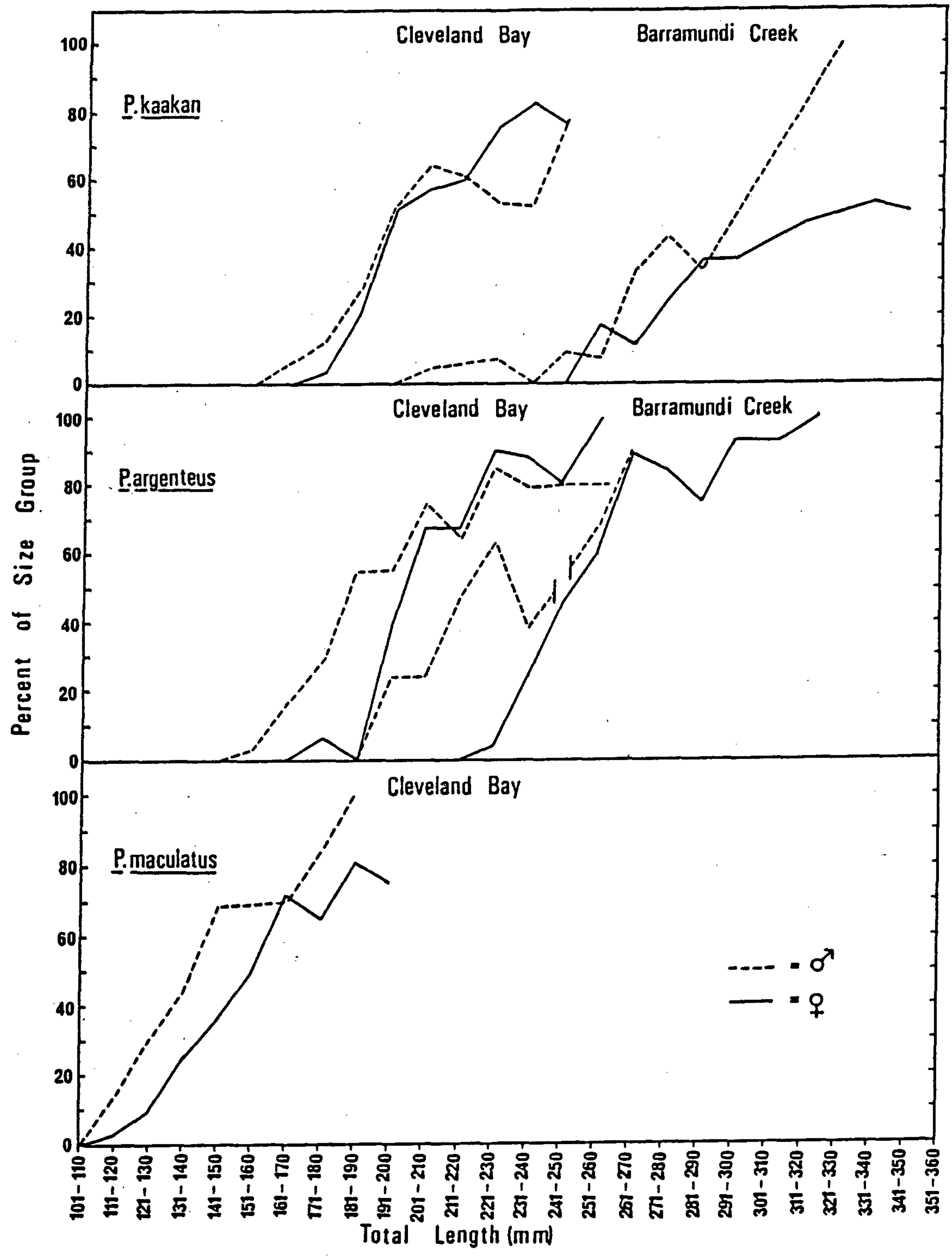

Fig. 7. Percent of mature fish in each size group, for *P. kaakan* and *P. argenteus* from Cleveland Bay and Barramundi Creek and for *P. maculatus* from Cleveland Bay.

For *P. kaakan* from Cleveland Bay, approximately half the fish in the samples were mature, and therefore capable of spawning, by a length of 200mm. For *P. argenteus* from Cleveland Bay, at least half the males were mature by a size of 190mm, while for females the size at which half were mature was closer to 210mm. For *P. maculatus*, at least half of the males were mature at a size of 150mm, while half of the females were mature at a size of 160mm. For Barramundi Creek samples, mature *P. kaakan* were not caught in large numbers and, for most size groups, less than half of the fish sampled were mature even for the larger groups. However, a considerable proportion were mature by the time they had attained a length of about 300mm. A far greater proportion of males were mature compared with females at sizes greater than 300mm. For *P. argenteus* from Barramundi Creek, about half the males were mature by a length of 220mm, while about half the females were mature between 240mm and 260mm. A far greater proportion of female *P. argenteus* were mature, compared with female *P. kaakan*, in the larger size groups.

5.3.3 Spawning:

(a) Gonad Condition:

On the basis of macroscopic determination, and confirmation by histological microscopic examination, the gonads could be graded according to their condition as outlined under Methods. No fish contained gonads which, by either macroscopic or microscopic examination, showed evidence of hermaphroditism or transitional sex change.

P. kaakan - Fig. 8 indicates the percentage of each monthly sample of female *P. kaakan* with a gonad condition stage greater than 0 (that is, showing some gonadal development) for each gonad stage for the two sites, Cleveland Bay and Barramundi Creek. For Cleveland Bay, females with mature (stage 3) gonads were sampled from August to April; with the highest proportions of mature fish in September, October, November and January. Fish in spawning condition (stage 4) were most abundant from August to November, though a few fish in this condition were also caught in December, January and April. As spawning condition is a very short-lived stage it would be expected that numbers of fish captured in this condition, as a proportion of the total sample, would be small. Spent and resting fish (stages 5 and 6 respectively) were caught mainly in February and March. For Barramundi Creek a similar distribution is seen, though about a month later, with most fish being mature from September to December, and a few in February. Few females in spawning condition or recently spent were captured at Barramundi Creek, however, *P. kaakan* with recovering spent and resting stage gonads (stage 6) formed a large proportion of the sample in January and from March to July inclusive. Recently spent (stage 5) females were caught in small numbers in August, October, December, February, and April. This indicates a prolonged spawning,

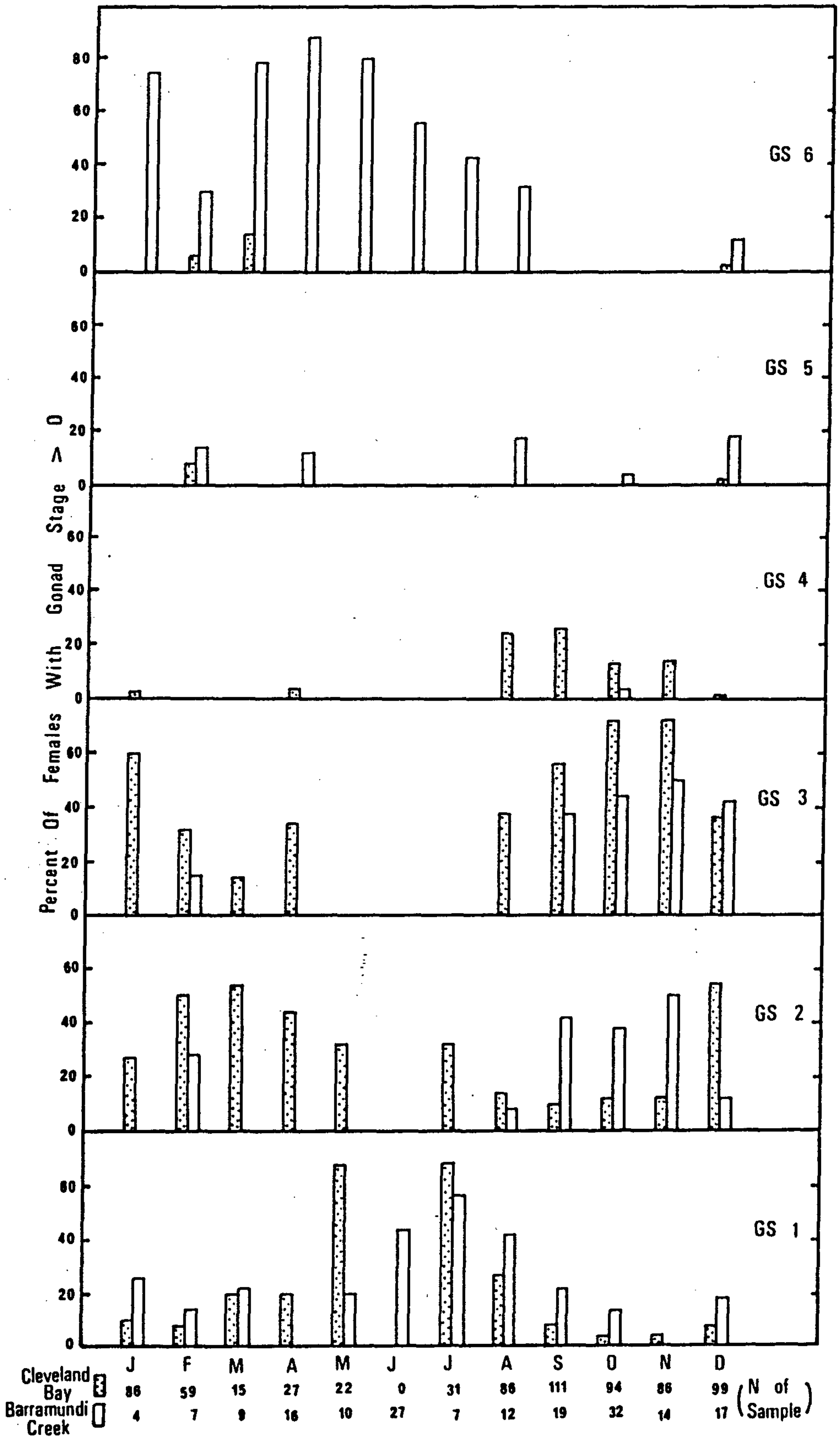

Fig. 8. Percent of monthly samples of female *P. kaakan* from Cleveland Bay and Barramundi Creek, with a gonad condition stage (GS) greater than 0.

though not all fish would necessarily spawn over this entire period.

P. argenteus - Fig. 9 is a plot of actual numbers of female *P. argenteus* with gonad condition stages greater than 0, for each month and for each gonad stage from the two sites. Actual numbers were plotted rather than percentages (compared with *P. kaakan* and *P. maculatus*), because of the small sample sizes involved for this species. No fish with a gonad stage greater than 0 were captured from March to June in Cleveland Bay, and only relatively low numbers were collected in other months, except for September, November and February. Stage 3 fish were caught in August, September and November, and stage 4 fish were caught from September to November, with the largest proportion of the September sample being stage 4. Single stage 5 fish were caught in both November and February, and several stage 6 fish were caught in February also. At Barramundi Creek no stage 4 fish were caught, though stage 3 fish were caught from August to May, but in very small numbers in the latter three months. A few stage 5 females were caught from December to May. Stage 6 females were most abundant in March and April, though this stage was collected throughout the whole year in small numbers. In both Cleveland Bay and Barramundi Creek, few *P. argenteus* were caught during the mid-winter months.

P. maculatus - Fig. 10 indicates the percentage of female *P. maculatus* with a gonad condition stage greater than 0, for each

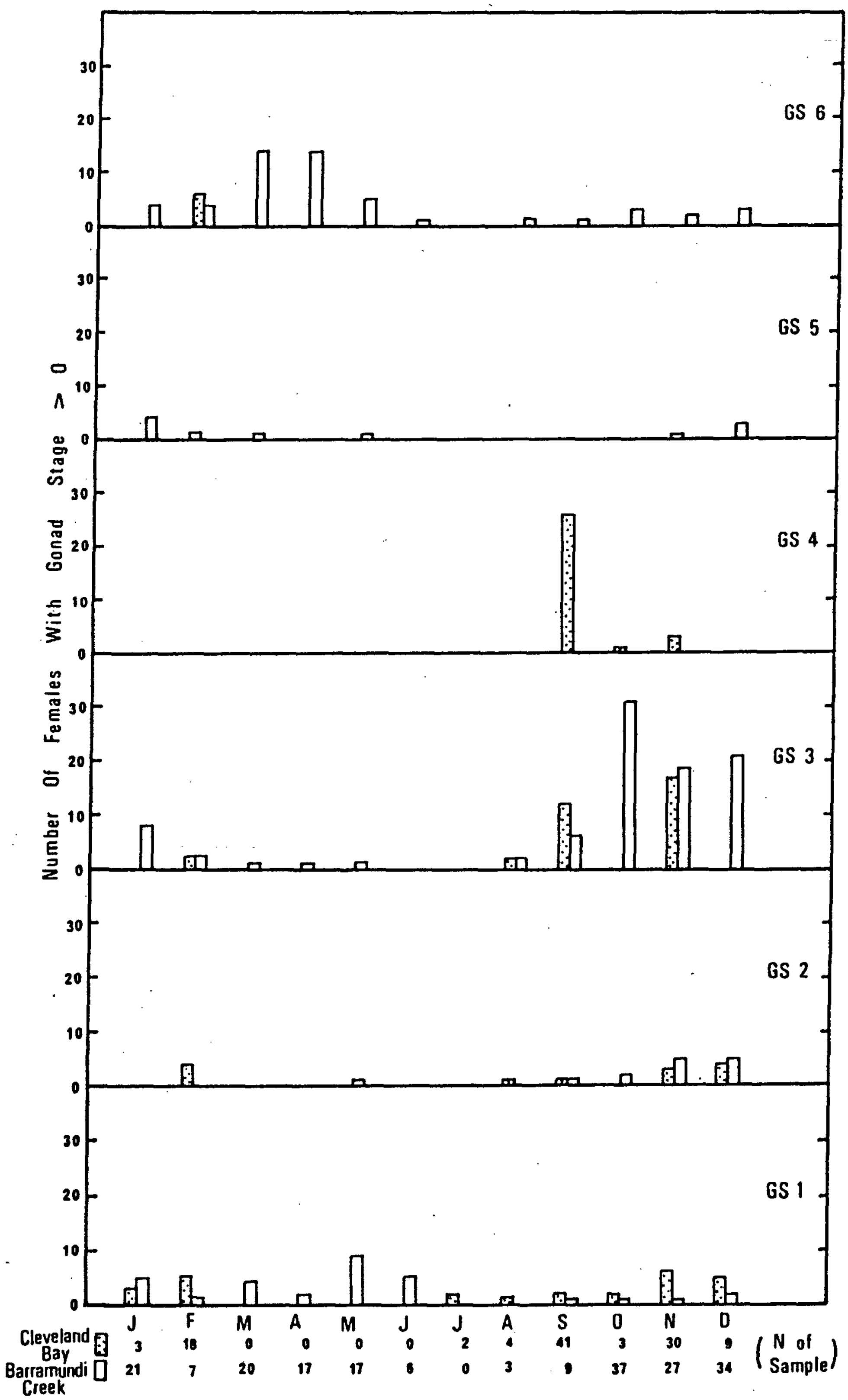

Fig. 9. Number of fish in monthly samples of female *P. argenteus* from Cleveland Bay and Barramundi Creek, with a gonad condition stage (GS) greater than 0.

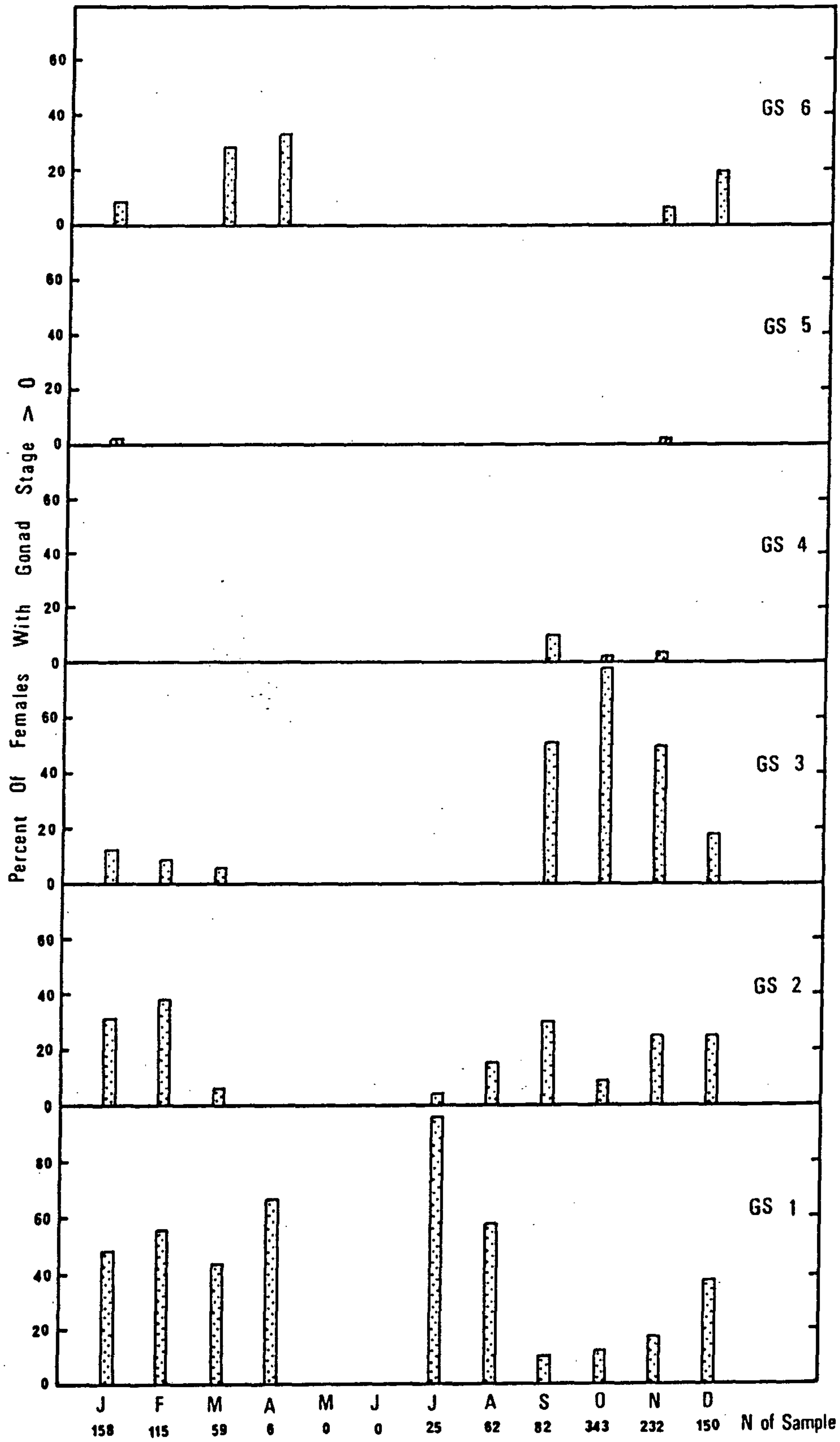

Fig. 10. Percent of monthly samples of female *P. maculatus* from Cleveland Bay, with a gonad condition stage (GS) greater than 0.

month and for each gonad stage. This species was only caught in Cleveland Bay. Females with stage 3 gonads were sampled from September to March, with the greatest proportion of each sample in this condition in September, October and November. Stage 4 females were also captured from September to November, and all stage 6 females were captured between November and April. Stage 5 fish were only caught occasionally, in November and January. Only a few *P. maculatus* with a gonad stage greater than 0 were caught in April, and none were caught in May and June. During this time these larger fish in the population appear to move offshore to deeper water where they are often taken by commercial trawlers.

(b) Larvae:

Plankton samples collected as part of a research project on the ichthyoplankton of the Great Barrier Reef lagoon (conducted by N.E. Milward and R.F. Hartwick from James Cook University) were sorted for *Pomadasys* larvae. These could be recognised by the general body shape together with spination of the operculum and preoperculum, flexion of the gut, and the space between the anus and the beginning of the anal fin (Leis and Rennis, 1983; Leis, pers.comm.).

Pomadasys larvae were found in samples collected from August to March, from close inshore to approximately 18km offshore, but rarely from further offshore. Plate 6 illustrates a *Pomadasys* larva collected off Saunders Beach just north of Townsville.

Plate 6. *Pomadasys* larva (3.0mm TL) collected off Saunders Beach, just north of Townsville.

The larvae of different *Pomadasys* species have not been described and therefore the collected specimens could not be distinguished to species level. The close similarity of the adult morphology suggests that the separation of species at a larval stage will be difficult, and further investigations will be required to resolve their systematics. This was beyond the scope of the present study.

(c) Rearing:

Artificial fertilization of eggs of *Pomadasys* species was attempted on several occasions, both in the field and in the aquarium system of the School of Biological Sciences at James Cook University, by mixing ova and milt, from stage 4 fish, in an aerated container. On one occasion several fertilized eggs were obtained but these did not develop past the second cleavage.

5.3.4 Fecundity:

Table 3 shows the estimated fecundity of five fish of varying sizes for each species studied. Generally the larger the fish the greater was the fecundity estimate, though the values are somewhat variable along with the size and weight of the gonads.

For *P. kaakan* the fecundity estimates ranged from 148,000 in a 200mm fish to 1,895,000 in a 605mm fish. For *P. argenteus* the range was from 161,000 in a 231mm fish to 1,094,000 in a 371mm fish. The

Table 3: Estimated fecundities of *P. kaakan*, *P. argenteus*, and *P. maculatus* for a range of lengths.

Species	Total Length (mm)	Estimated Fecundity	Weight of Gonads (g)	Month Sampled
P. kaakan	*605	1,895,000	113.18	Sept.
	540	1,142,000	72.78	Oct.
	360	320,000	20.50	Sept.
	325	230,000	13.78	Oct.
	200	148,000	11.16	Sept.
P. argenteus	387	830,000	48.40	Dec.
	*371	1,094,000	58.49	Sept.
	348	1,040,000	53.20	Nov.
	301	405,000	22.93	Sept.
	231	161,000	9.11	Oct.
P. maculatus	*182	135,000	12.01	Sept.
	176	82,000	6.15	Oct.
	166	56,000	5.31	Oct.
	163	98,000	8.40	Sept.
	162	63,000	5.60	Nov.

* designates lengths of fish from which gonads were selected for ova size measurements.

largest *P. argenteus* for which fecundity was estimated (387mm TL) had a relatively low estimate, which corresponded to a relatively low gonad weight. For *P. maculatus* gonad weights were fairly variable for a given size of fish and this was reflected in the fecundity estimates. The largest fish of this species examined, 182mm, had an estimated fecundity of 135,000.

Figure 11 shows the percentage of ova greater than 0.075mm in diameter, in size groups of 0.05mm, for a sample of 1,000 ova from a mature (stage 3) ovary from one fish of each species. There were also many small germinal cells less than 0.075mm in diameter which were not included in the fecundity estimates or in this figure. The figure shows that each species had a large proportion of ova in the size range 0.326mm to 0.625mm in the mature ovary. These were presumably developing for a spawning in the near future. There was also another group of ova in the size range 0.176mm to 0.275mm which were developing. This may suggest more than one spawning each season for these species. For *P. kaakan* and *P. argenteus* there was also another smaller group of ova in the size range 0.076mm to 0.125mm which were showing early development, though this was not the case for *P. maculatus*. Mature gonads that were sampled in December typically had fewer small ova (size range 0.176mm - 0.325mm) present, viz., < 5% compared with up to 14% in mature gonads in September.

Plates 7, 8, and 9, show a section of a mature ovary from each of the species *P. kaakan*, *P. argenteus*, and *P. maculatus*, respectively. The sections reveal the different development stages

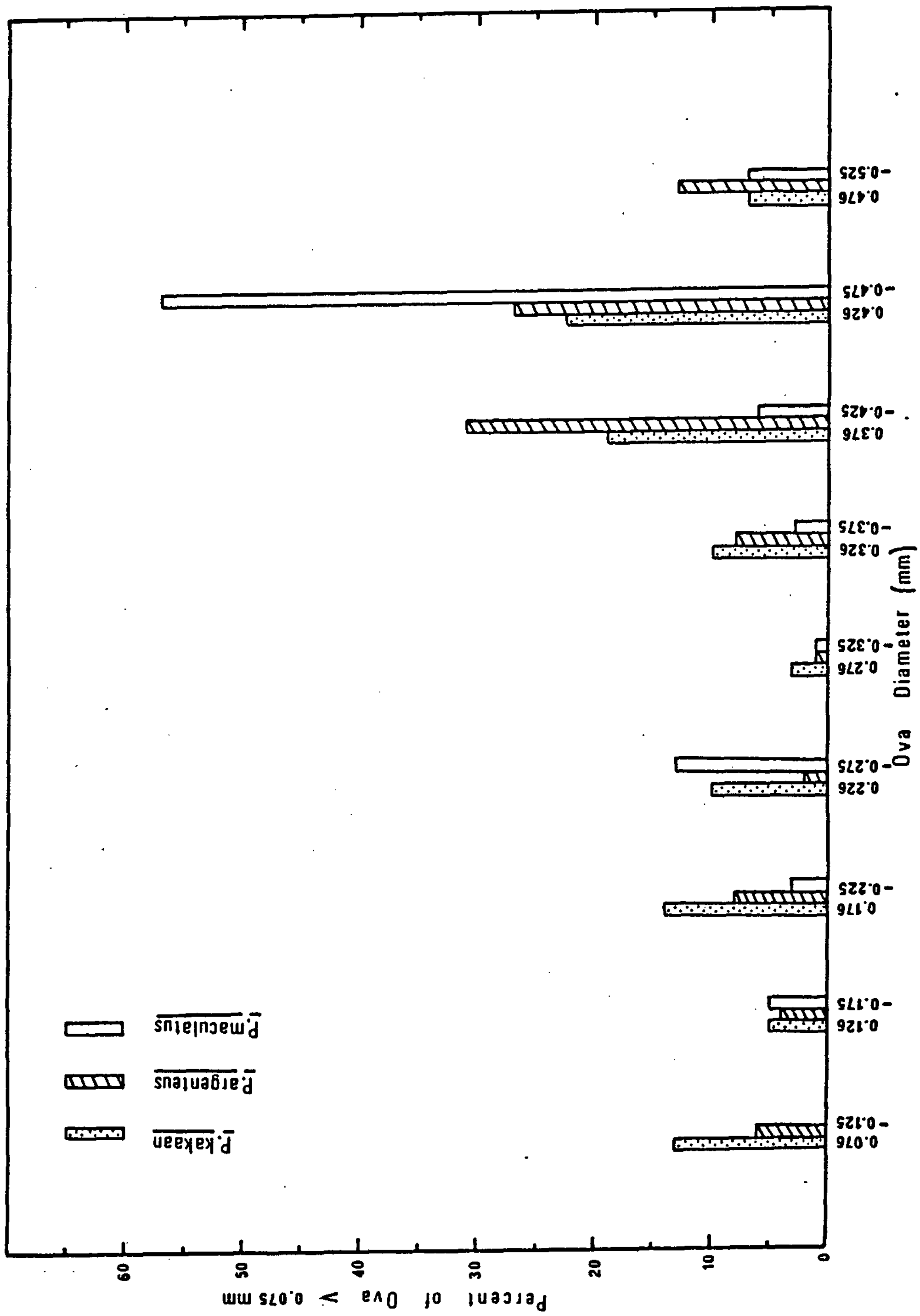

Fig. 11. Distribution of different ova sizes within selected ovaries from three species of *Pomadasys*.

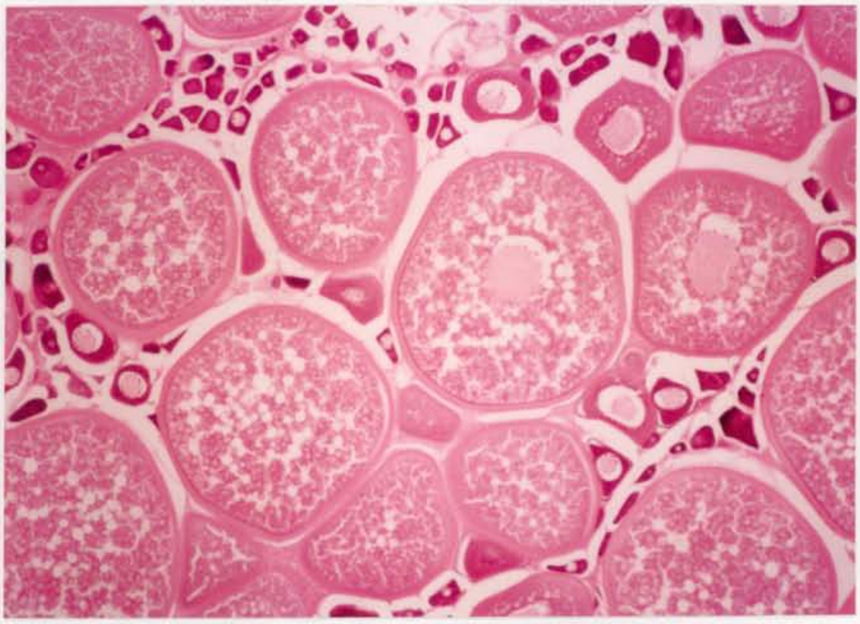

Plate 7. Transverse section of a mature (Gonad Stage 3) ovary from *P. kaakan*, showing different sized ova present. (X 75)

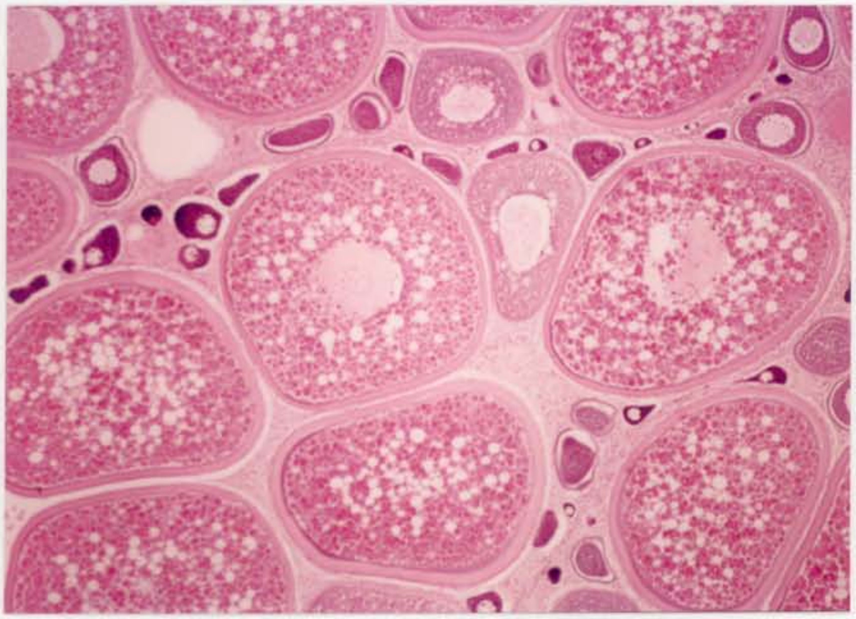

Plate 8. Transverse section of a mature (Gonad Stage 3) ovary from *P. argenteus*, showing different sized ova present. (X 75)

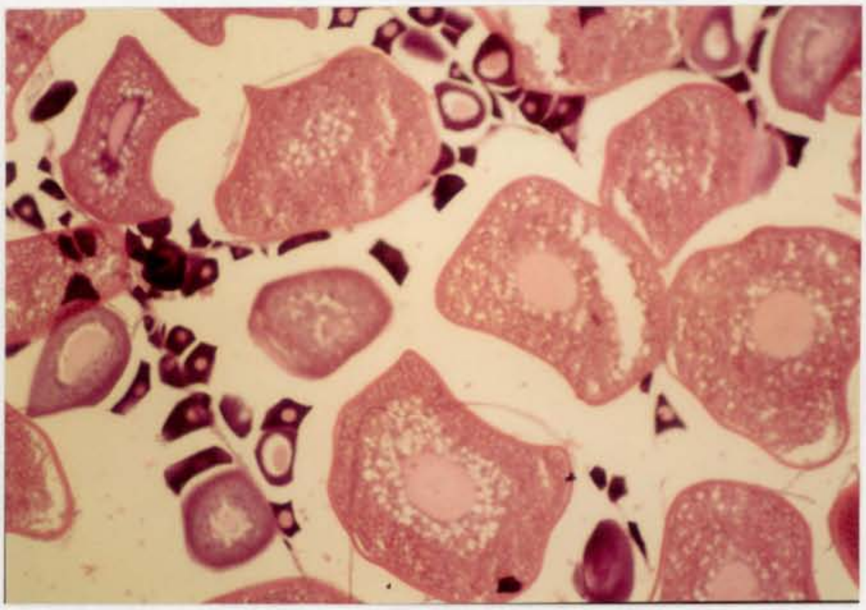

Plate 9. Transverse section of a mature (Gonad Stage 3) ovary from *P. maculatus*, showing different sized ova present. (X 75)

of ova within the ovaries, and reflect the differential numbers and sizes of them determined by the counts and measurements. (It should be noted, though, that these sections were not taken from the ovaries used for determining fecundity and ova size distributions, since the fixation procedure used for the latter was not suitable for sectioning.)

5.4 DISCUSSION:

The presence of spawning condition (gonad stage 4) fish in trawl samples shows that the three species of *Pomadasys* spawn in the inshore zone of Cleveland Bay, and no doubt all along the coast of North Queensland. There is no comparable evidence to suggest that these species spawn far upstream in estuaries, although spawning may take place in the lower reaches of estuaries. This has been suggested for *P.commersoni* in South Africa (Wallace, 1979), although *P.hasta* (? = *P.kaakan*) was noted to spawn offshore in that area. Only rarely were *Pomadasys* caught at the Barramundi Creek site in spawning, or very recently spent, condition, suggesting that spawning was not commonly taking place in that area. However, since all these fish were sampled by line fishing, another explanation may be that fish do not normally feed during the spawning stage or shortly afterwards. This seems unlikely since other species, for example the sparids *Acanthopagrus berda* and *A.australis*, and the sciaenid *Pseudosciaena sina*, were captured by line fishing at Barramundi Creek in spawning condition stage, and *Pomadasys* in spawning condition taken by trawl from Cleveland Bay did have food in their guts.

All *Pomadasys* species breed over the spring and summer months, from August to March, in the local area, with most reproductive activity taking place from September to November prior to the onset of the wet season. The species are oviparous and, from observations on a small number of eggs artificially stripped and fertilized in the laboratory, the fertilized eggs may settle to the bottom, at least initially. The larvae are planktonic.

From the evidence of ova size groups within the mature ovary it is probable that each fish spawns more than once in the breeding season. This may account for an observed second peak of spawning activity as late as February or March. Repeated spawning may also explain the apparent low fecundity value for the 387mm *P. argenteus* caught in December, which, despite its full appearance, may have already spawned during the earlier part of the breeding season and had fewer ova developed in the subsequent ripening. The protracted recruitment of young fish as evidenced from length frequency data from Cleveland Bay (cf. Ch.7 Growth) also points to the possibility of repeated spawnings.

The fact that all the species spawn in the same area in Cleveland Bay, and at the same time, may lead to the possibility of hybridisation. This may be particularly likely for *P. kaakan* and *P. argenteus*, which are very similar in many respects. Being frequently caught together in spawning condition, often in the same trawl, it could be expected that some chance natural hybrids may exist. Interspecific hybridization has been known to occur in quite a number of fishes for some time (Hubbs, 1955). Amongst Australian fishes it has been demonstrated in two species of sparids, *Acanthopagrus australis* and *A. butcheri*, (Rowland, 1984), which in many features of morphology, habits, and habitats occupied are not greatly unlike the *Pomadasys* species. In the course of this study, a few fish mainly characterised as either *Pomadasys kaakan* or

P. argenteus had some features, primarily colour pattern, resembling the other species or intermediate between the two. Although, at the time of capture, these were questionably assigned to one or other of the species, it is possible, on the above grounds, that these may have been genetic hybrids between the two. In all, less than 1% of the fish sampled fell into this category but it is an aspect of *Pomadasys* biology which could warrant further study.

The estimated fecundity of individual fish was closely related to the weight of the ovaries, as would be expected, but the ovarian weight was variable ranging, from 3% to 10% of body weight in similar sized fish within a species. This variability may be due to a number of factors, including, as noted earlier, the fish having previously spawned in the current breeding season. Fish that had already spawned once, or more, prior to capture may not have produced as many ova in the subsequent development. Other factors are environmental conditions e.g. availability of food, stress, etc. which can affect the fecundity of individuals (Wootton, 1982). To reduce the possibility that gonads used for ova size measurements had already been partly spawned, these were all selected from fish that had large gonads that were mature early in September, before the main spawning period.

Abu-Hakima's (1984) estimates of the fecundity of *P. argenteus* in Kuwaiti waters ranged from 625,848 in a 329mm fish to 2,424, 846 in a 521mm fish, but he stated that these values may be over-estimates as they include maturing oocytes which are not shed. In my study, oocytes larger than 0.075mm in diameter were included in the fecundity estimate, since the evidence above suggests that developing oocytes of this size found in the gonads of fish caught early in the spawning season would be spawned, or at least have the potential to be spawned, later in the season. My estimates of fecundity in *P. argenteus* are close to those of Abu-Hakima for smaller fish, for example 405,000 in a 301mm TL fish to 1,040,000 in a 348mm TL fish, compared with 625,848 in a 329mm (standard length) fish from Kuwait. No very large fish comparable with the largest in Abu-Hakima's study were caught during this investigation, and, unfortunately, the gonads of the largest specimen obtained, 415mm, were not available for a fecundity estimate.

The only other estimate of fecundity in *Pomadasys* species in the literature is that given by Deshmukh (1973) for '*P. hasta*' from Indian waters. The fecundity estimate given for one specimen 580mm long is published ambiguously as 2,86,520 (*sic*). It can only be assumed that this estimate is somewhere between 2 million and 3 million. My estimate for a 540mm *P. kaakan* is 1,142,000 and for a 605mm *P. kaakan* is 1,895,000. This disparity may provide further grounds for '*P. hasta*' being a different species from the local *P. kaakan*, as suggested earlier.

The fecundities of *P. kaakan* and *P. argenteus* estimated in the present study are relatively high (Nikol'skii, 1963; Lowe-McConnell, 1979; Thresher, 1984). Fish in their first spawning season, and probably only twelve to eighteen months old (see Growth chapter), are capable of producing around 150,000 ova, and the number of ova produced increases exponentially with size and age of the fish. A three or four year old fish would produce well over 1,000,000 eggs, and more likely closer to 2,000,000 eggs, each breeding season. *P. maculatus* on the other hand produces fewer eggs, no doubt related to the physical constraints of the size of the fish. The largest fish for which a fecundity estimate was made was 182mm, which is close to the maximum size of *P. maculatus* captured in this study. Its estimated fecundity was 135,000, while the fecundity of fish in their first spawning season is less than 100,000.

While fecundity estimates calculated in this study give an indication of the number of ova produced over a breeding season (since developing ova > 0.075mm diameter were included, though it cannot be discounted that smaller germinal cells may also be involved in later spawnings), it is important to recognise other attributes of reproductive effort that determine the final recruitment of the young. Examples of these are the age at first spawning, survival rate of the eggs, larvae and juveniles, the number of breeding seasons a fish participates in, population size, etc. Thus, while *P. maculatus* have small individual fecundity and are relatively short lived, this may be compensated for by a large population size and therefore a high population fecundity.

The difficulties that are involved with estimating the fecundity of a species that spawns repeatedly over a long breeding season have been considered in detail by Macer (1974), particularly the difficulty associated with distinguishing between reserve and developing oocytes. In the present study, the gonads selected for ova size frequencies were large and very full, indicating that they were very close to spawning condition. It is unlikely that the small ova size groups (up to 0.275mm) would have been able to mature before the larger ones were released and it is suggested that these develop for later spawnings within the prolonged breeding season. When and how often a fish would spawn would be decided by selection pressures affecting the survival of eggs and young, or adult fish, and may vary from year to year (Lowe-McConnell, 1979). As already noted, environmental effects will also have a marked effect on fecundity.

Where temperature and food conditions permit extended breeding seasons, as is the case locally, advantages result from repeated spawnings. As well as extending the period of juvenile recruitment, and thus reducing the possibility of total breeding failure due to short term adverse environmental conditions (Whitfield, 1980), it has also been suggested that staggering the peak spawning times in sympatric, closely related species may reduce competition for biotic factors such as spawning grounds and living space. This has been shown for *Haemulon* species on Jamaican reefs (Lowe-McConnell, 1979). While local pomadasyids, and especially *P. kaakan* and *P. argenteus*, fall into this category of sympatric and closely related species they appear to spawn at much the same time and in the same place, since spawning condition (stage 4) fish of these species were often caught together in the same trawl.

Clearly there is an interaction of a number of factors in determining the effective fecundity of a species and the values obtained in most studies can only be regarded as a guide.

It is obvious from the sex ratio results that there is a marked change in the sex composition of the population at different sizes in all three species of *Pomadasys*, but particularly for *P. kaakan* and *P. argenteus*.

The fact that there is a highly male biased sex ratio in small *P. kaakan* (101-200mm) could be partly due to the difficulty of visually assigning the gonads of very small fish to a particular sex. I am confident, though, that this would not cause such a disparity in this study since small ovaries were generally much shorter and more cylindrical than testes, even in the smaller fish, and there was no difficulty in distinguishing the sex of fish larger than 130mm. Also the gonads of small *P. argenteus* were very similar to those in *P. kaakan* yet the sex ratio determined for the small size group of *P. argenteus* was much closer to 1:1. Further, the fact that samples of *P. kaakan* from both Cleveland Bay and Barramundi Creek showed the same sort of ratio, suggests that the high proportion of males recorded for each is a valid observation. Thus there must be either a change of sex in some individuals between 200mm and 300mm, a differential mortality of males in this size group, or some other cause for the observed change in sex ratio. The fact that there is a continuation in the trend toward female bias in the sex ratio of larger fish suggests that the former may apply, though no strong evidence was obtained from the studies conducted to either support this or the alternative explanations. While there are several species of fish in the local area which do change sex, for example some polynemid species (N.E. Milward, pers.comm.), Barramundi, *Lates calcarifer* (Shaklee and Salini, 1983), and some nemipterid species (Young and Martin, 1985), none of the 8,500 *Pomadasys* examined in this study showed any visible signs of sex change in their gross gonad structure or in the histological features of the 360 sectioned gonads. However, in the absence of other explanations, such as a marked differential mortality of males in the population in these species, the possibility of a change in sex of some individuals should not be discounted. If sex change does take place it may occur after spawning when the gonads are in the resting stage, which would be more difficult to determine. This aspect requires further study.

P. argenteus from Barramundi Creek show a similar female bias in the sex ratio of fish larger than 200mm, but as noted above, the sex ratio in the smaller size group (101-200mm) is about equal. Since *P. argenteus* is a smaller growing fish than *P. kaakan* (see Growth section), the 101-200mm size group in *P. argenteus* may be equivalent, in this respect, to the 201-300mm size group in *P. kaakan*, which also had an approximately equal ratio of males to females. Perhaps for *P. argenteus* fish smaller than 100mm may have a male biased sex ratio, but this was not examined in the present study. It is interesting, however, that for *P. argenteus* from Cleveland Bay, all but one of which were less than 300mm long, the sex ratio was strongly male biased. One explanation could be that males stay in the Bay while the females move into estuaries. This would explain the higher proportion of females in estuaries but is contrary to the evidence from tagged fish of this size range in Barramundi Creek (cf., Ch.6 Tagging and Movement). Those recaptured showed little movement, though movement of others may not have been detected because of non reporting of recaptures by other fishermen from outside the study area. However, movement between estuary and bay and segregation of the sexes would not account for the female bias in the sex ratio of *P. kaakan* unless the larger males were moving into the bay and were not sampled in the study. Also, the differential length at maturity for *P. kaakan* (Fig. 7) would not be caused by differential movement of the sexes since most fish would be mature at a size smaller than 300mm TL, when sex ratios are approximately equal at both sites. Differential movement could explain the different lengths at maturity for *P. argenteus* if numbers of larger females moved into estuaries before maturity. These aspects require further study.

For *P. maculatus* the sex ratio is slightly female biased in fish between 101mm and 150mm, and the larger size group becomes more female biased. Again it is difficult to explain why a higher proportion of larger fish were females, other than by a differential mortality of males in the population, or as a result of sex change since the entire size range of this species was sampled from many parts of Cleveland Bay and further offshore. This species was not caught in estuaries.

For reasons of their relatively high fecundities, the probability of spawning more than once during a breeding season and so minimise the chance of a complete breeding failure, and the rapid growth rates in the first few years of life (see Growth chapter), *P. kaakan* and *P. argenteus* may be expected to withstand high fishing pressures. Such pressures may result, however, in a decrease in the average size of fish in exploited populations. The somewhat lower fecundity of *P. maculatus* is more likely to lead to a depletion of numbers of fish if populations of it should ever come under heavy exploitation. However, the fact that this species grows very rapidly and may reach a reproductive size in little more than a year (see Growth chapter), may counteract this. At present *P. maculatus* is not exploited by either amateur or commercial fishermen in this area, although large numbers are often taken as by-catch, and discarded as 'trash fish', during trawling in the prawn fishery. Increased effort in this fishery could lead to greater destruction of *P. maculatus*.

CHAPTER 6 - TAGGING AND MOVEMENT

6.1 INTRODUCTION

Tagging can be a very useful technique for obtaining direct information about growth and movements of individual fish in a population and, if a sufficient number of recoveries of tagged individuals can be made, the results may be extrapolated to the population as a whole. Certain problems however must be taken into account. Firstly, the fish tagged may not grow at the same rate as untagged fish due to interference in feeding, or stress, caused by the tag. Secondly, the tag may increase the chances of attracting a predator and therefore influence growth rate and survival; and thirdly, the effects of tagging may cause a change in normal behaviour patterns and movements. Despite these problems, fish tagging programs have been used widely, on many species of fish, as a direct method of studying growth and movements of individuals in a wild population.

Many types of tags exist for marking different species, including the Petersen disc tag, dart tags, anchor tags, streamer tags, opercular tags, 'spaghetti' tags, internal tags, etc. (Everhart *et al.*, 1975), and all have been used with some success. One of the more widely used external tags for marking relatively small fish is the anchor tag, consisting of a monofilament 'anchor' in the shape of a 'T' with an attached piece of polyurethane tubing, which can be imprinted with recovery instructions. The anchor is inserted through the flesh and behind the pterygiophores of the fish using a special tagging gun, the tubing remaining outside the body. This type of tag was initially used in the present study, since it has the advantages of being applied quickly and efficiently, and is fairly noticeable.

Anchor tags have been used in many tagging programs throughout the world, including Australia, although with varying success. In northern Australia this type of tag has been used on Barramundi (*Lates calcarifer*) in recent times (Davis and Reid, 1982; Davis and Kirkwood, 1984). By double tagging fish less than 350mm long with Floy FD67 tags, an instantaneous daily shedding rate of 0.0018 was estimated (Davis and Reid, 1982), and it was suggested that the rate declined with time. Eames and Hino (1983) also estimated a low tag loss rate of 2-5% for Floy anchor tags on juvenile chinook salmon in the U.S.A., and reported no significant effect on growth or survival over periods of up to two years. Ebener and Copes (1982), on the other hand, estimated a tag loss rate for Floy anchor tags of 11.1% in the first year and 20.5% over two years, for tagged Lake Whitefish (*Coregonus clupeaformis*) in the U.S.A., and Gilmore (1982) reported problems of tag breakdown for this type of tag in tropical waters.

Prior to the present study, there had been no tagging studies of *Pomadasys* species either in Australia or overseas, and only two tagging studies of *Haemulon* species (Moe, 1966; Beaumariage, 1969).

Both studies concerned *H.plumieri*, and the study by Moe also included *H.sciurus*.

Most of the information on movements of *Pomadasys* species has been inferred from changes in abundance in certain areas. For example, Wallace and Schleyer (1979) noted that the period of lowest occurrence of *P.commersoni* in South African estuaries is winter and they attributed this to emigration to the sea. Similarly, Shuntov (1971) noted the absence of concentrations of *P.maculatus* in the shallower southern Gulf of Carpentaria (northern Australia) during winter. He suggested a movement of the fish into deeper waters at this time, due to a cooling of the water to 20-23°C, whereas the temperature of the open water of the Gulf did not fall below 25°C.

The existing ideas on movements of *P.kaakan* and *P.argenteus* in North Queensland prior to this study were based on inference, and 'local knowledge' of fishermen. These suggested that during the spawning season there is a 'grunter run' when fish become much more plentiful, possibly associated with a downstream movement of these species within the estuaries to spawn. There was also a belief that larger fish tend to move progressively downstream during their lives.

The purpose of this tagging study was firstly to provide further data on growth of individual fish, and secondly to test the hypothesis that these fish move downstream at some time in their lives, and particularly during the spawning season.

6.2 METHODS

Fish were captured by line fishing using conventional rod and reel methods at various sites in Barramundi Creek (Fig. 2). Two species, *P. kaakan* and *P. argenteus*, were tagged in this study.

When captured, the fish were unhooked immediately and transferred to a 25 litre polystyrene container half full of water taken from the capture site. The fish were allowed to stabilise for a few minutes in the container and those that showed injury, or did not swim normally, were removed and retained on ice for later study. Undamaged fish were lifted from the container by hand, measured to the nearest millimetre in total length on a wet measuring board, then tagged. When using anchor tags special care was taken to ensure the 'anchor' was placed securely between the pterygiophores. The small tagging wound was irrigated with a 1:4000 Acriflavine solution and the fish was then released. Recaptured tagged fish were treated in the same way, though generally re-released with the original tag rather than being retagged. Most fish tagged were less than 350mm TL.

Initially fish were tagged with yellow Floy FD67-C anchor tags. These were found to be unsuitable due to breakdown of the adhesive between the 'anchor' monofilament and the polyurethane tubing (Gilmore, 1982) and thereafter fish were tagged with grey Floy FD68-BC anchor tags and/or a modified one-piece clothing 'Tagger Tail' fastener (Plate 10), also of an anchor type but which will be referred to as a 'clothes tag'. The Floy tags were a total

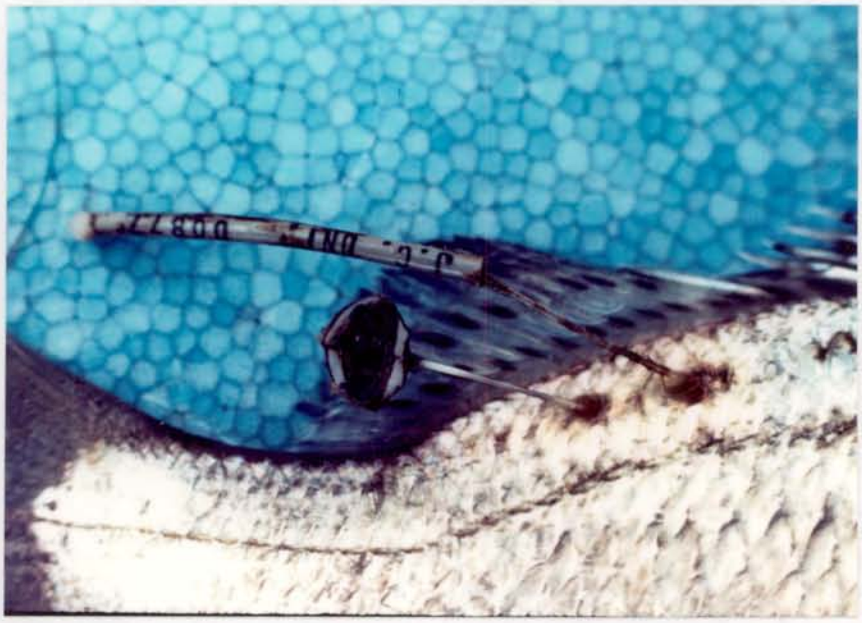

Plate 10. Floy FD-68BC anchor tag and modified one-piece 'clothes' tag in place on a recaptured *P. kaakan* (Tag N° 877 374), after 31 days of freedom. (TL = 184mm)

of 55mm long, with 25mm of monofilament from the anchor and 30mm of polyurethane tubing, which was imprinted with the information 'Inform Biol. J.C.Uni.' plus an identifying number. The clothes tags were 30mm long, with 25mm of monofilament from the anchor to a semicircular nylon disc 5mm in radius. The semicircular disc was trimmed at the ends to reduce the likelihood of it becoming tangled in snags or weed. This tag was printed by hand with a three digit number and the letters 'J.C.U.', using a black Stabilo (OHPen 76P) permanent overhead projection marking pen. Tags were implanted just anterior and ventral to the posterior end of the dorsal fin, using a Monarch 3030 tag applicator. Larger fish were often double tagged. As a countercheck to effective tag retention and effects on the fish, a number of tagged (Floy and 'clothes') specimens were held in cylindrical tanks (1m diameter with a volume of 950 litres) in a circulating saltwater aquarium system. These fish, of each species and variable size, displayed no obvious ill effects with respect to feeding and activity and survived equally well as untagged fish under the same conditions, over keeping times up to six months.

Monel opercular tags were also used in the early stages of the project to double tag fish but this was discontinued due to the rapid loss of these tags from the fish.

A sign (120cm by 80cm) was erected at the only boat launching facility on the estuary, informing the public that tagged fish had been released in the river and indicating the action to be taken if a tagged fish was caught. This sign remained in place for the duration of the project.

6.3 RESULTS

A total of 1623 *Pomadasys* were tagged at Barramundi Creek from June 1981 to August 1985, with a total recovery of 258 (15.9%). Most of the fish recovered were recaptured by the author, either fishing alone or with a colleague, and only 4% were returned by other fishermen. The advantages resulting from the author making most of the recoveries were that accurate measurements of length at recapture could be recorded, which increased the usefulness of the data, and also the fact that fish could be re-released allowing additional data to be obtained from some individuals. A number of fish were recovered more than once, with a few fish being recaptured three and four times. These advantages are usually not possible when sole reliance is placed upon the public for recoveries. Recovery data for individual recaptures are presented in Appendix 1.

Of the *Pomadasys* tagged, 1288 were *P. kaakan* of which 202 (15.7%) were recovered, while 335 were *P. argenteus* of which 56 (16.7%) were recovered. Table 4 shows the recovery rate, and loss rate where this could be determined, of the various types of tags used in this study, for *P. kaakan* and *P. argenteus* combined.

From Table 4 it can be seen that most fish were tagged using the 'clothes tag', or double tagged with both a Floy FD68-BC and a

Table 4: Number of fish tagged, recovery rate and known loss rate for *Pomadasys* tagged at Barramundi Creek.

Tag Type	Nº of Fish Tagged	Nº of Fish Recaptured	(%)	Nº of Tags Known Lost		(%)
Floy FD 67-C	306	52	(16.9)		12	(3.9)
Floy FD 67-C + Monel	36	11	(30.5)	Fl	5	(13.8)
				Mo	9	(25.0)
Monel only	40	3	(7.5)		?	?
Floy FD 68-BC	126	9	(7.1)		3	(2.4)
Floy FD 68-BC + Clothes	524	61	(11.6)	Fl	14	(2.7)
				Cl	0	(0)
Clothes only	554	122	(22.0)		5	(0.9)

Fl = Floy Tag   Mo = Monel Tag   Cl = Clothes Tag clothes tag. The recovery rate for the clothes tag alone was very high (22%), while that for the Floy FD 68-BC tag alone was 7.1%. When fish were double tagged, 11.6% were recovered; of these 2.7% had lost the Floy tag but retained the clothes tag, while none had lost the clothes tag and retained the Floy tag. Possibly some fish had lost both tags but this could not be determined. Similarly, for those fish single tagged with a clothes tag or a Floy tag, the tag loss rate could not be determined. However, for the clothes tag, 5 (0.9%) had the outer part of the tag removed and only the shaft remained, while 2.4% of Floy tags suffered the same fate. These losses may possibly be attributed to biting off by the puffer fish *Gastrophysus lunaris* which was often caught in the study area.

Fish that were tagged solely with monel opercular strap tags had a recapture rate of 7.5% but this applied for only short periods of freedom (less than 30 days). There was no way of determining the loss rate of these tags but as recaptures were not continued it appeared to be high. Those fish tagged only with Floy FD-67C tags had a recapture rate of 16.9%, though maximum freedom time was 118 days. These tags had a minimum known loss rate of 3.9%, where only the monofilament shaft of the tag remained and the polyurethane tubing had been lost, but the total loss rate could not be assessed as numbers of missing whole tags could not be determined. Where both Floy FD-67C tags and monel opercular tags were used together the recovery rate was unusually high (30.5%). However, again the periods of freedom were short, with all recaptures in less than 46 days. All recaptures after 16 days had lost the monel opercular tag. Of the total number of fish tagged in this way, 13.8% had lost the Floy tag and retained the monel tag (within 16 days), while 25% had retained the Floy tag but lost the monel opercular tag, at recapture. This suggests that a considerable proportion would have lost both tags but this cannot be determined from the data.

From the high loss rate, particularly of the monel opercular tags but also the Floy FD-67C tags, it is clear that the recapture rates of fish singly tagged with these tags are underestimated. The fact that no clothes tags were lost from fish that were double tagged, also with Floy FD-68BC tags, suggests that the recovery rate for clothes tags used alone would be a good indication of the actual recapture rate, which is about 23% (allowing for the 0.9% loss of the outer part of the tag from some fish). This figure does not take into account tag loss due to predation on the tagged fish, so that the likelihood of a fish being removed from the population, within say a year, would be considerably greater than 23%.

While the overall recapture rate for *P.kaakan* and *P.argenteus* is fairly similar, 15.7% and 16.7% respectively, there is considerable difference in the mean period of freedom for the two species. The average period of freedom for tagged *P.kaakan* was 58.5 days (SD = 71.9) while the average period of freedom for tagged *P.argenteus* was 95.1 days (SD = 86.7). From Table 5 it can be seen that more *P.kaakan* were caught in the first 20 days after release while *P.argenteus* were recaptured at a more constant rate up to 100 days after release. A chi-square analysis indicated that there was

Table 5: Freedom time distribution of recaptured tagged *P. kaakan* and *P. argenteus* from Barramundi Creek.

Days free	P. kaakan (n=202)		P. argenteus (n=56)	
	Nº	%	Nº	%
0 - 20	67	33.0	6	11.0
21 - 40	45	22.0	10	18.0
41 - 60	29	14.5	7	12.5
61 - 80	19	9.5	9	16.0
81 - 100	9	4.5	7	12.5
101 - 120	10	5.0	4	7.0
*121 - 160	11	5.5	4	7.0
>160	12	6.0	9	16.0

* 121-140 and 141-160 combined

a significant difference ($0.01 > P > 0.001$) in the freedom times of the two species ($\chi^2 = 20.8$; df = 7). The maximum period of freedom for a tagged *P. kaakan* was 517 days, compared with the maximum for *P. argenteus* of 473 days.

The only fish recaptured which was larger than 300mm at release was a 322mm *P. kaakan* (Tag N° 113 000). This fish was released at site B on the 8th of November, 1982, and after 33 days of freedom had moved to site F, a distance of approximately 8km downstream.

Most of the tagged fish, of both species, were recaptured at the same site at which they were released. Only 13 (5%) of the *P. kaakan* had moved from one site to another, while 14 (25%) of the *P. argenteus* had moved from one site to another, but only 4 had moved more than from one site to the next adjacent site. The greatest distance moved by a tagged *Pomadasys* was approximately 11km.

Because a number of fish were recaptured more than once, valuable information on growth of these species was obtained. Additional results are presented in the Growth chapter to follow, but some basic data are presented here.

Figures 12 and 13 show the growth in length of tagged *P. kaakan* and *P. argenteus* respectively, that were less than 300mm TL at release and had been free for periods between 28 days and 100 days. This time interval was chosen to allow a reasonable number of fish to be included in the data set, while also enabling a reasonable comparison of the effects of seasonal climatic changes

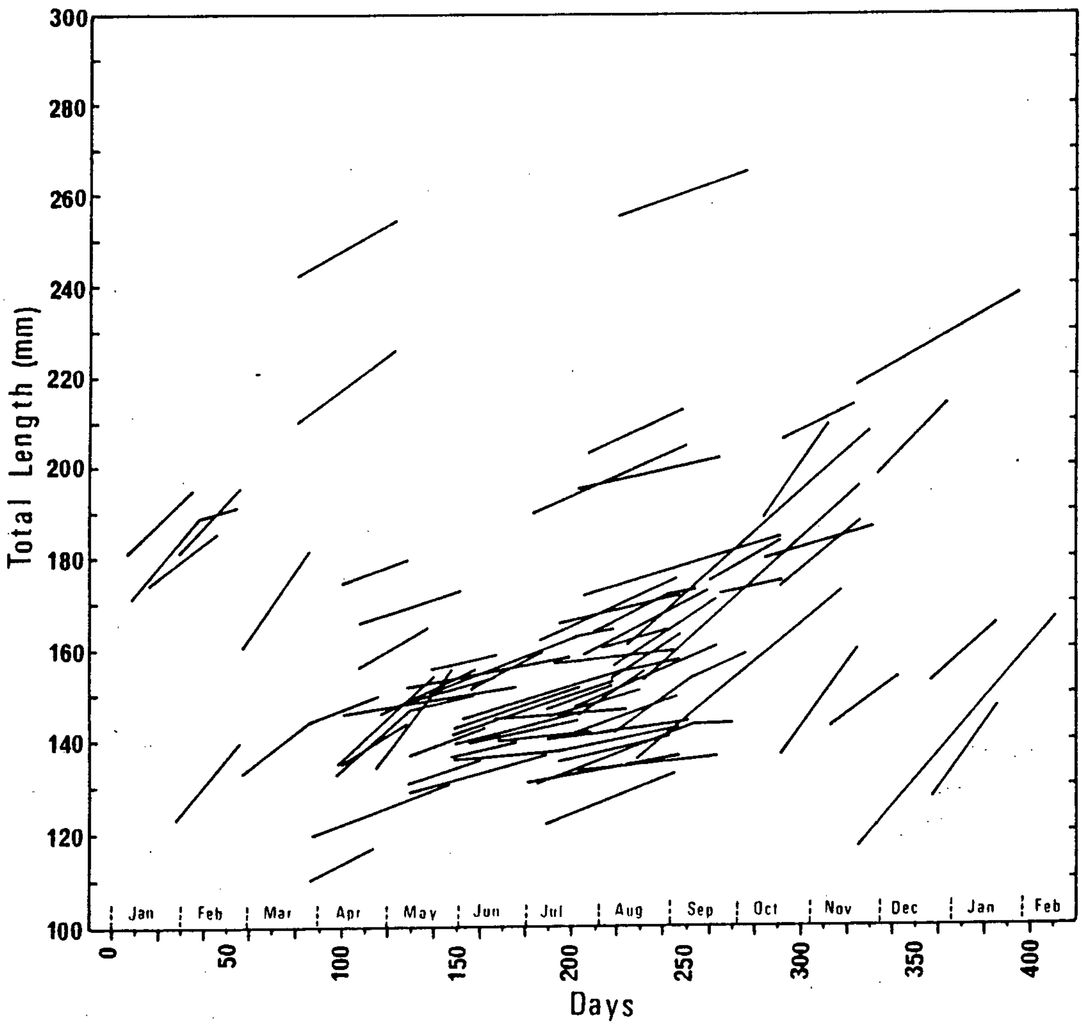

Fig. 12. Growth in length of tagged *P. kaakan* from Barramundi Creek, less than 300mm TL at release and free between 28 days and 100 days.

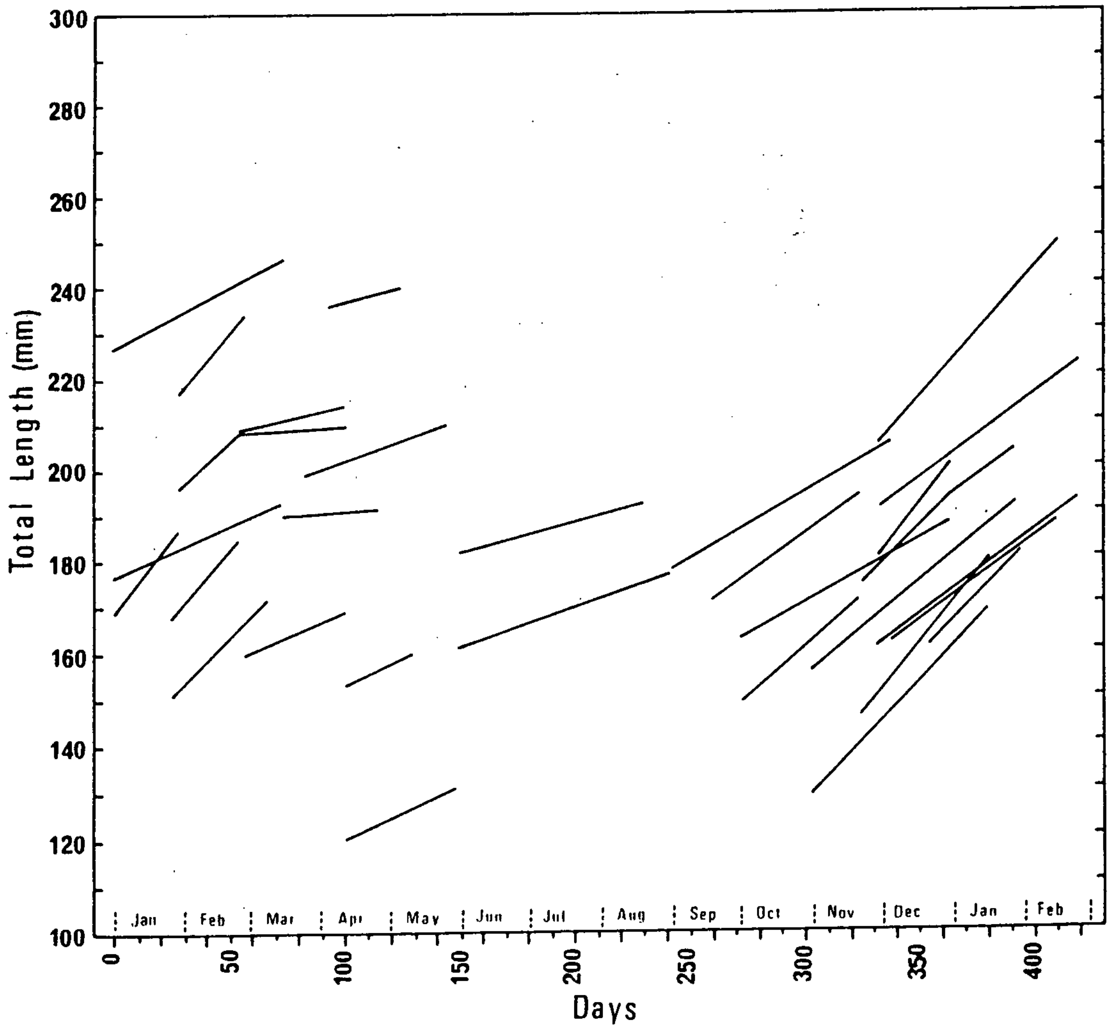

Fig. 13. Growth in length of tagged *P. argenteus* from Barramundi Creek, less than 300mm TL at release and free between 28 days and 100 days.

on growth. Since 100 days is just over three months, this seemed a reasonable unit of relative climatic stability. Recoveries over this duration would be expected to give the best indication of growth over the given months, since there would be less melding of seasonal differences in growth rates. These would be obliterated over longer time periods. Thus the slopes of the growth lines between, say May and August, are much flatter on average than the growth lines of fish tagged from August to December.

The results of mean growth per day plotted against time for individual tagged and recaptured fish, less than 300mm at release and free between 28 days and 100 days (Figs. 14 and 15 for *P. kaakan* and *P. argenteus* respectively), show that the slowest average growth per day for *P. kaakan* is recorded for fish tagged from May to July and growing over the winter months. Growth of between 0.1mm and 0.2mm per day is indicated over this period. For fish tagged between October and January growth averaged 0.4mm to 0.5mm per day within the size range tagged. The results are very similar for *P. argenteus*.

Results from single tagged fish and double tagged fish are differentiated in Figs. 14 and 15 but show no consistent pattern.

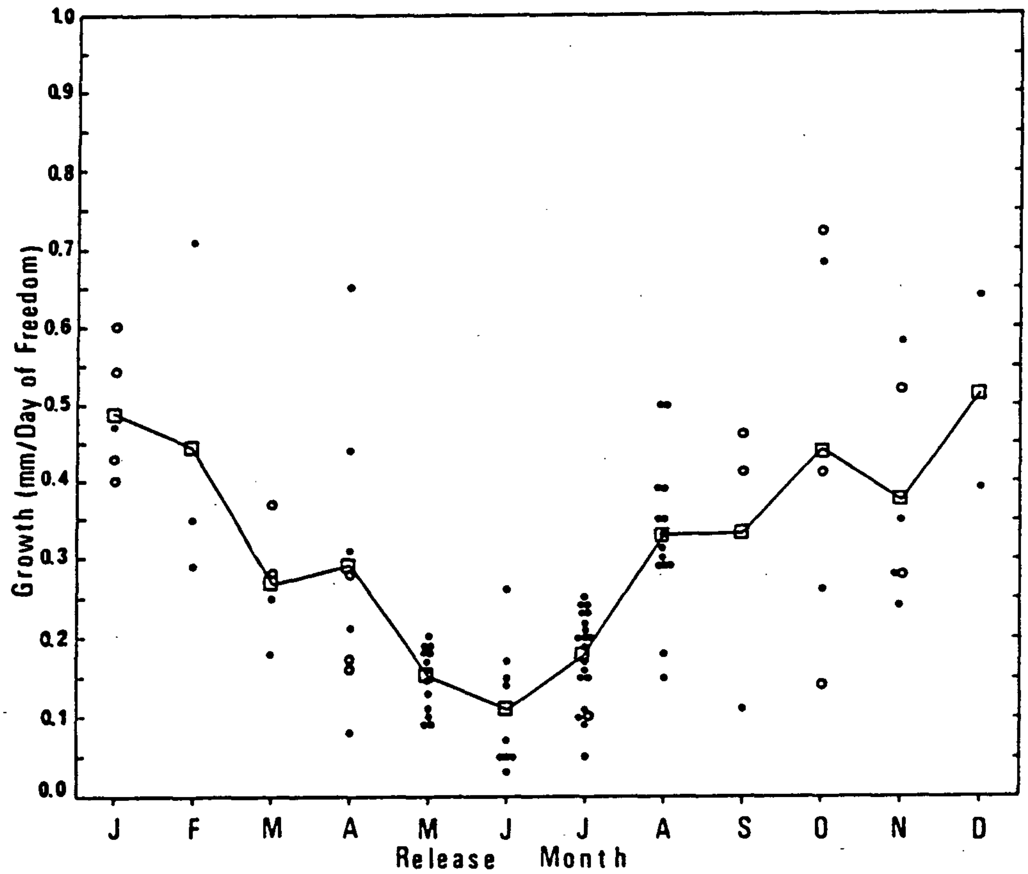

Fig. 14. Growth per day for recaptured tagged *P. kaakan* from Barramundi Creek less than 300mm TL at release and free between 28 and 100 days.

(● = single tagged fish. o = double tagged fish. □ = mean)

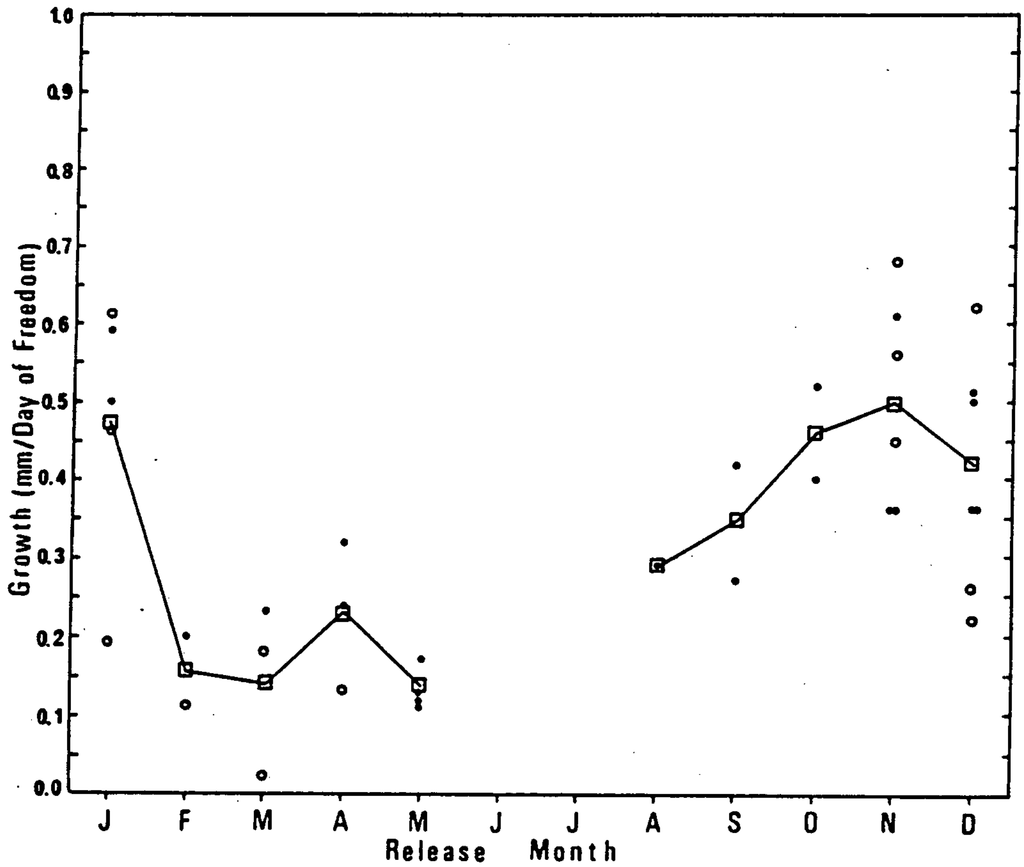

Fig. 15. Growth per day for recaptured tagged *P. argenteus* from Barramundi Creek less than 300mm TL at release and free between 28 and 100 days.
(● = single tagged fish. o = double tagged fish. □ = mean)

6.4 DISCUSSION

One of the reasons for selecting Barramundi Creek as the tagging site was its high usage by fishermen and, consequently, the anticipation of good recapture rates. The fact that only 4% of recoveries were taken by fishermen other than the author was very surprising, since the tags were printed with recovery information and a large sign was erected, at the only boat launching facility on the estuary, drawing attention to the fact that tagged fish had been released and advising the procedure to be followed if a recapture was made. However, although the sign was 120cm by 80cm and located right beside the boat ramp, it was apparent from conversations with fishermen that some had not taken much notice of the sign.

One possible explanation of low recovery rate by other fishermen is that some use heavy gear and live bait specifically for larger fish and thus may not have sampled the size range of tagged fish. Nevertheless, many fishermen using the estuary also fish with light gear similar to that of the author and would have been catching fish in the size range tagged. This was evident from the fact that on several occasions the author recaptured tagged fish that had clearly been caught and released by another fisherman a few days before, judging from hook wounds around the mouth of the fish. None of these recaptures by other fishermen were reported.

Other explanations of non-reporting of tag recoveries may have been that the fisherman did not see the tag, for example if fishing at night; or, because most tagged fish were smaller than the minimum legal size for the species, fishermen may have decided that it was best to release the fish without reporting the capture, even though the sign specified that any tagged fish should be kept and reported.

The large number of recaptures taken by the author is probably also attributable to the fishing of specific sites on each research trip. The results suggest that many fish of the size range tagged may have moved very little, if at all, from the tagging sites. This attachment to a particular site for significant lengths of time would have increased the chances of an individual being recaptured. On many occasions though, other fishermen were noted to fish these same sites but few recoveries were reported. Thus the general low recovery rate by other fishermen is probably the result of a number of factors, but non-reporting of recaptures was undoubtedly fairly common.

There could be a number of possible explanations for the different freedom times of the two species. These include better tag retention by *P. argenteus*, though this seems unlikely considering the morphological and habitat similarities of the two species. There could have been better survival of *P. argenteus* after tagging since the average size of these fish at release was a little larger than for *P. kaakan*. It is also possible that the difference may be accounted for by different feeding behaviour. *P. kaakan* are likely to be more aggressive feeders since they typically take mobile prey such as crustaceans in their diet, while

P. argenteus feeds to a greater extent on less mobile prey such as bivalve molluscs. In competition for a bait, *P. kaakan* may have had an advantage and therefore been more likely caught or recaptured. Thus, it is difficult to say whether the difference observed is a real one or an artifact of the sampling method.

'Local knowledge', gleaned from conversations with fishermen, suggested that there is a downstream movement or 'run' of grunts to spawn in the spring. This is not generally supported by the tagging results, though most of the fish released were smaller than spawning size, and non-reporting of recaptures by other fishermen would have meant that most fish that may have moved from the tagging site would not have been reported. Of *P. kaakan* larger than 200mm at recapture, and probably close to mature, only 7 (21%) had moved further than 1.5 km, however, 6 of the 7 had moved downstream. The movements of these fish occurred between August and October, November and December, April and November, January and April, June and January, and May and October. The one fish that had moved upstream did so between November and January.

Of 29 *P. argenteus* larger than 200mm at recapture, 8 (28%) had moved more than 1.5 km, three downstream between the months September to February, May to June, and March to June, while five moved upstream between the months November to February, December to March, January to February, May to December, and May to February.

Only 3% of recaptured *P. kaakan*, and 19% of *P. argenteus*, smaller than 200mm at recapture had moved more than 1.5km. About half of the recaptured individuals of each species had moved upstream and about half had moved downstream. Therefore, while there does not seem to be any regular pattern in the movements of tagged fish indicated in this study, larger fish may move further than those tagged. It seems most likely that *P. kaakan* and *P. argenteus*, up to 200mm at least, 'settle' at a particular site in the estuary and move short distances either side of this area to feed. The fact that few larger fish were captured near spawning condition may indicate movement of larger fish from the tagging sites close to spawning time, or as noted earlier, may indicate inactivity at spawning time. Moe (1966) and Beaumariage (1969) reported no significant movement of tagged *Haemulon* species in their studies.

Observation of captive pomadasyids indicated that individuals of *P. kaakan* and *P. argenteus* in the tagged size range tended to stay close to a 'preferred' position of shelter provided by a particular piece of wood or rock in preference to others. They were often aggressive and exhibited territorial behaviour toward other fish, especially other grunts. If the same behaviour was exhibited by individuals within wild populations it would favour survival against predatory fish, such as Barramundi (*Lates calcarifer*) (Russell and Garrett, 1982), Cooktown Salmon (*Eleutheronema tetradactylum*), Mangrove Jack (*Lutjanus argentimaculatus*), Estuary Cod (*Epinephelus tauvina*), and Trevallies (Carangidae), common in local estuaries. Small *Pomadasys* were often caught with obvious tooth wounds on the body, suggesting a recent encounter with a predator, and remaining close to a known shelter may be a distinct survival advantage in limiting such attacks and assisting escape. This would also help explain the localised recaptures of tagged fish in this study.

The most reliable tag used in this study was the personally modified clothes tag. This type was retained effectively on the fish and only caused a very small wound which generally healed over rapidly. All the tags used, except the monel tags, attracted a growth of algae after about one month in the water. The algal filaments rarely grew longer than 1mm but sometimes formed a dense cover which obscured the printed information on the tag when fish were free for long periods. However, the algae were easily removed by scraping the tag with a fingernail, and the printing underneath was unaffected. The algal growth did not appear to affect the retention of the clothes tags because of their small size, but may have had an effect on the Floy tags.

The fact that a number of fish were recaptured more than once suggests that the capture and tagging process used in this study had little adverse effect on the fish. In fact, on one day two fish were recaptured that had each been caught and tagged less than three hours before, at the same place and using the same gear. These observations concur with those on the fish kept under aquarium conditions.

The high recovery rate of fish tagged with the clothes tag (23%, allowing for losses due to predation on the tag itself) points to a high exploitation rate of the two species in Barramundi Creek. This result could be biased since it is based on recoveries of smaller fish, which appear to remain around the same areas. However, it probably relates to a reasonably high exploitation rate of the larger fish also, recognising that these are the preferred target of most recreational fishermen. The recovery rate for the clothes tag is high compared with most studies (Gilmore, 1982), for which a 10% recovery has been considered good. As noted, this may partly be due to the fact that the tagged fish were not moving far and therefore were accessible to recapture, but no doubt it is also due to the use of a successful tag which had little effect on the general habits and survival of the fish. Recovery rates for the Floy tags were much lower, indicating that a considerable percentage of these were being lost.

There is considerable variation in the calculated mean growth per day of tagged fish. This would have been dependent on the duration of freedom, the time of the year, and also on the size of the fish when tagged. A fish tagged in June and free for 28 days would be expected to have slower growth, on average, over that period than one free for 100 days and therefore growing during July, August, and September as well, since there is a marked change in water temperature from summer to winter; and as the growth of fish is asymptotic, fish tagged at a larger size would be expected to have smaller length increments over a given period of time than smaller fish. However, most of the tagged fish were within the 100mm to 200mm size range when tagged, and for a given 28-100 day period growth rate might be expected to be more comparable than observed. The considerable individual variation in average growth per day for fish tagged in a given month therefore indicates a real difference in the growth rates of individuals of both species.

Another possible factor influencing individual growth rate may have been the effect of the tag. As will be noted in the Growth chapter, however, the average growth per year estimated from the tagged fish in this study is very close to that estimated from length frequency analysis and scale reading. Also, a number of fish were double tagged (see Figs. 14 and 15) and this may have been expected to have an adverse effect on growth. This is not evident from the results shown in the figures since many double tagged fish had relatively high average growth per day values.

Therefore it can be confidently concluded that, in most cases, the tags had little effect on normal growth rate and that observed differences between tagged fish largely resulted from the individual variation of fish in the population.

CHAPTER 7 - GROWTH

7.1 INTRODUCTION

Various methods have been employed to study growth in fishes. Most commonly these include the analysis of length frequency distributions; the analysis of marks on hard parts of the body especially scales, otoliths and vertebrae; and the analysis of tag and recapture data when the period of freedom is of a reasonable duration. Each of these methods has been employed in the present study.

There are relatively few reports in the literature of growth in haemulids, and only a few concerning the genus *Pomadasys*. In these reports most authors have relied on length frequency analysis and the use of scales, otoliths and vertebrae to determine growth rates. There have also been a few studies of the growth of larval and postlarval *Haemulon* species in North American waters (Saskena and Richards, 1975; Brothers and McFarland, 1981) in which more direct rearing techniques were employed.

The fact that most species of *Pomadasys* are tropical or subtropical fishes may help to explain the paucity of growth studies undertaken on them, since tropical species are often more difficult to age than temperate ones due to the lack of marked climatic seasonality at low latitudes. Most of the studies of growth that have been undertaken on this group concern species from Indian waters (Basheerudin and Nayar, 1962; Deshmukh, 1973; Namalwar, 1974), some of which may be conspecific with Australian species; and from Central America (Warburton, 1979; Blake and Blake, 1981) which are different species to those in Australian waters. Some work on *Pomadasys* species has also been undertaken in the Middle East (Ovens and Salekhova, 1970; Hussain and Abdullah, 1977; Abu-Hakima, 1984) and China (Chevey, 1934), but little information on growth has resulted. There have been no previous studies on growth of *Pomadasys* species in Australian waters.

Blake and Blake (1981) used check marks on the scales of *Pomadasys macracanthus* from a Mexican coastal lagoon to study growth in this species. They found that one check mark per year was formed on the scales corresponding to the time of the rains (July to October). They suggested that the mark was a result of the rapid decrease in salinity and temperature in the lagoon system due to freshwater inflow. Warburton (1979) used length frequency analysis to study growth in *P. macracanthus* from the same area.

Deshmukh (1973) used length frequency analysis, and scale and otolith reading, in his study of growth in '*P. hasta*' from Indian waters. As previously noted in the Taxonomy section, there is some confusion in the literature due to the application of the name *P. hasta* to different species. It is most likely that the species studied by Deshmukh as *P. hasta* is a similar but different species to *P. kaakan* (which has been referred to in some of the Australian literature as *P. hasta*). Deshmukh used 40mm class intervals to analyse lengths of fish taken by commercial trawlers, and 10mm class intervals for fish from barrier nets. He suggested that an

85mm size group in January/February is a result of the September to December spawning and that by May (after a further 3 months) these have grown 60mm to be 145mm TL. From this he extrapolated that by one year old these fish would be approximately 240mm. Assuming second and third year growth at 10mm per month he suggested that in October the first three year classes were, on average, 225mm, 345mm and 465mm respectively. Deshmukh found scales to be unreliable for growth studies due to the presence of false annuli and thickening at the centre of the scale, so he used otoliths instead. He noted that rings were completely absent in the otoliths of fish smaller than 120mm, and the first three rings corresponded to total lengths of 246mm, 346mm and 465mm, which corresponded to the first three modes in the length frequency study, and so he concluded that only one ring was formed per year. It was suggested that these were not spawning rings but were due to lower water temperatures from November to January. Growth of 60mm in the fourth year and 40mm in the fifth year was suggested.

Namalwar (1974) studied the vertebrae of '*P. hasta*' from Indian waters for growth rings. He found that specimens of 235mm, 380mm, 485mm, 532mm and 568mm had 1 to 5 rings respectively. These rings were also found in other bones such as the operculum, cleithrum and palatine.

Chevey (1934), in studies on fishes in Chinese waters, found for *Pristipoma argenteum* (= *Pomadasys argenteus*) that marks were present on the scales of fish from the Gulf of Tonkin but not of fish from Cochin-China, the latter locality being closer to the equator. He interpreted this variation as being due to winter conditions of reduced temperatures in the Tonkin area, which were absent in Cochin-China. He concluded that a difference of only 4°C or 5°C between summer and winter water temperatures was sufficient to cause slowing of growth in fish and marking on the scales. No actual growth values were given for *P. argenteus* in that paper. Menon (1953) on the other hand suggested inherent physiological rhythms to be the more likely causative factor in the formation of growth checks on scales of fish from tropical waters, rather than changes in temperature or food supply.

The only indications of what growth rates may be in *Pomadasys maculatus* are given by Basheerudin and Nayar (1962) and Naumov (1968, in Konchina, 1978), the latter giving only a maximum size. Basheerudin and Nayar sampled some *P. maculatus* from Indian waters and reported a size range of 20-50mm, with the major group around 50mm, in March and April.

Konchina (1978) attempted to summarise the literature concerning the family Haemulidae. From the *Pomadasys* data maximum lengths were indicated for *P. hasta* (? = *P. kaakan*) of 600mm (with a weight of 6kg); for *P. argenteus* of 500mm; and for *P. maculatus* of 450mm. Konchina stated that the bulk of species of Grunt are represented by fish 300mm to 600mm long, which may live to 7 years of age. Ovens and Salekhova (1970, in Konchina, 1978) gave values for length at age for '*P. hasta*' in the Gulf of Aden. They indicated a very slow growth rate, suggesting a length of 175mm at 3 years old, together with annual length increments of 20mm, 14mm, and 4mm over the next three years respectively. From this they concluded a 213mm fish would be 6 years old and close to its maximum size. These values vary markedly from growth rates given for *Pomadasys* species by other workers.

7.2 METHODS

Three different methods were used to study growth in local *Pomadasys* species; progression of length frequency modes, scale and otolith reading, and tag and recapture.

Fish from Cleveland Bay were sampled both by trawling and by small mesh beach seine. Each fish collected was measured to the nearest millimetre in total length, and most in fork length and standard length also. A representative sample of the trawled fish from each collecting trip was taken to provide scales and otoliths.

Scales were removed from under the pectoral fin, just posterior to the axil of the fin. Six to ten scales from each fish were cleaned by rubbing between two fingers with a drop of fresh water. Replacement scales, which could be easily recognised by their large opaque focal area with no circuli (Plate 13), were rejected for individuals of *P. kaakan* and *P. argenteus* but were included in the scale samples for individuals of *P. maculatus*. The latter species often had very few non-replacement scales, and the replacement scales appeared fairly uniform in the size of the focal area. This suggested that most of them were formed at about the same time.

Scales were mounted between two glass microscope slides, bound at the ends with adhesive tape and labelled with an identifying number. These were examined using a Nikon model 6C Profile Projector, which allowed an image (of fixed magnification) of the scale to be projected onto a ground glass screen and for check marks to be distinguished. These could be recognised by the 'crossing over' of the circuli, that is where one or more circuli end against an outer circulus (see Plates 11 and 12). Image measurements were made along a line from the focus of the scale to the anterior margin, and from the focus to each check mark, using a transparent millimetre rule for at least three scales of the sample. All scale samples were 'read' at least twice on separate occasions, and the few that could not be read consistently were eliminated.

It was also intended to use otoliths to complement scale reading data and the sagittal otoliths were removed from all fish from which scale samples were taken in the early part of the study. The otoliths were excised, washed and stored in small paper envelopes labelled with the same identifying number as the scale sample. The otoliths were observed both as whole structures immersed in glycerine, using a stereo dissecting microscope with either transmitted or reflected light; and as sectioned material having been cut longitudinally with a diamond saw and polished. This involved embedding the cut otolith in Hatricks epoxy resin, preliminary grinding with up to 600 grit (30μm) aluminium oxide,

Plate 11. Scale of a 200mm TL *P. argenteus*, showing two marks.

Plate 12. Magnification of a mark on the scale of *P. argenteus*.

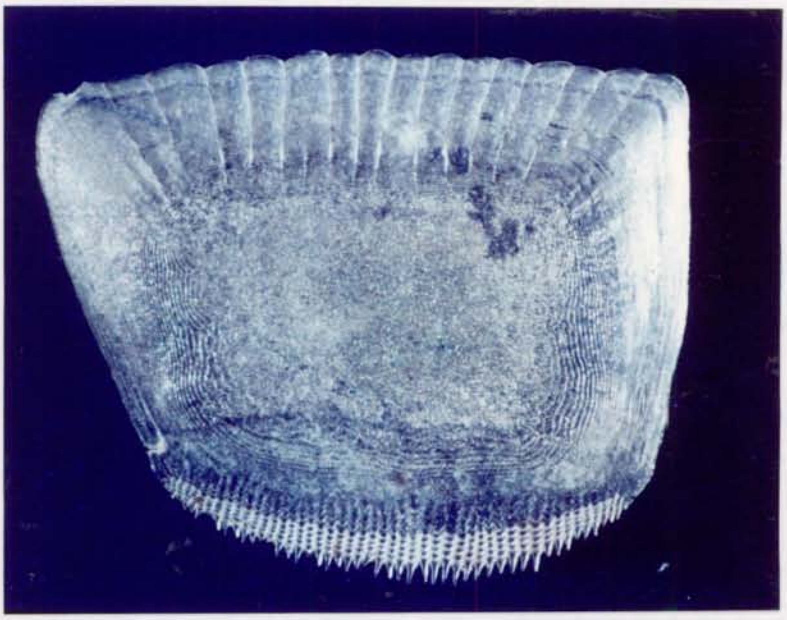

Plate 13. Replacement scale of a 160mm TL *P. maculatus*.

then polishing with 0.05μm alumina polishing powder on a Hypocel P.S.U. lapping pad.

Only fish from Barramundi Creek were used in the tagging program experiments, since the fish collected from Cleveland Bay were generally damaged in the trawl and unsuitable for marking and release. At Barramundi Creek, fish were caught by line fishing and only fish that had been hooked in the mouth and were undamaged were tagged (see Tagging chapter for details of method). Several different tags were used but the most successful was a modified nylon clothes tag, originally intended to attach price labels to garments. Recaptured fish were measured and re-released whenever possible.

Total length measurements were used in the length frequency analysis and for back-calculations of lengths from mark positions on the scales.

7.3 RESULTS AND DATA INTERPRETATION

Otoliths proved to be of little value in ageing local *Pomadasys* species. In most cases growth rings could not be distinguished clearly and could not be counted consistently on replicate attempts. Scales, on the other hand, exhibited more distinctive markings. These varied in clarity but for individual fish showed considerable constancy, and, once some familiarity with them had been gained, could be read with good, repetitive consistency.

Least squares regression equations of scale radius against fish length indicated a linear relationship. No significant difference (P > 0.05) was found between the relationship of males and females and data from the scales of the two sexes have been pooled for each species. The equations relating scale radius (R) in millimetres to total length (L) are

P. kaakan $L = 5.32 + 36.18\ R$ $(r = 0.95)$

P. argenteus $L = 6.67 + 36.67\ R$ $(r = 0.95)$

P. maculatus $L = 10.80 + 44.33\ R$ $(r = 0.95)$

This allowed confident back calculation of fish length at annulus formation.

7.3.1 *P. kaakan* - Barramundi Creek.

(a) Length Frequency:

Figures 16, 17, and 18, show the length frequencies, in 10mm size classes, of *P. kaakan* caught at Barramundi Creek each month during 1982, 1983 and 1984 respectively. From the figures it can be seen that the smallest *P. kaakan* were taken in February of each year at a size between 80mm and 100mm. This is the lower size limit of fish that were sampled by line fishing. A few of these small fish continued to be captured through most of the remaining months of the year, but the bulk of this size group can be followed through the length frequency modes to form the 'young of the year' age class. As has been shown in the Reproduction section, spawning occurs over a prolonged period with fish probably being capable of

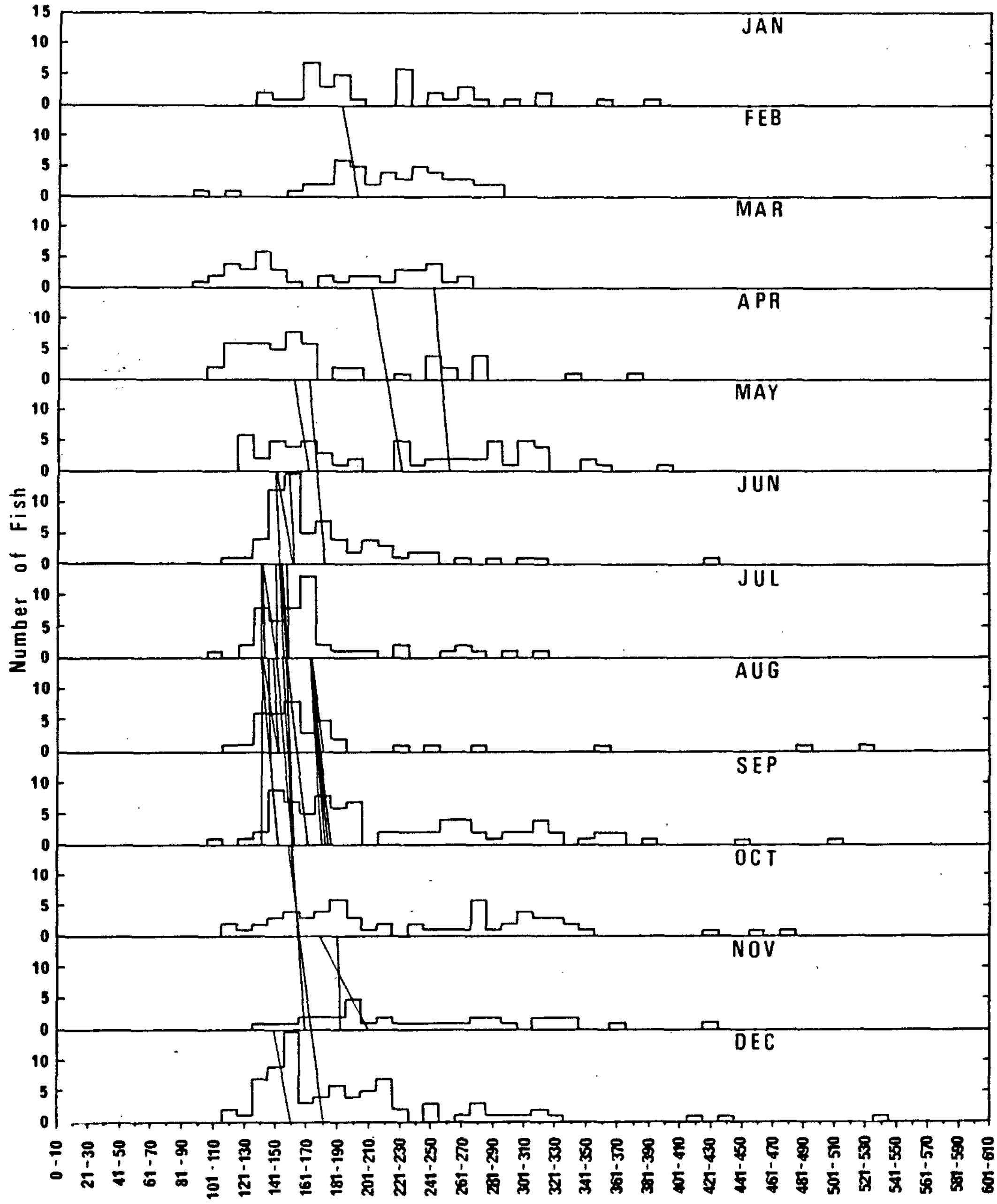

Fig. 16. Length frequency histograms of *P. kaakan* caught from Barramundi Creek each month in 1982, with tag recovery data superimposed. Straight lines join size at release and recapture.

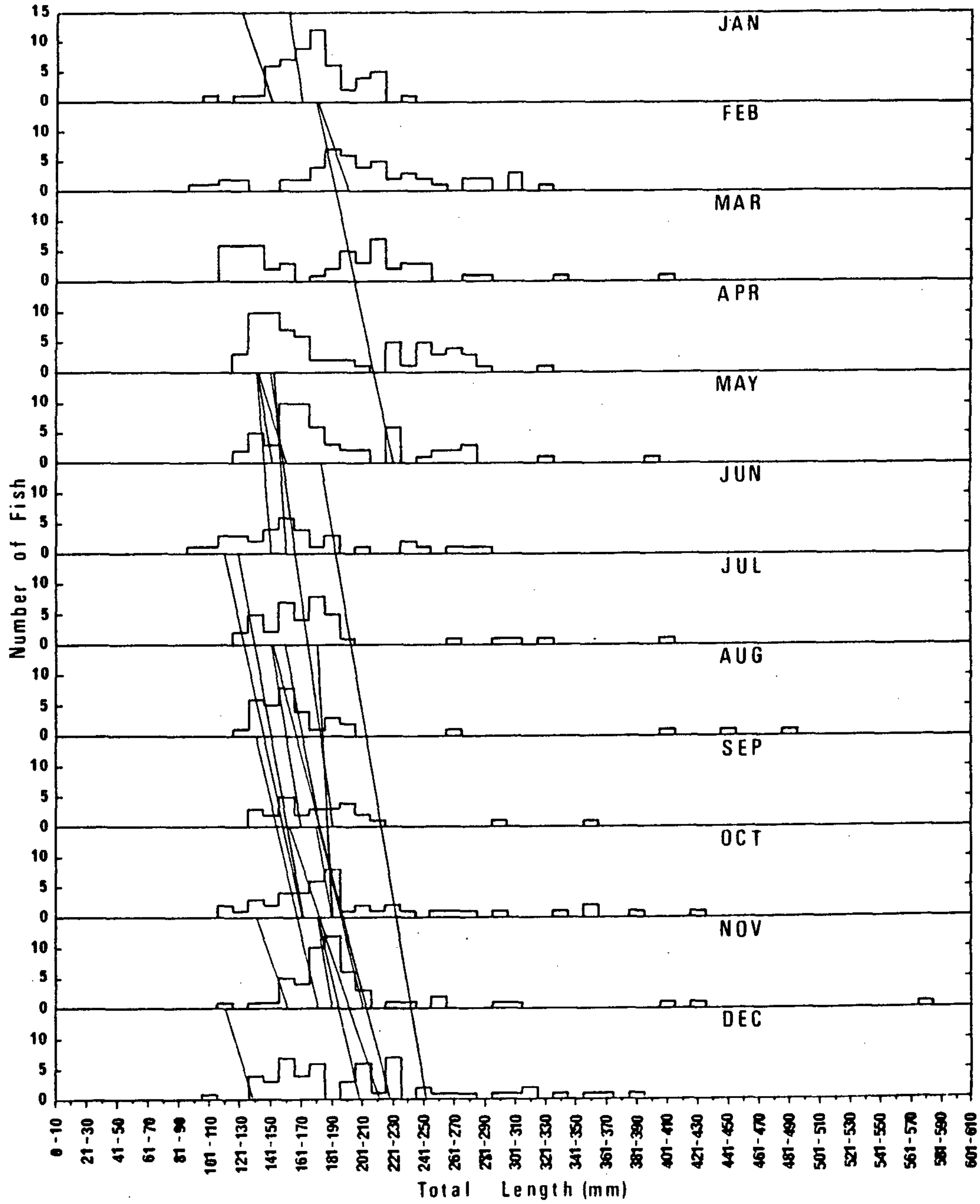

Fig. 17. Length frequency histograms of *P. kaakan* caught from Barramundi Creek each month in 1983, with tag recovery data superimposed. Straight lines join size at release and recapture.

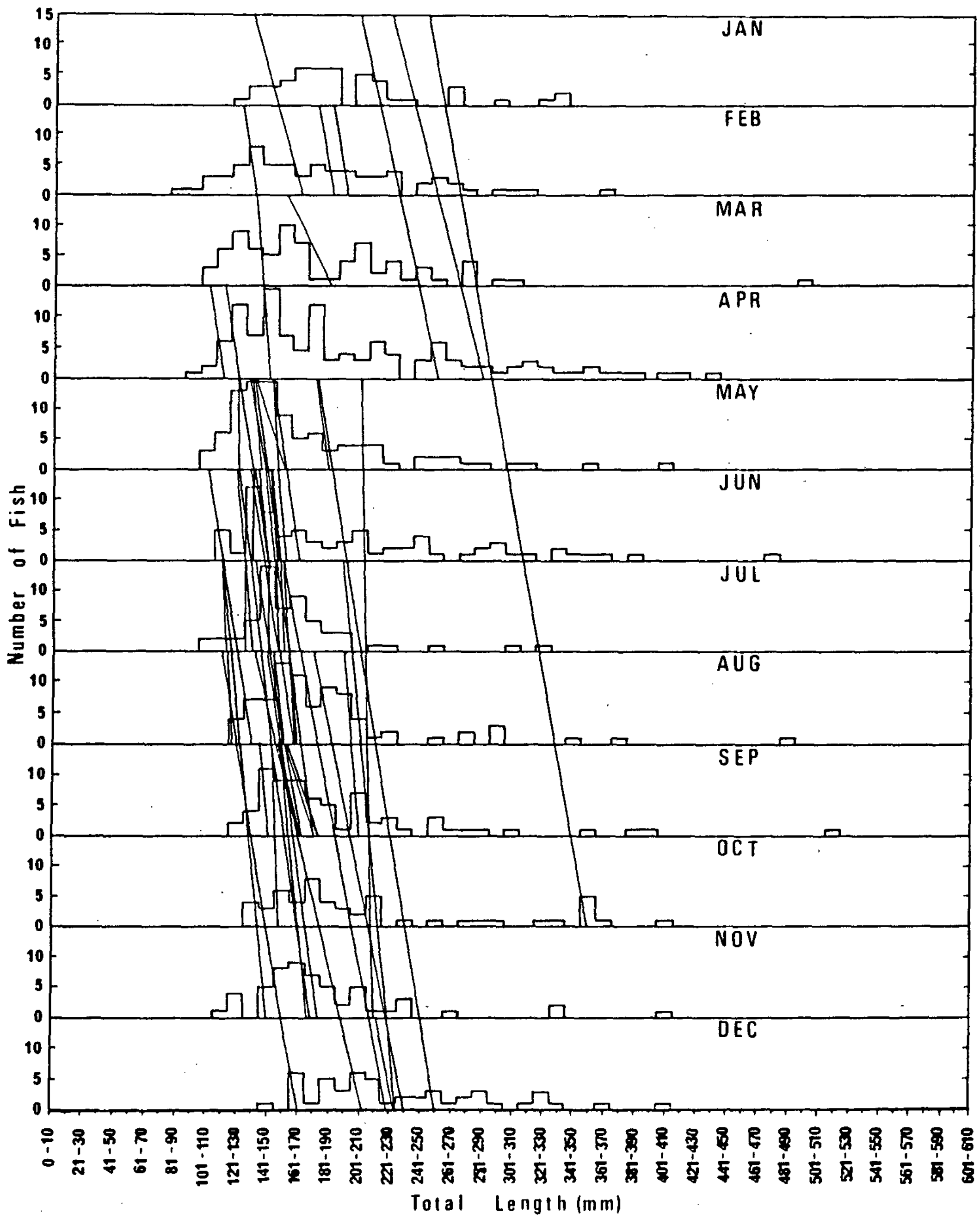

Fig. 18. Length frequency histograms of *P. kaakan* caught from Barramundi Creek each month in 1984, with tag recovery data superimposed. Straight lines join size at release and recapture.

spawning more than once. From this it follows that recruitment will also be a protracted process, which explains the few small fish which continue to be caught later in the year after the majority of the age class have attained a larger size.

By March the 'young of the year' group, referred to above, is well established in the sample and the distribution appears somewhat bimodal, with the maximum size being approximately 150mm to 160mm. It will be argued, however, that the larger members of this bimodal group probably result from late spawned fish from the previous spawning period. The rest of the fish in this distribution would be the result of the current spawning, having been spawned from about August and right through the summer. The earliest spawned fish would be included in the upper mode of the distribution, having probably reached a size of between 130mm and 140mm by March and would be about 6-7 months old, while the smaller size mode in the distribution at around 110mm to 120mm in March and 110mm to 140mm in April, would be the result of the major spawning peak around September and October. As spawning continued the lower end of the size distribution would be added to since these fish were not sampled at a size smaller than 80mm.

There is evidence of a smaller size group being added to the population again from about July to September at approximately 100mm and it is suggested that these were fish resulting from a later spawning peak, about February or March (see Reproduction section). It is suggested that the latest of these late recruits would overlap in size with the early spawned fish from the next spawning to result in the initial bimodality observed earlier in the March samples. Thus, fish spanning the whole size range could be caught at any time during the year, a consequence of the long spawning period and the variation in individual growth rates, resulting from both physiological differences and whether or not the fish were spawned early or late in the breeding season. It has been shown that growth rate slows in winter (see Fig. 23 and Tagging section Fig. 14), so that late spawned fish grow slower than earlier spawned fish, at least initially.

The bimodality in the length frequency distribution of smaller fish evident in December 1982 (Fig. 16), therefore, is consistent with two spawning peaks in an overall extended breeding season for the 1982 'young of the year'. This is observed again in 1983 samples (Fig. 17) but is less evident in 1984 (Fig. 18), possibly due to a poor late spawning in the previous breeding season.

Assuming that the fish entering the samples in about February and March are 'young of the year' from the major spawning, with a mean size of 110mm to 120mm, it can be seen that by September/ October these fish have attained a size of 150mm to 190mm, with fast growing fish probably a little larger. The data suggest that fish from the major spawning would be, on average, between 160mm and 180mm TL at one year old. In these same months there is a further group of fish in the length frequency distribution between about 210mm and 330mm. It is suggested that these are the result of the spawning from the previous year and range from about 18 months old to a little more than 2 years old, with the 2 year old fish averaging about 300mm to 320mm. Similarly there is a larger size group in the distribution, represented by only a few specimens, which lie outside the previous groups and would be older fish of probably 3 or 4 years old.

Interpretation of the length frequency data becomes difficult after the first two year classes because of variable growth of individual fish and because of lack of numbers of larger fish in the samples, the latter undoubtedly resulting from high fishing pressure in the sampling area as well as natural mortality.

Figure 19 shows the likely separation of the year classes for *P. kaakan* from Barramundi Creek. The lines separating the year classes were fitted by eye, taking into account both length frequency and tagging data, and while it is not suggested that these lines represent the absolute limits of the size range for all individuals of a year class, they would include the vast majority. There may be a few fish that, for one reason or another, have grown excessively quickly or slowly, so that they have become incorporated into the size range of another year class. Thus, Fig. 19 gives an indication of the expected size ranges resulting from a given spawning (for example, between the lines L1 and E1, L2 and E2, etc.), and the different growth rates of early and late spawned fish. The lines for the early spawned fish of each year class (E) show that a fish spawned in August could be as large as 221-230mm in that month a year later (E1), 361-370 by two years old (E2), and by extrapolating from this, up to 481-490mm by three years old

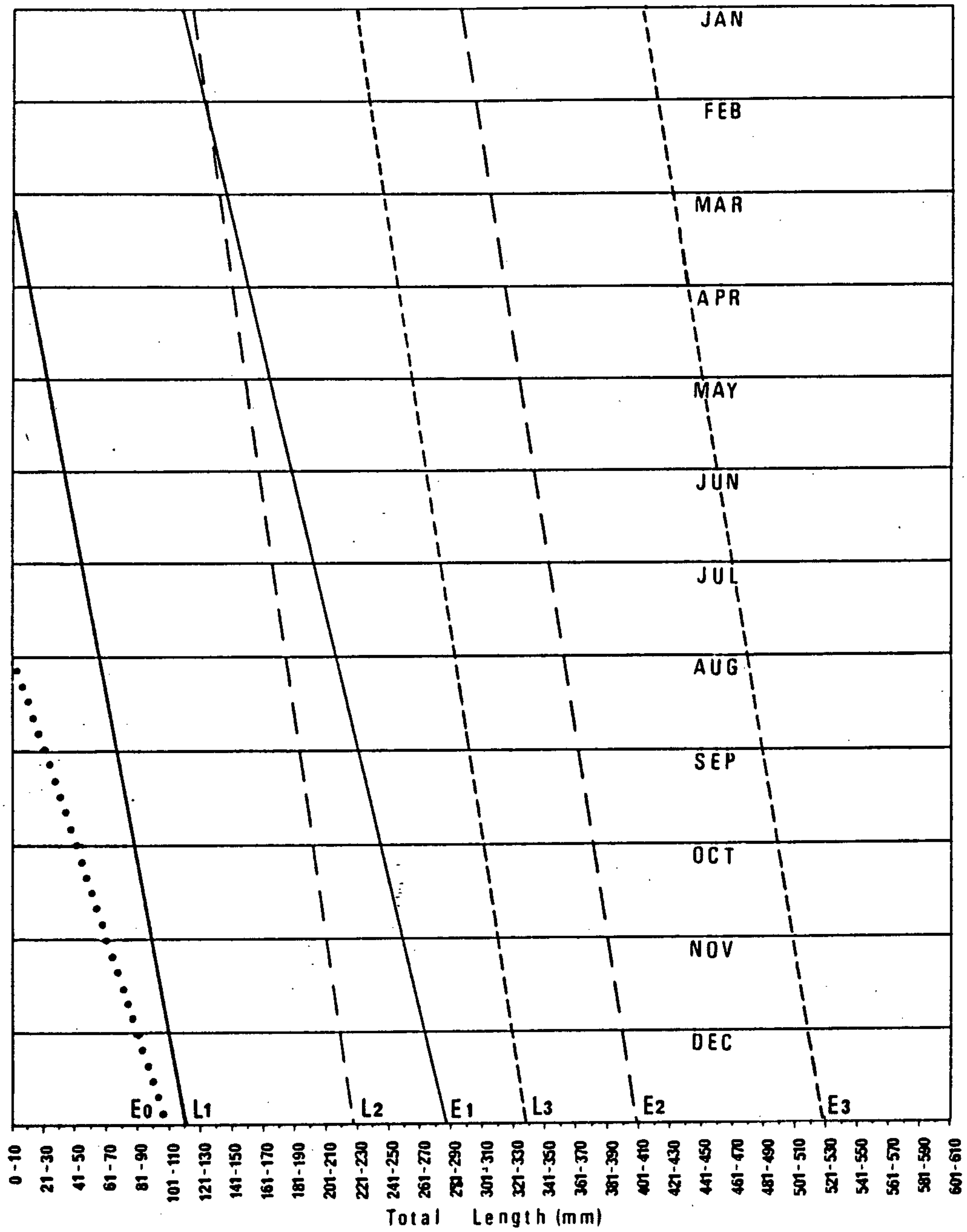

Fig. 19. Likely separation of year classes for *P. kaakan* from Barramundi Creek.

0 to E0 = young of the current (n) breeding season

L1 to E1 = fish from the previous (n-1) breeding season

L2 to E2 = fish from the (n-2) breeding season

L3 to E3 = fish from the (n-3) breeding season

(N.B. Lines E0 and L1 up to 90mm TL interpolated from data for larger fish.)

(E3). These attained lengths would be for a very fast growing fish. A late spawned fish (L), spawned in late February or early March, at one year old could be as small as 131-140mm (L2), at two years old 241-250mm (L3), and, by extrapolating, about 341-350mm at three years old. These lengths would be for a slow growing fish. These interpretations suggest that late spawned fish are considerably slower growing in their first year or two of life, as noted earlier, probably due to spending their early life in winter. A consequence of this slow start is that both two year old and three year old fish may be in the 341-350mm size group.

In summary, recognising that the growth rates of individuals may be extremely variable and that the size of individuals resulting from the same breeding season may extend over a wide range, it is useful to think of an 'average' *P.kaakan* resulting from the major spawning period (mid-point approximately October) as being about 160-180mm in length at one year old, about 300-320mm at two years old, and about 420-430mm at three years old.

(b) Scale Reading:

The use of scales for age determination and growth studies in *P.kaakan* from Barramundi Creek was reasonably successful in that marks on the scales could be distinguished and these corresponded to fairly discrete back-calculated length ranges, though some practice was needed before the scales could be read confidently. This was due to the fact noted earlier that while some scales had clear marks, those on other scales were much less distinct.

The back-calculated lengths at formation of each of the marks on the scales of 593 fish from Barramundi Creek were used to produce Fig. 20. This figure shows that there is a small group of fish which had a 'readable' mark on the scales corresponding to a modal back-calculated length of 111-130mm. This is represented on Fig. 20 as A1. It is suggested that many more fish may have had this mark, but due to some thickening of the central part of the scale it was not obvious for all fish. Most fish, of appropriate size, did have a recognisable mark on the scales at a modal back-calculated length of 141-180mm, another at 191-230mm, another at 271-300mm, and so on. The respective back-calculated length ranges are represented as A2, A3 etc., on Fig. 20. Thus, all fish having an A1 mark also had an A2 mark, but not conversely. After about the fourth mark there is some difficulty in interpreting the marks, probably due to variability in the growth rates of fish and the fact that some fish had very indistinct marks. In a few fish, comparison of back calculated lengths at annulus formation for that individual suggested a mark had been missed and on reexamination of the scales an indistinct mark was often found.

Figure 21 shows the separation of males and females at formation of the first four marks. This indicates no significant sexual difference in the lengths at mark formation in the population, so it can be concluded that growth of males and females is about the same in these age groups.

Figure 22 gives an indication of the months when marks are being laid down on the scales. This figure shows the percentage of

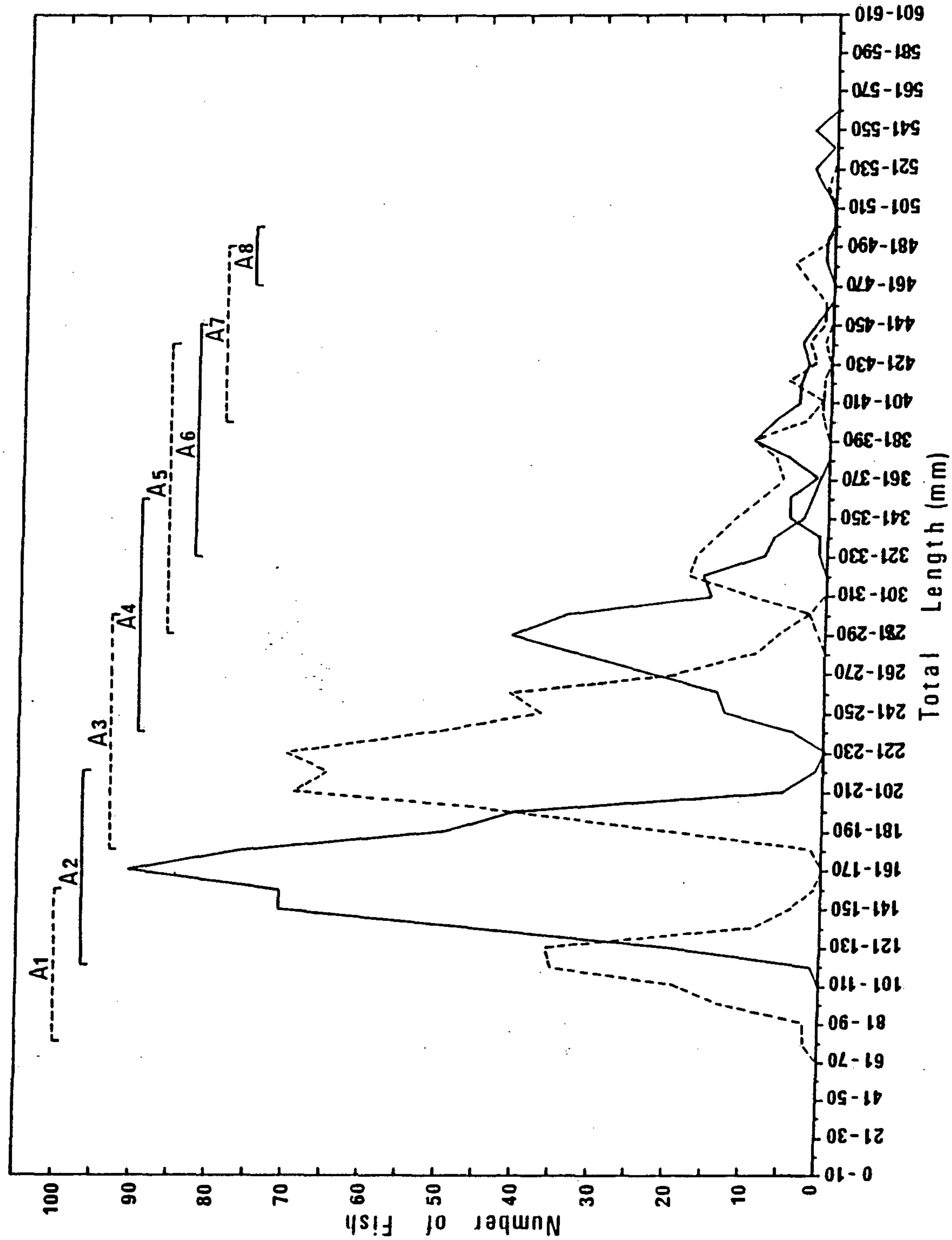

Fig. 20. Back-calculated lengths at mark formation on the scales of 593 *P. kaakan* from Barramundi Creek.

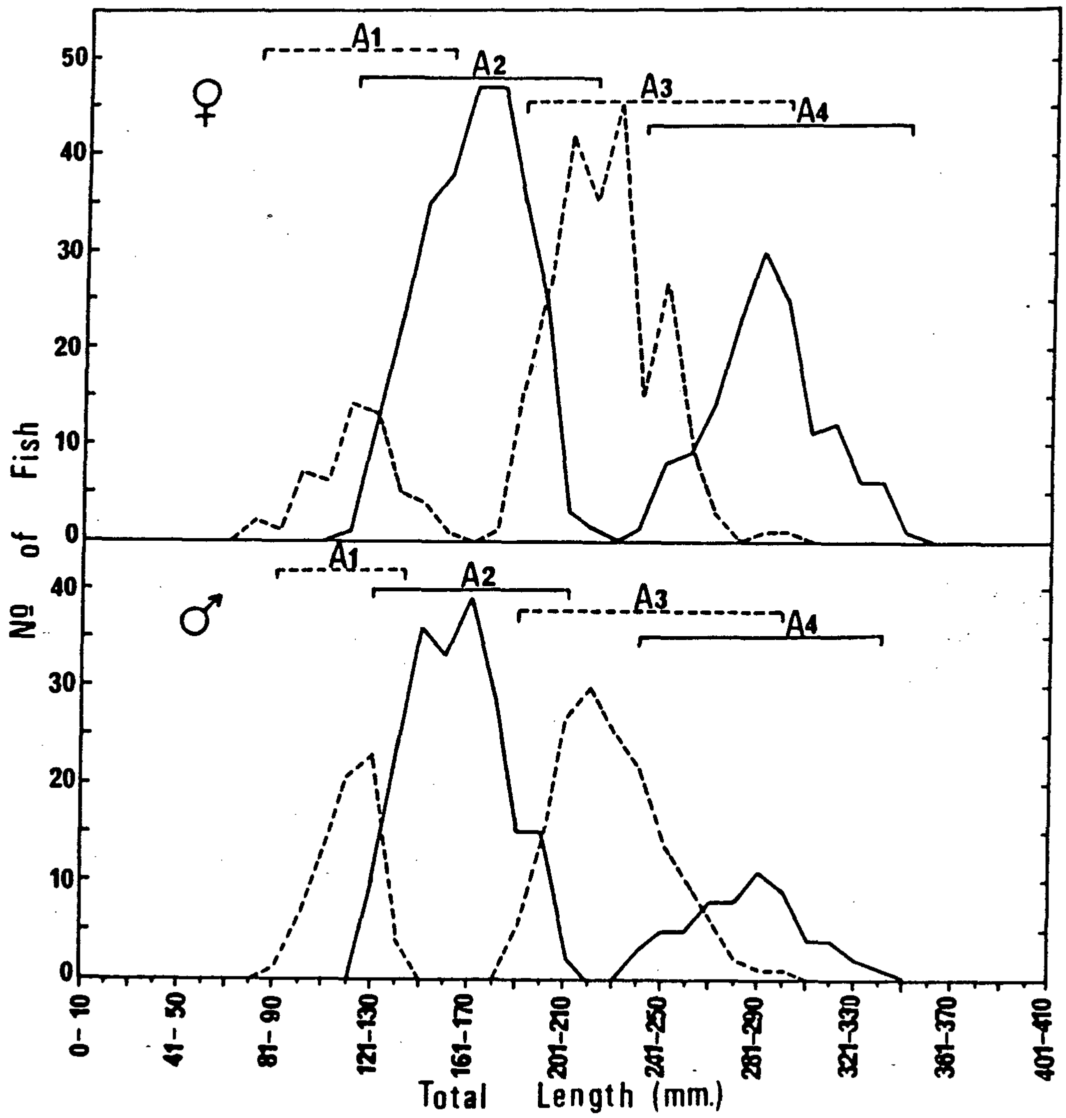

Fig. 21. Back-calculated lengths at mark formation for the first four marks on the scales of *P. kaakan* from Barramundi Creek, with males and females figured separately.

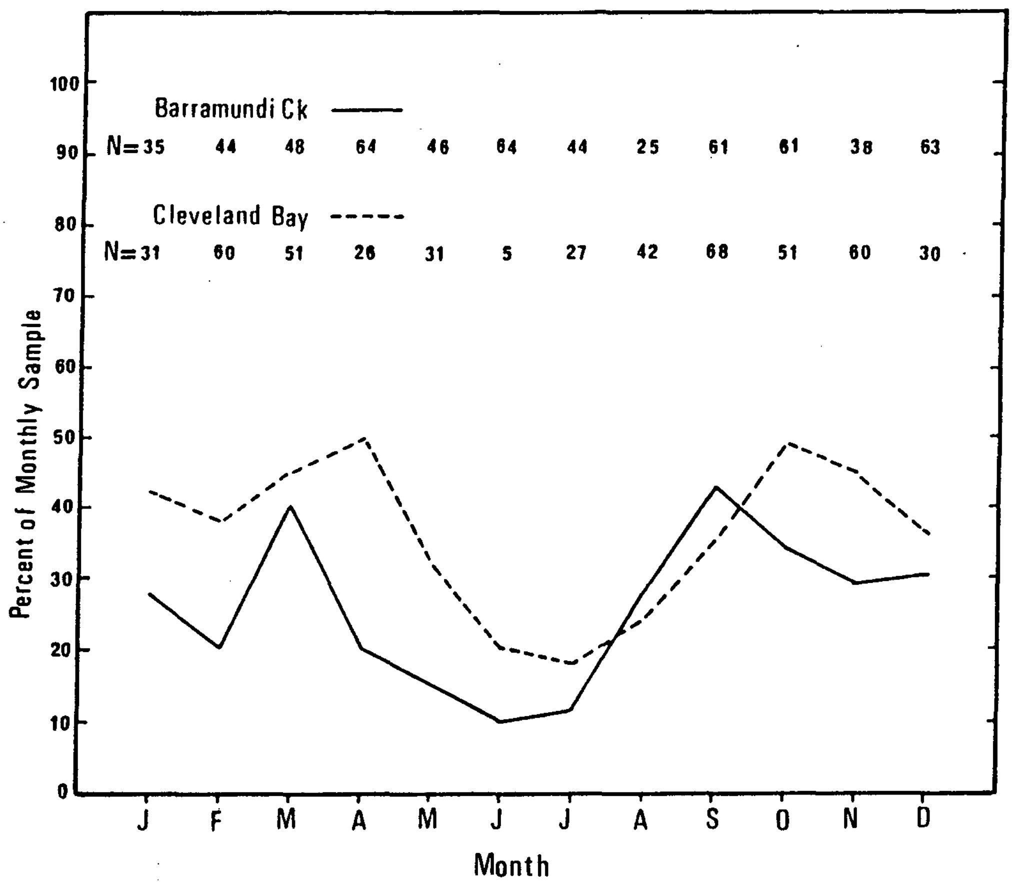

Fig. 22. Proportion of scales, from each monthly sample of *P. kaakan*, with a mark close to the edge corresponding with less than 10mm in back-calculated length since mark formation.

each monthly sample of fish, for which scales were read, which had a mark very close to the edge of the scale, *i.e.* corresponding to growth of less than 10mm in back-calculated length since the mark was laid down. This procedure was adopted as providing a good indication of the month of mark formation, since most of the fish from which scales were sampled were of an age when about 10mm growth in length per month could reasonably be expected, namely 1+ and 2+ year old fish. Thus, the peak percentage in April for Cleveland Bay fish indicates that a large proportion of individuals in that sample laid down a mark on the scales within the previous month, *i.e.* about March.

From Fig. 22 it can be seen that marks are laid down on the scales over a prolonged period, but primarily in the spring and summer months with peaks, for Barramundi Creek samples, from about July/August to September/October and again from December to February. Peaks occurred about a month later for Cleveland Bay samples. The times of these peaks correspond quite closely with the maximum spawning periods during the breeding season. The interpretation of these data is that individuals of *P. kaakan* lay down two marks on the scales for each year of life, with one mark being a 'birthday' mark and being laid down in the part of the breeding season corresponding with when the individual was itself spawned, either early or late; while the other mark is laid down at a time corresponding with the other spawning peak.

The month that a mark is laid down varies for different fish, which supports the suggestion that the mark may not be primarily due to an environmental change, but may result from some inherent physiological process. If the former was the case one might expect a shorter duration of mark formation. Also, the fact that most marks are being formed on scales at times corresponding with the spawning periods suggests that changes associated with reproductive development may be an underlying causative agent. These are not spawning marks, however, since fish that have not yet spawned still lay down marks on the scales.

Thus, as has been shown in the length frequency analysis, fish spawned early in the spawning season (August/September) would be large enough (up to 120mm TL and about 6 months old) to lay down the A1 mark on the scales by the time of the late spawning peak in February or March. The fish spawned somewhat later, from about the end of November, may not be large enough to produce a readable mark on the scales by February or March and would lay down their first readable mark as the 'birthday' mark (A2) towards the end of the year at about one year old. Fish spawned late in the breeding season (February/March) would obviously not be able to lay down a mark in February/March. These fish would lay down their first mark (A1) at the time of the next early spawning (August/September) at about 6 to 7 months old, and lay down their 'birthday' mark (A2) at about one year old in the following February/March.

From these considerations it can be seen that all fish lay down the A2 mark though not all may lay down the A1 mark, depending on when they were spawned over the long breeding season. Thus the majority of fish in the population, spawned mid way through the major spawning period (late September/October) will correspond with the modal group of fish in the A2 distribution (141-180mm) at one year old, to the modal group in the A4 distribution (271-300mm) at two years old, and to the modal group in the A6 distribution (371-400mm) at three years old. Fish either side of this modal group correspond with either earlier spawned fish or slightly later spawned fish. A similar argument can be raised for the fish derived from the late spawning activity in February/March, though these will be represented by the smaller fish in the size range for each of the 'birthday' mark distributions.

Further support for this hypothesis has been obtained from examination of scales from recaptured tagged fish. For example, the tagged fish that was free for the longest period (tag number 000 294, free for 17 months) had four marks on the scales corresponding to back-calculated lengths at mark formation of 123mm, 192mm, 286mm, and 341mm for A1 to A4 respectively. As noted in the Tagging results of this Growth section (7.3.1 c), this fish was tagged at a length of 174mm in late May, and therefore would almost certainly have been early spawned. From this it is reasonable, given an average growth rate of 19mm per month as determined, that the A1 mark would have been laid down 2-3 months prior to release, which would have been February or March, and, perhaps allowing for some retardation in growth immediately after tagging, that the A2 mark at 192mm could have been laid down at about 12 months of age in say August. The third mark at a back-calculated length of 286mm is within the A3 distribution in Fig. 20 and the mark at 341mm is in the A4 distribution, though these values are toward the upper limit of the distributions as would be expected for an early spawned and fast growing fish. Similarly, back-calculations on scales of other long term tag recoveries indicate lengths at mark formation that fit in well with the distributions in Fig. 20.

The results used to plot Fig. 20 are based on the reading of all the scale samples. It should be noted that the scales of every fish did not have the full complement of marks as expected on fish size, and, further, that although the marks on the scales of many fish were very clearly and easily distinguishable those on some were very faint and much less obvious. Despite their clarity, however, all the marks that were discernible provided, according to their position, back-calculated lengths that fitted the expected size ranges at the times of mark formation. Thus, while scale reading may not be feasible for all *P. kaakan* individuals, the technique has very valuable application, especially with developed experience at recognising the marks and when used in conjunction with other methods, for determining age and growth in this species. Similarly, it may be successfully applied in *P. argenteus*.

(c) Tagging:

A total of 1288 *P. kaakan* ranging in size from 92mm to 330mm were tagged and released at various sites in Barramundi Creek (see Fig. 2). A total of 202 recaptures were made including 27 double and four triple recoveries (where recaptured fish had relevant data recorded and were then re-released to be caught later a second or third time).

Freedom times between tagging and recovery ranged from several hours (2 fish) to 517 days, though those caught the same day are not included in the data. One hundred and twenty three fish, which were free for periods of 28 days or greater, were used in the study of growth. The size increase of each of these fish has been indicated on Figs. 16, 17, and 18, by means of a straight line between the lengths at the time of release and at the time of recapture. It is not strictly accurate to use a straight line to join release and recovery sizes over more than a few months since there is strong evidence to suggest varying growth rates over different months of the year, with a slower growth rate during the cooler months compared with the warmer months (see Fig. 23). However, use of straight lines allows the clearest indication of growth increments and is acceptable for this component of the study. Also, plotting of the tag recovery results on the same figures as the length frequency data, enables comparison with the conclusions drawn from the latter.

The tagging data clearly support the existence of the age groups indicated in Fig. 19. What is also evident is that there is some considerable variation in growth rate of individuals, as not all the lines lie parallel. This is partly caused by the use of 10mm class intervals for size so that a fish at large for just over 28 days which had grown 19mm would be plotted the same as a fish that had grown only 11mm. However, the longer a fish is at large the less important will be that error, and, as can be seen, fish at large for longer periods still show fairly variable growth rates. This should not be unexpected as different individuals will encounter different influences in their lives such as food availability, predators and parasites.

The fish with the longest period of freedom (tag 000 294) was tagged with a 'clothes' tag on the 24th of May, 1983, at a length of 174mm and was recaptured on the 22nd of October, 1984, at a length of 356mm after 17 months of freedom. As previously noted, the size of this fish at release suggested that it was early spawned, since it would have been close to the largest of its age class in May. It showed, for a fish of this size, substantial growth while tagged (an average of 10.7mm per month) and, therefore, could be expected to have remained near to the largest of its size class up to recapture. Thus, assuming this fish was spawned in August of 1982 it would have grown 174mm in approximately 9 months, that is at an average rate of 19mm per month. This would be expected of an early spawned fish growing through the summer months. The growth rate while tagged was also fairly rapid, considering much of the growth was during cooler months and that the fish was in the older 1+ age group. By the end of October when recaptured this fish would have been about 26 months old, hence its estimated length at 24 months would have been approximately 336mm, taking into account reduced growth increments at the larger size as against expected increasing growth rate in the spring months. This is consistent with the results from the length frequency analysis, though this fish grew slightly faster than an 'average' fish possibly due to an advantage resulting from being spawned early in the breeding season; and is also consistent with scale reading data which suggested that the A4 (2nd 'birthday') mark on scales from this fish was formed at a back-calculated length of 341mm.

Other long term recoveries are tag number 000 834, tagged on the 28th of May, 1984, at a length of 141mm and recaptured on the 10th of August, 1985, at a length of 285mm, having been free for 14½ months and having grown 144mm, an average growth of 10mm per month; and tag number 000 875, tagged on the 26th of June, 1984, at a length of 170mm and recaptured on the 8th of October, 1985, at a length of 280mm, having been at large for about 15½ months and having grown 110mm. The latter fish had a somewhat slower growth rate, averaging 7mm per month while tagged, which, in this case, might be partly explained by the effects of tagging since this fish was originally double tagged with both Floy and 'clothes' tags, and was then recaptured and re-released after one month. It had not grown over the initial period but had lost the Floy tag. This, plus being captured and handled a second time, may have had some influence on the growth rate.

The average growth per day for tagged *P. kaakan* less than 300mm at release and free between 28 and 100 days is plotted on Fig. 14 (Tagging and Movement chapter). Longer term recoveries were not included in this figure to avoid fusion of different growth rates over summer and winter months. Such differences in seasonal growth rates are quite evident from the size increments of fish that were free over only one or other of the periods. From the mean growth per day of tagged fish free between 28 and 100 days, the mean growth per month (30 days) was calculated. These values are plotted in Fig. 23. From this figure it can be seen that there was greater than a three fold increase in average growth per month in the summer months (December/January) compared with the cooler months (May/June/July). When the mean growth for each month was summed over a year, the average growth for the year was approximately 120mm (10mm per month on average) which was noted in two of the previous long term recoveries. This is also in keeping with previous growth estimates, using different methods, for fish of the size range tagged. The majority of tagged fish were between 130mm and 230mm when released and most of these fish would have been from the late 0+ age group and the 1+ age group.

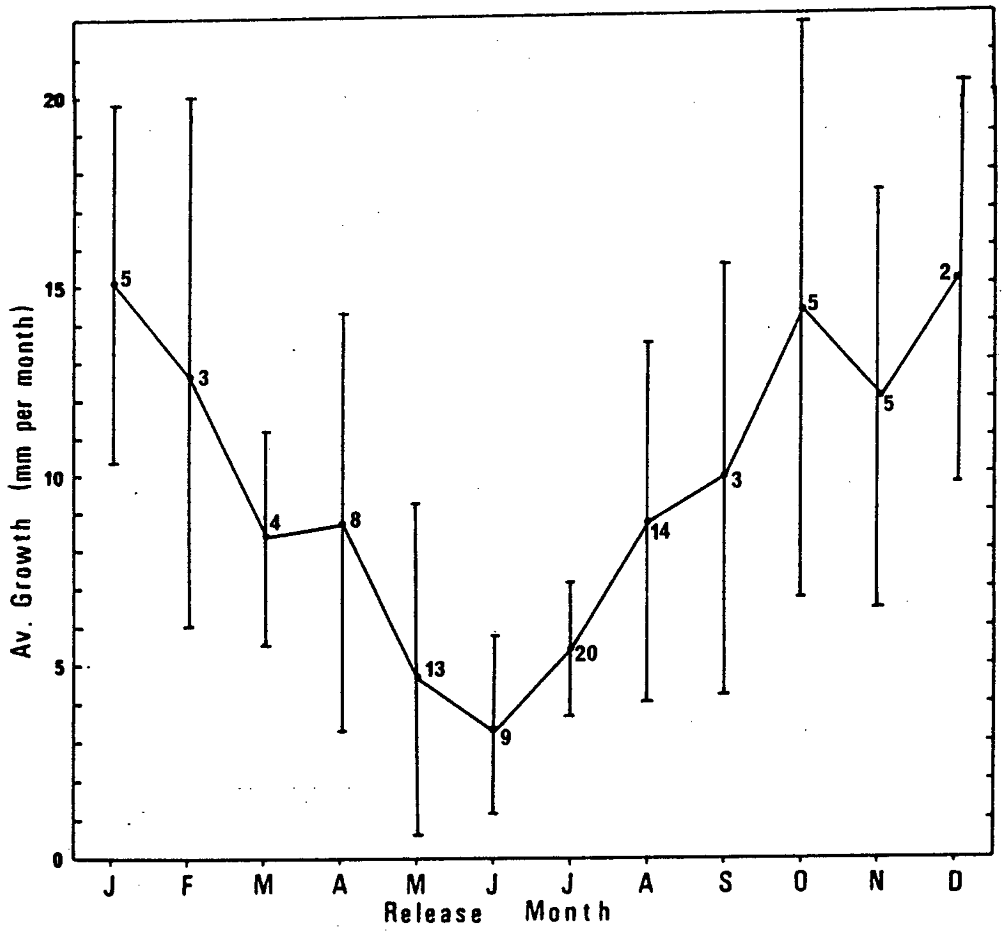

Fig. 23. Average growth (± S.E.) per month and number of recaptures for tagged *P. kaakan*, less than 300mm in length at release and free for 28-100 days, from Barramundi Creek.

7.3.2 *P. kaakan* - Cleveland Bay

(a) Length Frequency:

The length frequencies of *P. kaakan* trawled from Cleveland Bay each month during 1981 and 1982 are plotted on Figs. 24 and 25 respectively, together with data for small *P. kaakan* sampled by small mesh beach seine at Pallarenda on the shores of Cleveland Bay in 1984 and 1985. As the trawled fish data and Pallarenda seined fish data were collected two years apart they do not represent contemporaneous information, but assuming a fairly similar pattern of spawning and recruitment from year to year, a comparison of them provides an indication of growth from settlement to the size taken by trawling.

The length frequency analysis of the trawl samples shows a similar growth pattern to that observed for the Barramundi Creek fish. Again lines were fitted by eye to indicate likely size ranges for each age class (Fig. 26). Fish spawned as early as August form a group that by one year old could be as large as 211-220mm, and by two years old (by extrapolation) could be as large as 371-380mm. Fish spawned late, say February, would be approximately 121-130mm at one year old and approximately 240-250mm at two years old. The majority of fish from a given breeding season would be between these two extremes. Few fish larger than 300mm were caught in the Cleveland Bay trawl samples.

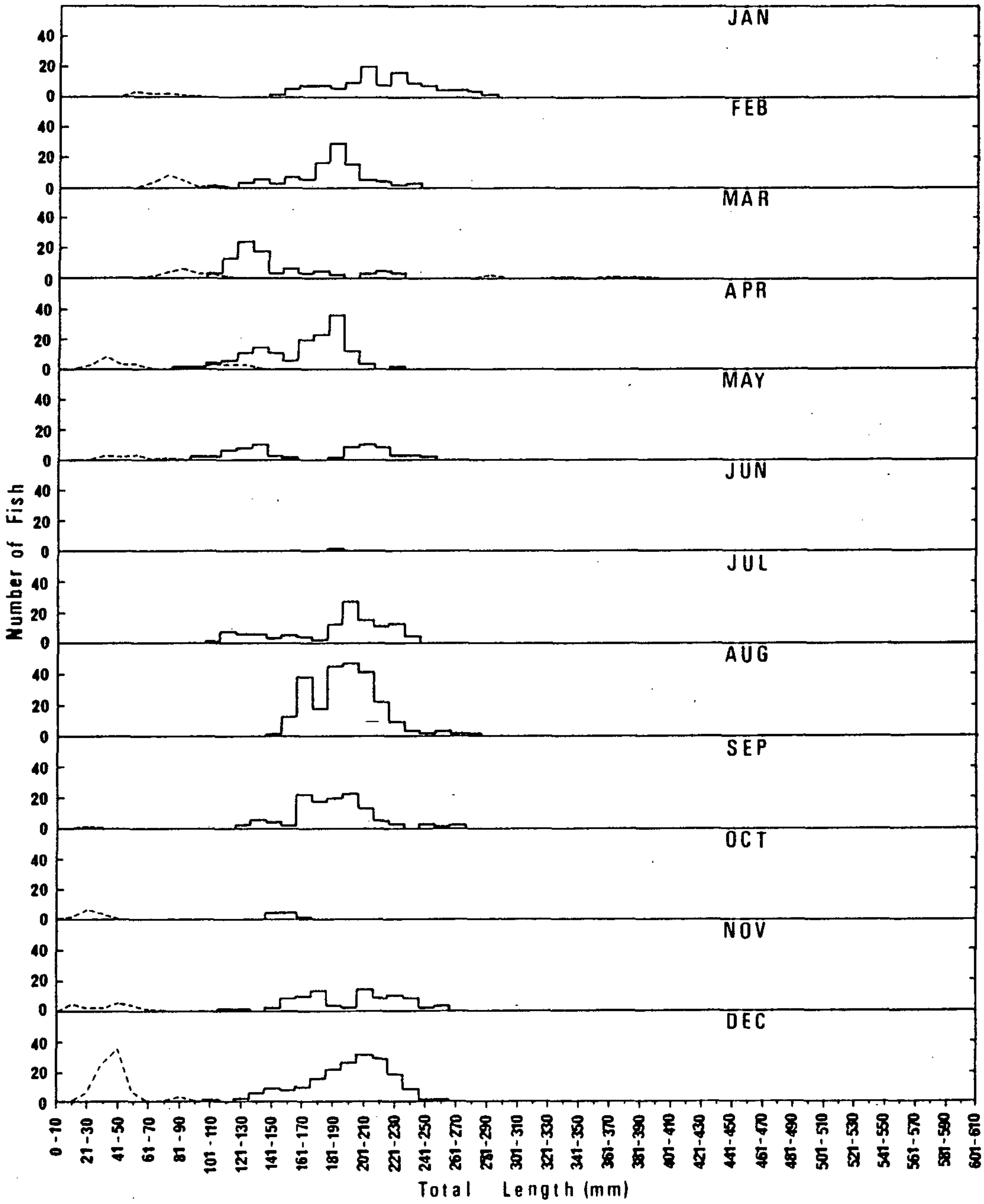

Fig. 24. Length frequency histograms of *P. kaakan* trawled from Cleveland Bay each month in 1981 (——), and collected by small mesh beach seine from Pallarenda in 1984 (----).

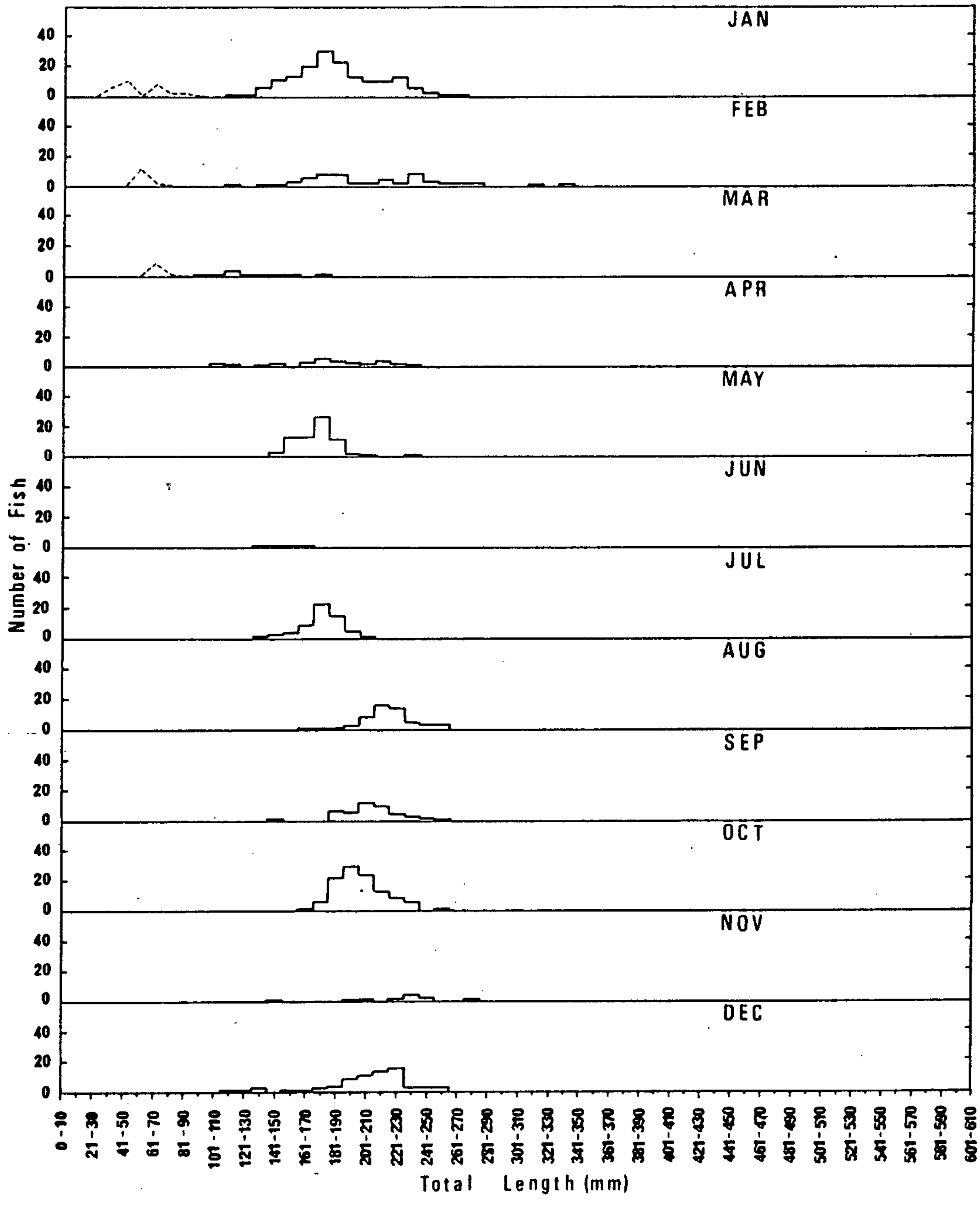

Fig. 25. Length frequency histograms of *P. kaakan* trawled from Cleveland Bay each month in 1982 (——), and collected by small mesh beach seine from Pallarenda in 1985 (----).

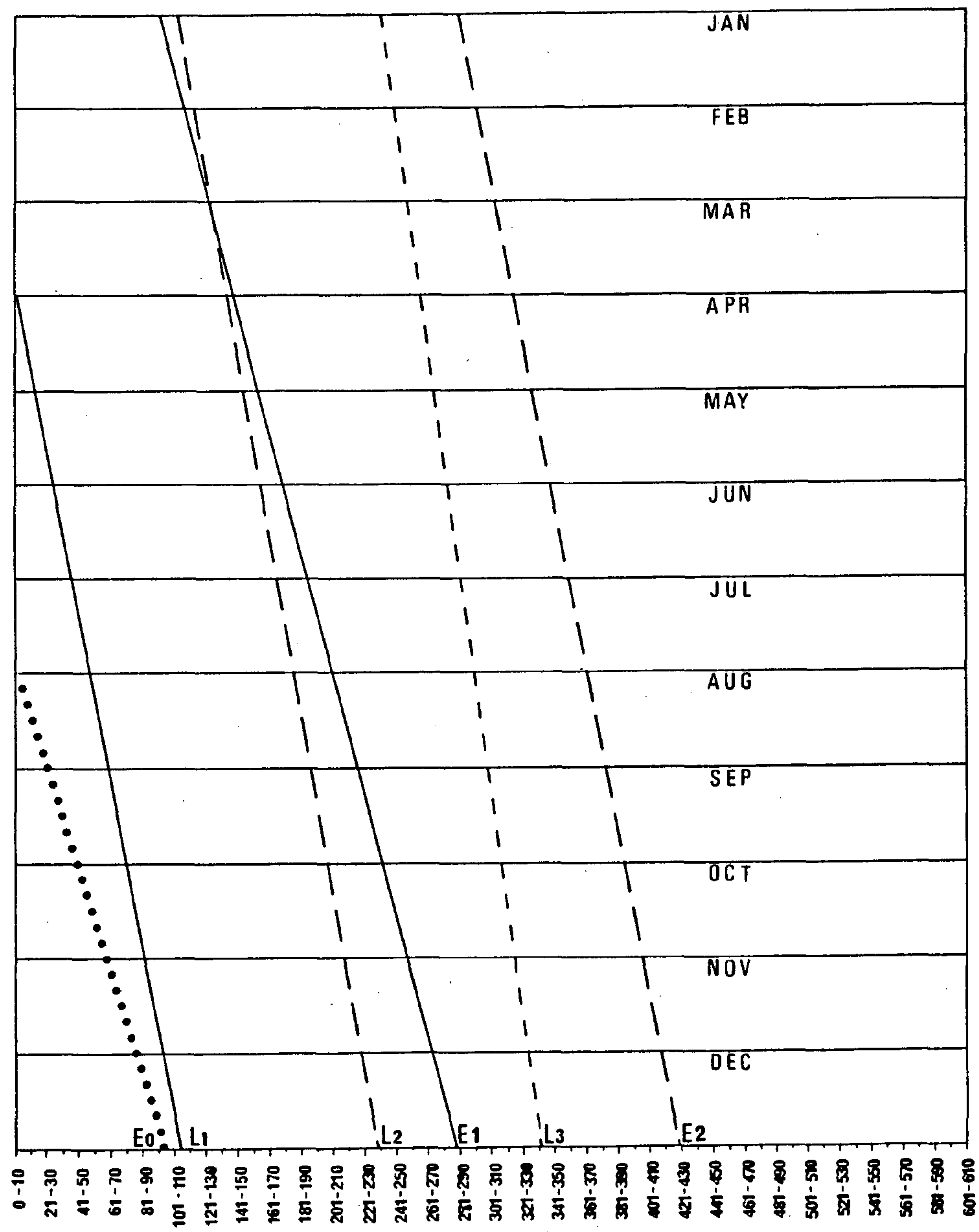

Fig. 26. Likely separation of year classes for *P. kaakan* from Cleveland Bay.

0 to E0 = young of the current (n) breeding season

L1 to E1 = fish from the previous (n-1) breeding season

L2 to E2 = fish from the (n-2) breeding season

L3 = late spawned fish from the (n-3) spawning

From the Pallarenda sampling, very small *P. kaakan* were collected in weed beds and shallow surrounding areas as early as September, at a size of 20-30mm total length. Analysis of length frequency data over the following months shows that these small fish grow rapidly, at up to 20mm per month, and were most abundant during the months of October, November and December. These fish were a result of the main spawning period. Another peak in abundance of very small fish occurred in April and May of 1984, obviously as a result of a later burst of spawning activity probably in February and March, but this peak was not observed in the same months in the 1985 samples. This may have been due to failure in the late spawning in that year.

A few large *P. kaakan* were caught in one haul of the small mesh net in March 1984. This suggests larger *P. kaakan* occasionally inhabit, or at least move through, the close inshore zone of Cleveland Bay as well as the estuaries. There is no evidence to indicate movements further offshore.

(b) Scale Reading:

Back-calculated lengths at mark formation on the scales of samples of fish from Cleveland Bay are shown in Fig. 27. These results show that fish from Cleveland Bay lay down a mark on the scales at a back-calculated length of between 71mm and 140mm, another, usually quite distinct, between 111mm and 210mm, a third between 171mm and 240mm and a fourth between 221 and 290mm. The

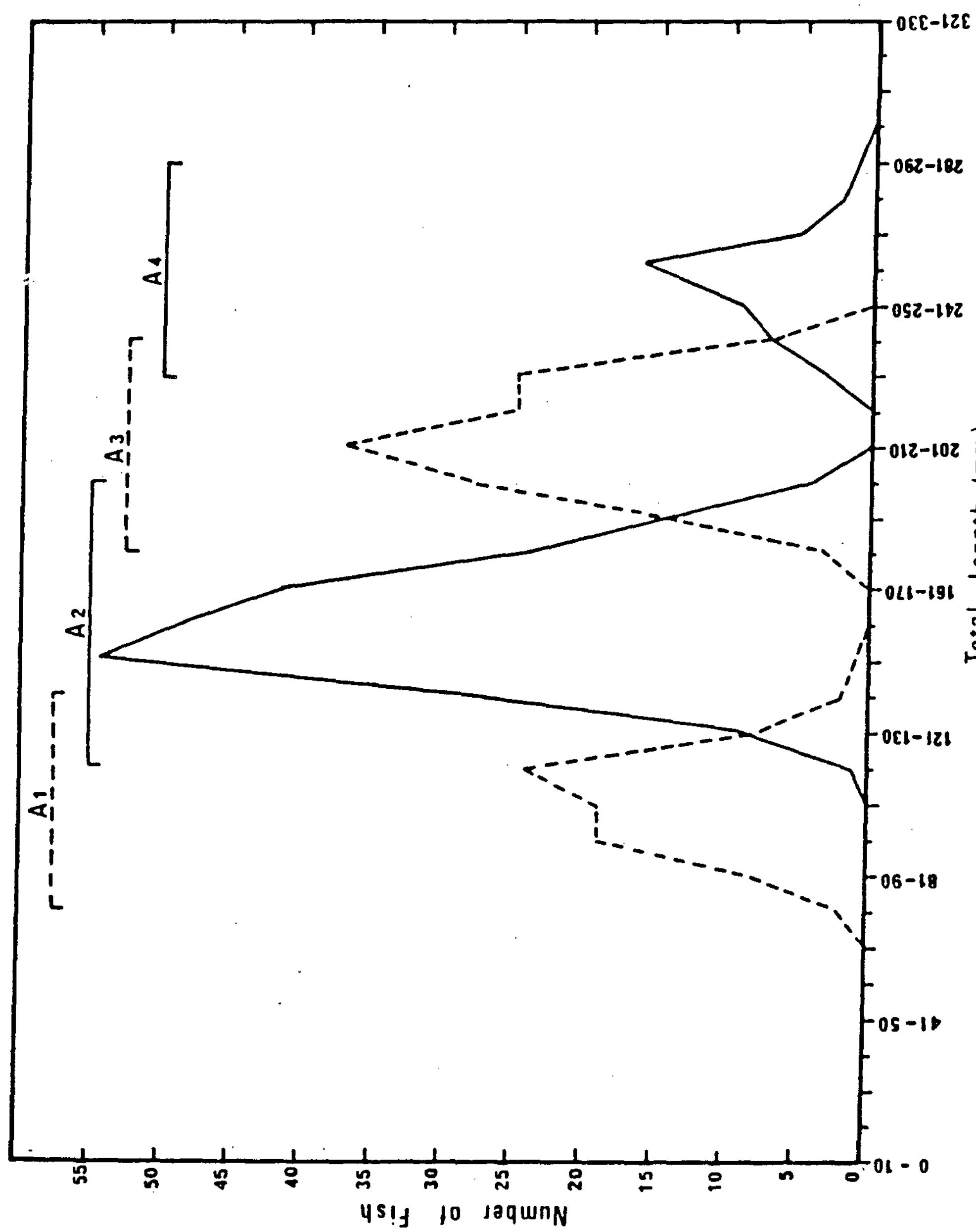

Fig. 27. Back-calculated lengths at mark formation on the scales of 477 *P. kaakan* from Cleveland Bay.

second and fourth marks correspond with the first and second 'birthday' marks as noted for Barramundi Creek fish and thus represent one year old and two year old fish respectively. These findings are in keeping with the length frequency data, which suggest that fish from the last spawning are between 120mm and 220mm at one year old and fish from the previous spawning are between 240mm and 380mm. The lack of larger sized fish in the two year old group in the trawl samples was probably the result of movement of these fish out of the trawling area (as discussed later). From Fig. 27, the modal group of one year old fish (A2) from Cleveland Bay, determined from scale reading, was in the size range 140mm to 170mm and that of two year old fish (A4) 240mm to 270mm.

As for the fish sampled from Barramundi Creek, there was a large variation in the clarity of marks on scales of fish from Cleveland Bay. Further to this, there were often several marks on the scales of relatively small fish, but one mark was generally much more distinct than the others, and often several marks were grouped close together. An analysis of the marks indicated that false 'annuli' were commonly laid down in fish from Cleveland Bay, since the small size of fish captured by trawling, coupled with results from the length frequency analysis, suggested most fish would be less than two years old. For this reason only the most distinct marks on the scales were used to back-calculate length at mark formation, these being more consistent in disposition one with another.

(c) Tagging:

Fifty *P. kaakan* were tagged in Cleveland Bay from initial trawl samples. This tagging was discontinued early in the project, however, since most of the fish captured by trawling were either nearly dead or seriously damaged and it was considered that they would probably not survive after tagging. None of the few fish tagged in Cleveland Bay were recovered.

7.3.3 *Pomadasys argenteus* - Barramundi Creek

(a) Length Frequency:

Figures 28, 29, and 30, show the length frequency distributions for *P. argenteus* caught at Barramundi Creek during 1982, 1983, and 1984 respectively. Relatively few fish were caught in 1982 so most of the analysis is based on results from 1983 and 1984. Even in these years the number of fish sampled was not large and probably reflects the relative numbers of this species in the fish community at Barramundi Creek, being caught much less commonly than *P. kaakan*. In particular, *P. argenteus* was sampled in very small numbers during the winter months in Barramundi Creek. With these constraints in mind, the length frequency data do, nevertheless, give a good indication of size groups in this species over the first two or three years of life, especially when taken in combination with the tag recovery data (also included on Figs. 28, 29, and 30).

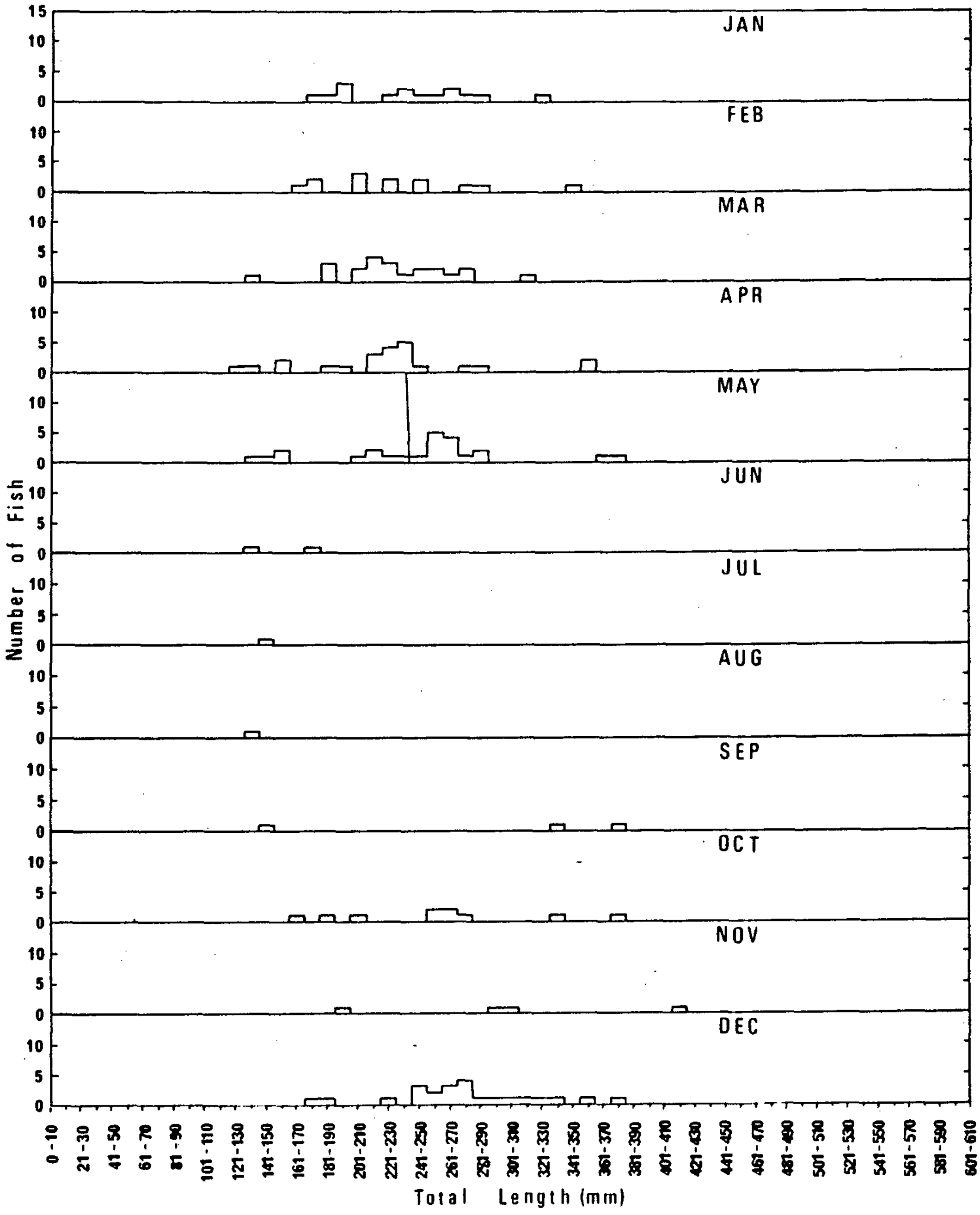

Fig. 28. Length frequency histograms of *P. argenteus* caught from Barramundi Creek each month in 1982, with tag recovery data superimposed. Straight lines join size at release and recapture.

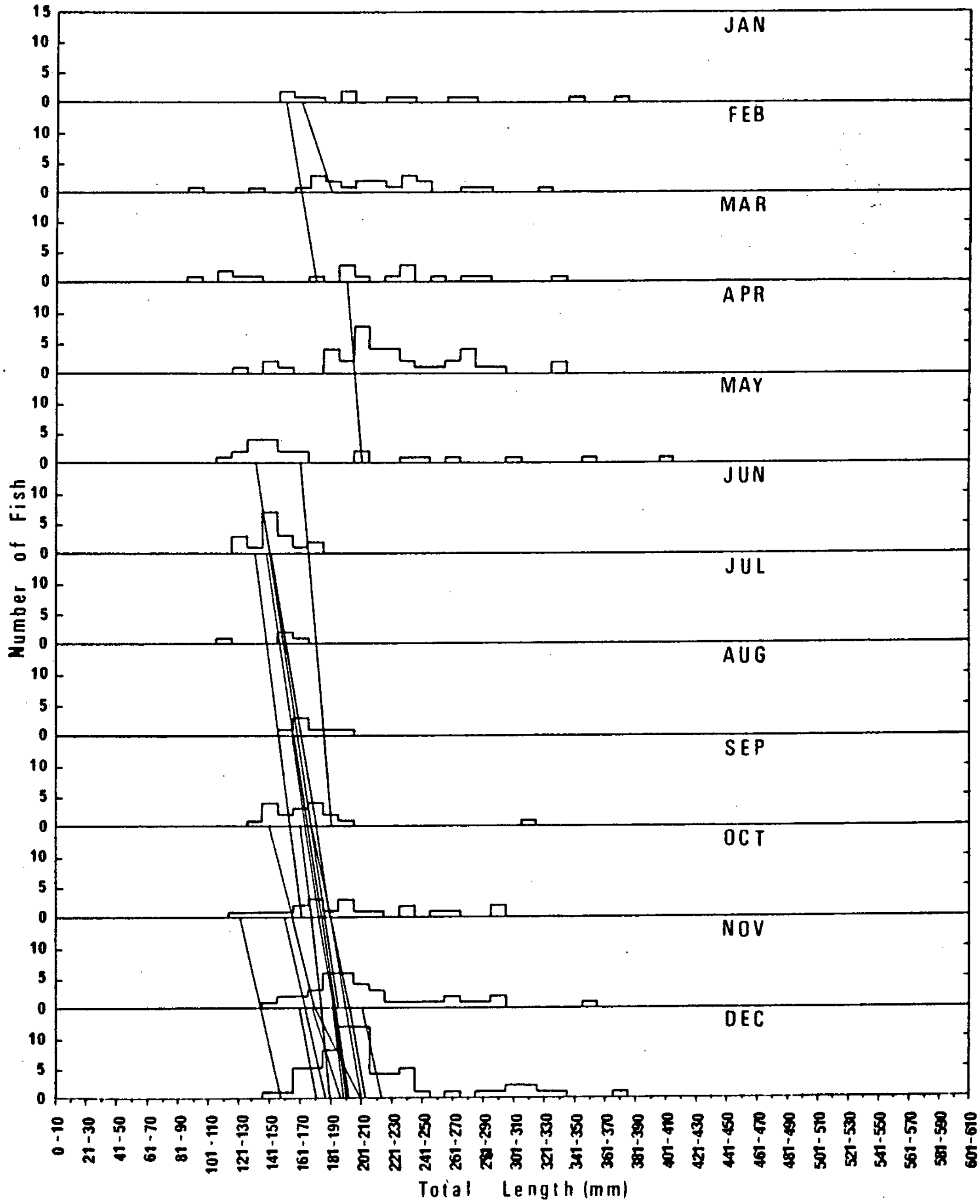

Fig. 29. Length frequency histograms of *P. argenteus* caught from Barramundi Creek each month in 1983, with tag recovery data superimposed. Straight lines join size at release and recapture.

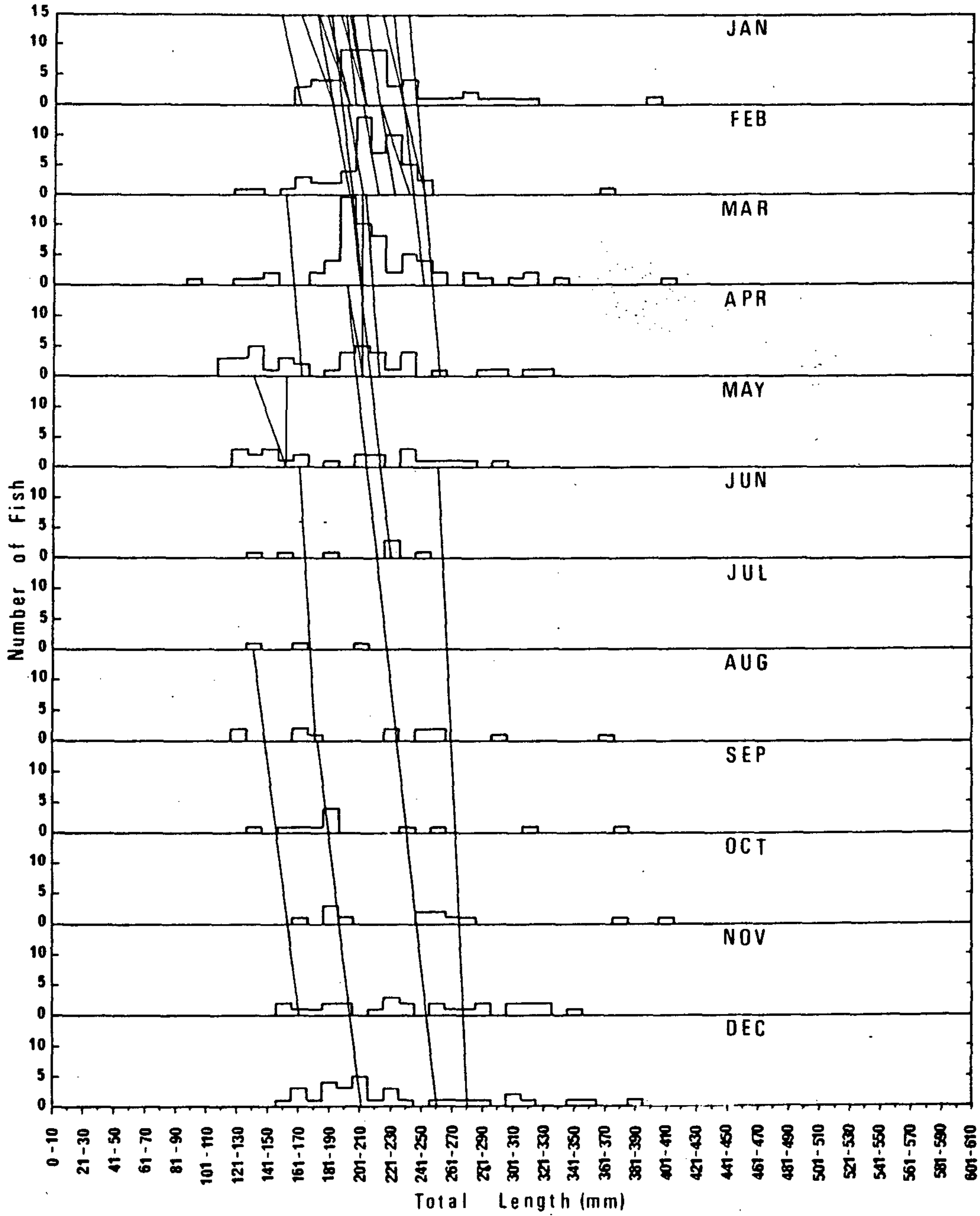

Fig. 30. Length frequency histograms of *P. argenteus* caught from Barramundi Creek each month in 1984, with tag recovery data superimposed. Straight lines join size at release and recapture.

The smallest individuals of *P. argenteus* in the years sampled were taken in February or March of each year, with a few small fish again taken later in the year, for example in October 1983 and August and September in 1984. It is suggested that these represent the extent of the age class for a particular year, with the small fish first sampled in February (at approximately 91-100mm) comprising fish spawned early in the breeding season while the small fish sampled later in the year are fish spawned late in the breeding season. As noted in the Reproduction section, and similarly to *P. kaakan*, there is a prolonged spawning period in this species with the potential for more than one spawning per individual during the breeding season. There is little evidence from the length frequency data, however, of a very late spawning, for example in February or March, suggesting that in the years sampled at least, there is a shorter spawning period compared with *P. kaakan*, of perhaps 5 or 6 months duration. This gives rise to more discrete age groups as indicated in Fig. 31.

To take the 1983 data (Fig. 29) as an example for this species, it is postulated that the small fish first sampled in February and March between approximately 100mm and 140mm are a combination of early spawned young of the immediate spawning and some late spawned fish from the previous spawning season. Fish from the immediate spawning would be up to 7 or 8 months old at this time, having been spawned in August/September, with smaller fish spawned progressively later. These fish form the major year class in the samples for the remainder of the year and by October range

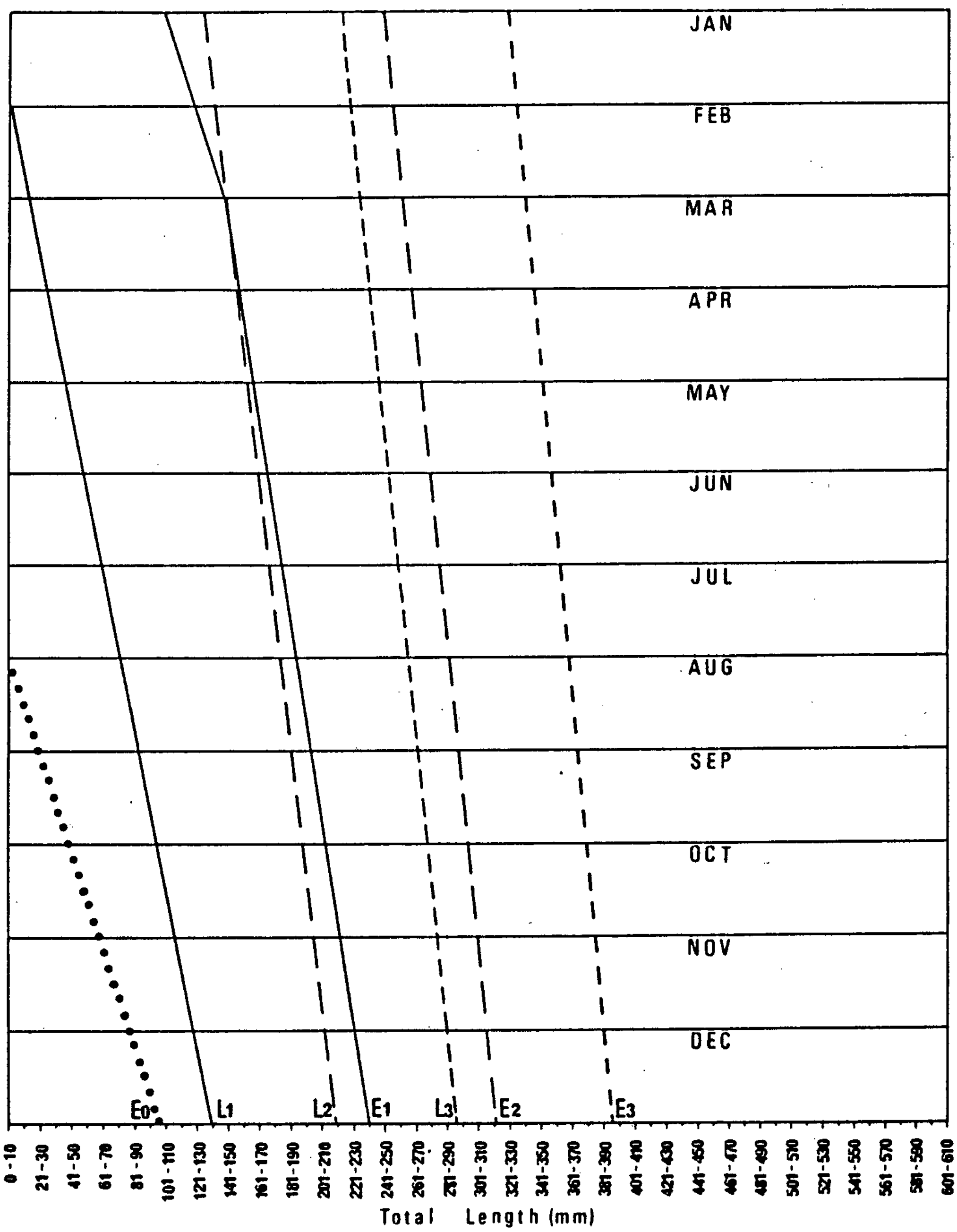

Fig. 31. Likely separation of year classes for *P. argenteus* from Barramundi Creek.

0 to E0 = young of the current (n) breeding season

L1 to E1 = fish from the previous (n-1) breeding season

L2 to E2 = fish from the (n-2) breeding season

L3 to E3 = fish from the (n-3) breeding season

(N.B. Lines E0 and L1 up to 100mm TL interpolated from data for larger fish.)

in size from about 121mm to 220mm, at an age of approximately 10 to 14 months respectively. The earliest spawned fish in the group, spawned in August, would be expected to be the largest in the group the following August and would therefore be approximately 191-200mm at one year old (see Fig. 29). Later spawned fish would probably be slightly smaller than this at one year old, having missed some of the initial, favourable growth period.

In the years sampled, the evidence from recruitment of small fish suggests that most of the spawning had been completed by January. No fish in spawning condition were caught in Barramundi Creek and of 74 that were mature (stage 3 gonads), the majority (57) were caught from September to December. A few mature fish were taken in January and February, and occasional ones right through to May. Therefore, although there was the potential for some later spawning, as was also noted from the ova size groups earlier, this was not evident from the samples collected. Peak reproductive activity appears to occur in late September/October.

As may be seen from the 1984 results (Fig. 30), again the smallest *P. argenteus* caught in that year were sampled in February and March.

The length frequency data suggest that by July or August the earliest spawned fish of the current year class (11-12 months old) were approaching approximately the same size as the latest spawned and slowest growing fish of the previous year class which were approximately 18-19 months old. This gives a good indication of the advantage a fish has if it is spawned early, with the entire spring and summer period in which to grow, compared with a late spawned fish that is growing initially in late summer and autumn. The differences in growth rate results in some overlap of sizes of variously aged fish, so that by November 1984, for example, fish caught at 230mm may have been spawned either early in the 1983 breeding season or late in the 1982 breeding season. This leads to some confusion in separating the extremes of the age groups in the length frequency distributions, but the general trends in size increase for the 'average' fish can still be observed clearly (Fig. 31).

If October is taken as the mid point in the main spawning period, then in this month the range of sizes from the previous spawning is about 101-220mm with the mode (approximately 12 month old fish) between 160mm and 190mm. The size range resulting from the preceding spawning is 191-310mm with the mode (approximately 24 month old fish) between 261mm and 280mm; and from the earlier spawning again the range would be 271-380mm with the mode (approximately 36 month old fish) expected at about 351-360mm, though no fish of this size range were caught during this month and few fish larger than 310mm were caught during the total study. Finally, it should be borne in mind that the analyses on *P. argenteus* were based on fairly small sample numbers and the estimates of growth rates presented here may best be treated as close approximations.

(b) Scale Reading:

Scales from 351 *P. argenteus* from Barramundi Creek were examined, and back-calculated lengths at mark formation on the scales were determined. These data are plotted in Fig. 32. When the data for males and females are plotted separately (Fig. 33) it is obvious that scales from more females than males were sampled (see Sex Ratio). From the figure it is apparent that both sexes were laying down corresponding marks on the scales over the same length ranges, and it may be concluded that growth in the fish sampled was similar in both males and females. The greater length ranges of A3 and A4 for females compared with males, derived from the back-calculations to the third and fourth marks, are probably a simple sampling artifact being a result of the larger number of scales read for females.

As was found for *P. kaakan*, the marks on some scales of *P. argenteus* were distinct and on others less distinct. The first mark, which was not obvious on all scales, corresponded to a back-calculated length between 50mm and 140mm. The second mark was laid down between 110mm and 210mm, the third mark was laid down between 170mm and 270mm, the fourth mark was laid down between 210mm and 310mm, and the fifth mark was laid down between 270mm and 340mm. After the A5 mark there tends to be considerable overlap in the back-calculated lengths at which the marks form, resulting from smaller annual increments in length and possibly the effect of

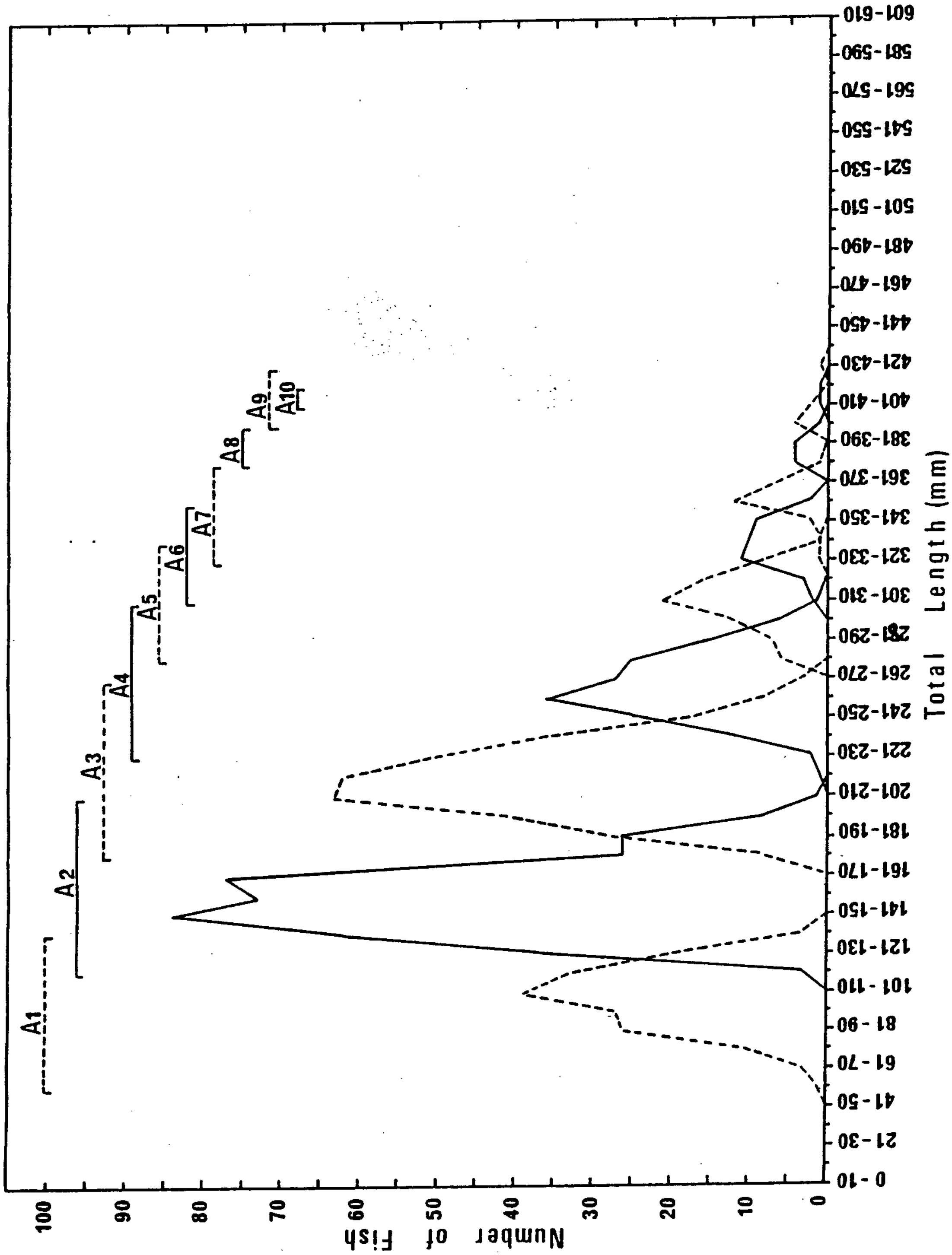

Fig. 32. Back-calculated lengths at mark formation on the scales of 351 *P. argenteus* from Barramundi Creek.

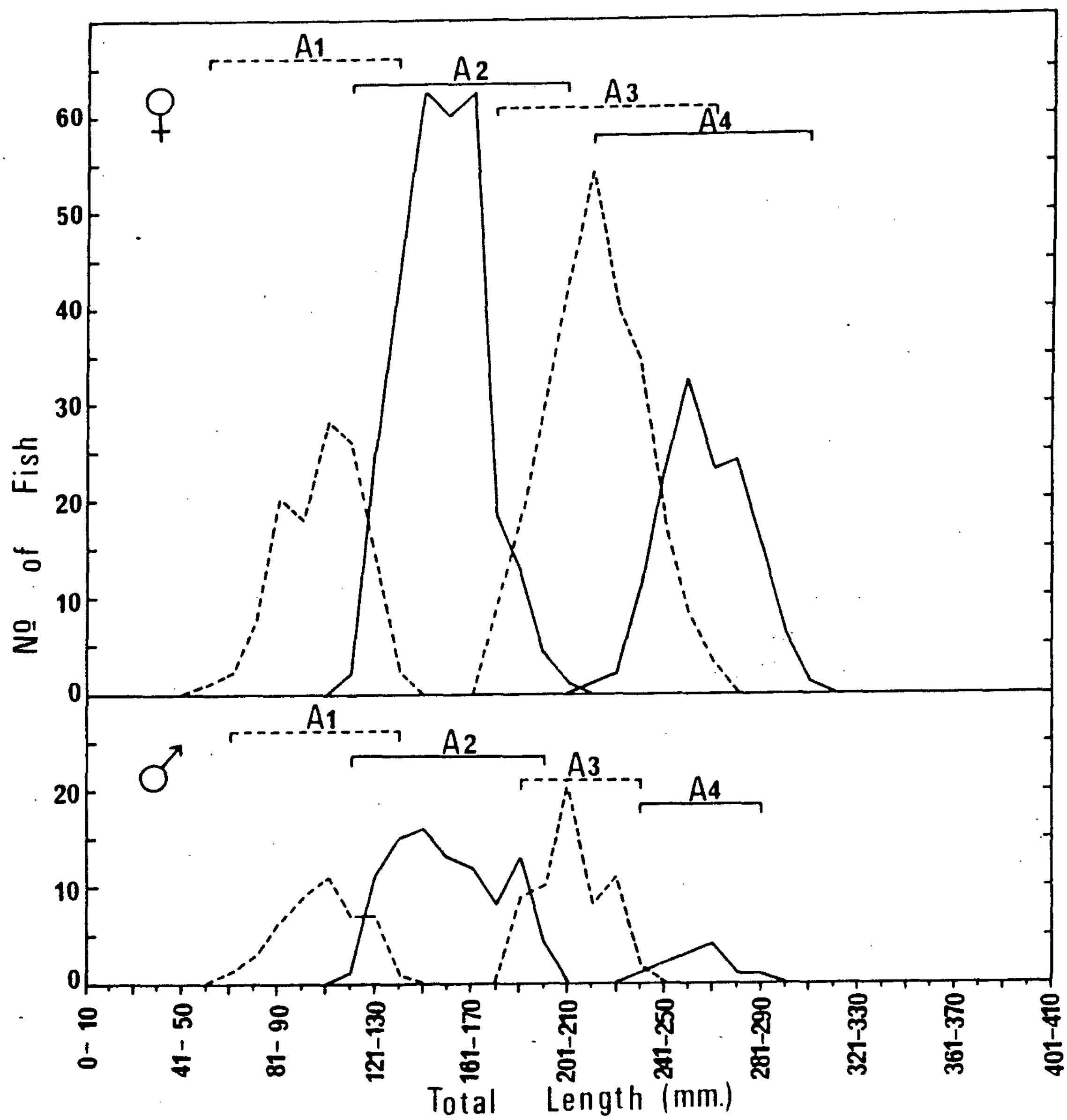

Fig. 33. Back-calculated lengths at mark formation for the first four marks on the scales of *P. argenteus* from Barramundi Creek, with males and females figured separately.

fairly variable growth rates in individuals after the first two or three years of life.

It is suggested that two marks are being laid down each year on *P. argenteus* scales, as noted for *P. kaakan*, and this is supported by evidence from length frequency analysis and tagging results. It is apparent from Fig. 34 that fish with a mark close to the edge of their scales, corresponding to a growth increment of less than 10mm in back-calculated length since the mark was laid down, were sampled over most of the year, but particularly from August to November and again from February to April. Thus, the times of actual mark formation on the scales would be a little earlier, within about the previous month of each of these periods. It can also be seen for this species that marks are being laid down about a month later for fish from Cleveland Bay, compared with those from Barramundi Creek.

Also, similarly to *P. kaakan*, it is suggested that of the two marks laid down each year one is a 'birthday' mark while the other corresponds with the time of the second spawning peak, which would occur under normal conditions. Thus, the A1 mark would normally be laid down by early spawned fish in the immediately following summer, and by late spawned fish in the following spring, in both instances about 6 to 7 months after spawning. In each case the second mark (A2) would be laid down on the scales at about 12 months of age, corresponding approximately with the time of year when the fish was spawned, either early or late. The range of sizes back-calculated for the A2 mark, therefore, is a result of early

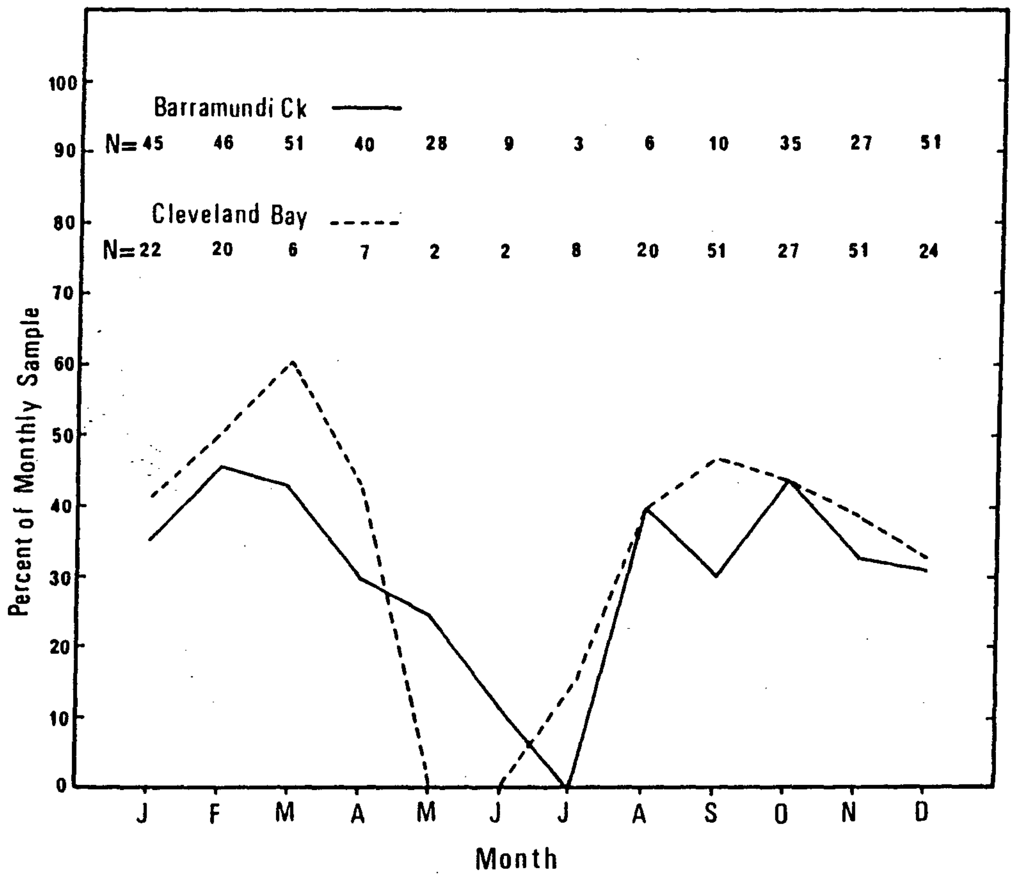

Fig. 34. Proportion of scales, from each monthly sample of *P. argenteus*, with a mark close to the edge corresponding with less than 10mm in back-calculated length since mark formation.

spawned fish which may have grown as large as 210mm in one year, and late spawned fish which may have been as small as 120mm, with the majority lying toward the middle of this range. Similarly, the results indicate that at two years old (A4) the size range was 221-310mm, at three years old (A6) 301-360mm, and at four years old (A8) 370-400mm. These values correspond with the results from the length frequency analysis for the first two years but the size range at three years old, derived from the length frequency data, is a little overestimated compared with that from the scale reading. This is probably partly a result of the small number of fish sampled in this size range.

From the scale reading data then, the back-calculated lengths at which most fish lay down the 'birthday' or yearly marks are within the range 141-170mm for the first (A2), 241-270mm for the second (A4), 321-350mm for the third (A6), 371-390mm for the fourth (A8), and 401-420mm for the fifth (A10). From these the mean growth increments estimated for each of the first five years of life in *P. argenteus* from Barramundi Creek are 155mm, 100mm, 80mm, 45mm and 30mm respectively.

The modal back-calculated length ranges of 141-170mm, 241-270mm and 321-350mm complement the length frequency data from fish of the respective age classes in the July to October period, while the modal lengths of the A1, A3 and A5 marks correspond with the lengths of fish sampled in the other peak period of mark formation, around February.

The largest fish sampled was 430mm and had 11 marks on the scales, suggesting that it was 5 or 6 years old.

(c) Tagging:

A total of 335 *P. argenteus* between 110mm and 330mm total length were tagged at Barramundi Creek and of these 56 recoveries were made. One fish (tag number 000 383) was recaptured on four separate occasions between 91 and 221 days of freedom. Eight fish were recaptured twice and 36 fish were recaptured once. Fifty one recaptures were recorded with freedom times of 28 days or greater, and these were used in the study of growth. Length increments of these fish have been plotted on Figs. 28, 29 and 30, as was done for the *P. kaakan* data (Figs. 16, 17 and 18). The tag recovery data clearly support the existence of the age groups indicated in Fig. 31. Similar arguments to those presented for *P. kaakan* also apply here in relation to joining release and recovery sizes with a straight line.

The *P. argenteus* at large for the greatest length of time (tag number 000 654) was tagged in March 1984 at a length of 198mm and after 473 days of freedom was recaptured in June 1985 at a length of 300mm. Over this period the average growth was 6.47mm per month. The fact that this fish was 198mm on initial capture in March suggests (from the length frequency results) that it was a fairly late spawned fish from the previous breeding season, rather than being from the immediate breeding season, and as such its growth was likely to be somewhat slower than that expected from an early spawned fish. From Fig. 30 it can be seen that this fish would have been approximately 251-260mm in December 1984, if growth had been consistent throughout the period of freedom. As may be observed from Fig. 35, growth in *P. argenteus* is not consistent throughout the year, as was similarly observed for *P. kaakan*. However, the fact that this fish would have been growing for about the same time in cooler months as in warmer months between March and December, it is reasonable to conclude that its average growth over this period would be close to the 6.47mm per month noted earlier. It is suggested that in December 1984 this fish would have been approximately two years old. The estimated size at this time correlates with the scale reading results, which indicate that a two year old fish (A4) would be expected to be between 220mm and 310mm. The growth rate of this recovery also fits in well with the separation of year classes indicated in Fig. 31, based on length frequency data.

The fish recovered four times (tag number 000 383) was released on the 30th of September 1983 at a length of 163mm. It was first recaptured on the 30th of December 1983 at a length of 188mm, then again on the 27th of March 1984 at a length of 210mm, again on the 9th of May 1984 at a length of 220mm, and for a fourth time on the 25th of June at a length of 221mm. In its first period of freedom (91 days) it had grown 25mm, averaging 8.2mm per 30 days and in its second period of freedom (87 days) 22mm, averaging 7.6mm per 30 days. At this time the fish was double tagged, adding a Floy

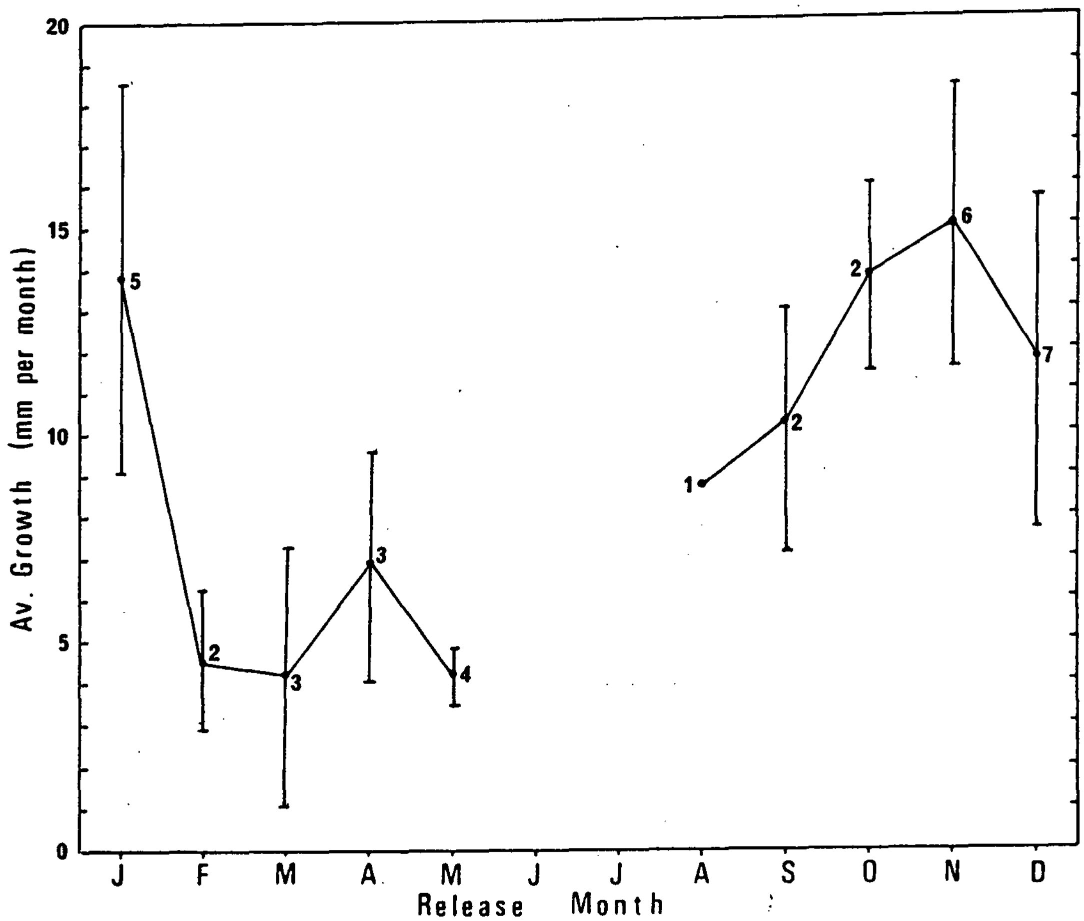

Fig. 35. Average growth (± S.E.) per month and number of recaptures for tagged *P. argenteus*, less than 300mm in length at release and free for 28-100 days, from Barramundi Creek.

FD 68-BC tag as well as the previously used 'clothes' tag. In its third period of freedom (43 days) the fish grew 10mm, averaging 7.0mm per 30 days and in the fourth period of freedom (47 days) the fish only grew 1mm. At its fourth release it was noted that the fish was slightly injured by the hook when it was caught, and this, combined with growth over the winter period, would probably account for the small length increment recorded over the last period of freedom.

The total growth of this fish from September 1983 to May 1984 was 57mm, from 163mm to 220mm, at a rate of approximately 7mm per 30 days. Extrapolating, and accepting a lower growth rate from May 1984 to September 1984 but not as low as indicated by the apparently aberrant growth of the fish in the final period of freedom, it is not unreasonable to assume a growth rate averaging 6.5mm per month over the months May to September. Such a rate would give an anticipated length of approximately 245mm in September, which agrees with the size distribution of two year old fish during this month (see Fig. 31). Similarly, the 163mm size of the fish when first caught and released in the previous September is close to the mode of the expected distribution for fish spawned a year earlier in the main spawning period, and therefore about one year old.

Most of the tag recovery data show good agreement with the length frequency and scale reading results, although the occasional fish appeared to grow faster or slower than normal, as might be expected for this sort of data. In géneral, however, the growth results from tagging correlate with the results from the other methods very well. From this it can be concluded that tagging had little effect on the growth rate of most *P. argenteus*, as was also the case for *P. kaakan*.

From Fig. 35 it can be seen that for recaptured individuals of *P. argenteus* there was a marked increase in growth rate over the summer months compared with the cooler months. So, as concluded for *P. kaakan*, it is not strictly correct to use straight lines to indicate growth between release and recapture over many months, but, as evident in Figs. 28, 29 and 30, it aids simplicity and clarity to do so. This complication is why only data for fish at large for a period of 28-100 days were used to produce Fig. 35 rather than including data for longer recovery periods.

Since no *P. argenteus* were released in June or July no data are available for those months. Likely values of 5mm per month were assumed in order to allow a calculation of approximate expected growth over a 12 month period from the data. This suggests growth of about 105mm over a year for an 'average' fish in the size range tagged, most of which were between 150mm and 250mm in total length and between one and two years old at the time of tagging.

7.3.4 *P. argenteus* - Cleveland Bay

(a) Length Frequency:

Figures 36 and 37 show the length frequencies of *P. argenteus* taken in trawl samples from Cleveland Bay during 1981 and 1982 respectively, together with data for small fish of this species seined from Pallarenda, on the shore of Cleveland Bay, in 1984 and 1985 respectively. From these figures it is evident that there are primarily two size groups being sampled in the trawls; firstly, the 'young of the year' and secondly, fish from the previous spawning, with some late spawned fish from two breeding seasons earlier. The smallest fish were sampled from January to March at 110mm to 130mm and these represent the earliest spawned fish of the immediate breeding season (5-7 months old), together, perhaps, with some of the very late spawned fish of the previous breeding season (up to 14 months old). Most of the fish in the August to November samples, between about 120mm and 300mm in length, would have been fish spawned in the two previous breeding seasons and, therefore, would have been between 7 months and about 2 years old.

Thus, if October is taken as the mid point in the early spawning period, it can be seen from Figs. 36, 37, and 38, that at one year old these fish would be approximately 161-170mm, while the two year old fish would average 211-220mm or perhaps a little larger. It appears that, as with *P. kaakan*, the larger fish in this age group were not sampled in the trawls.

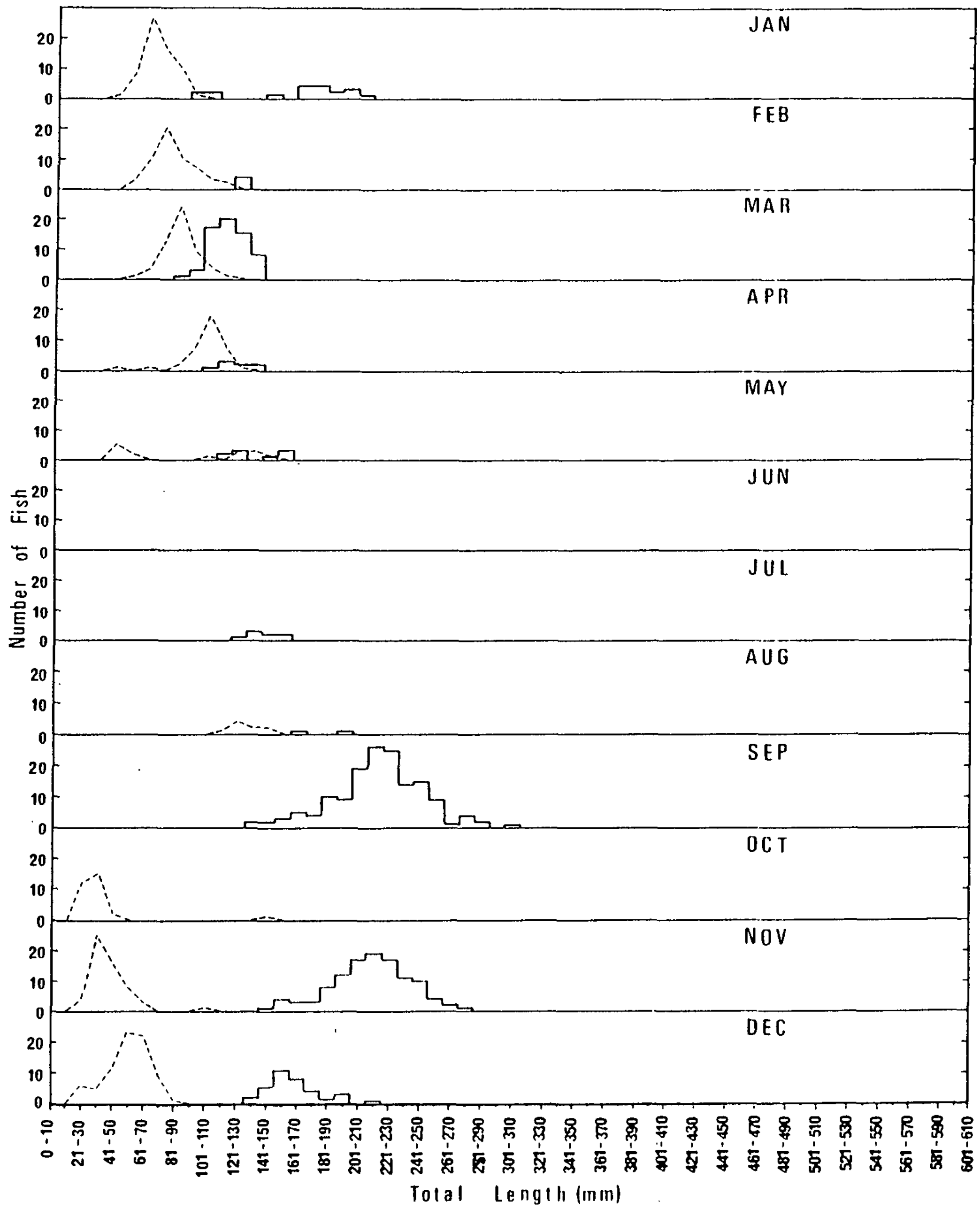

Fig. 36. Length frequency histograms of *P. argenteus* trawled from Cleveland Bay each month in 1981 (——), and collected by small mesh beach seine from Pallarenda in 1984 (----).

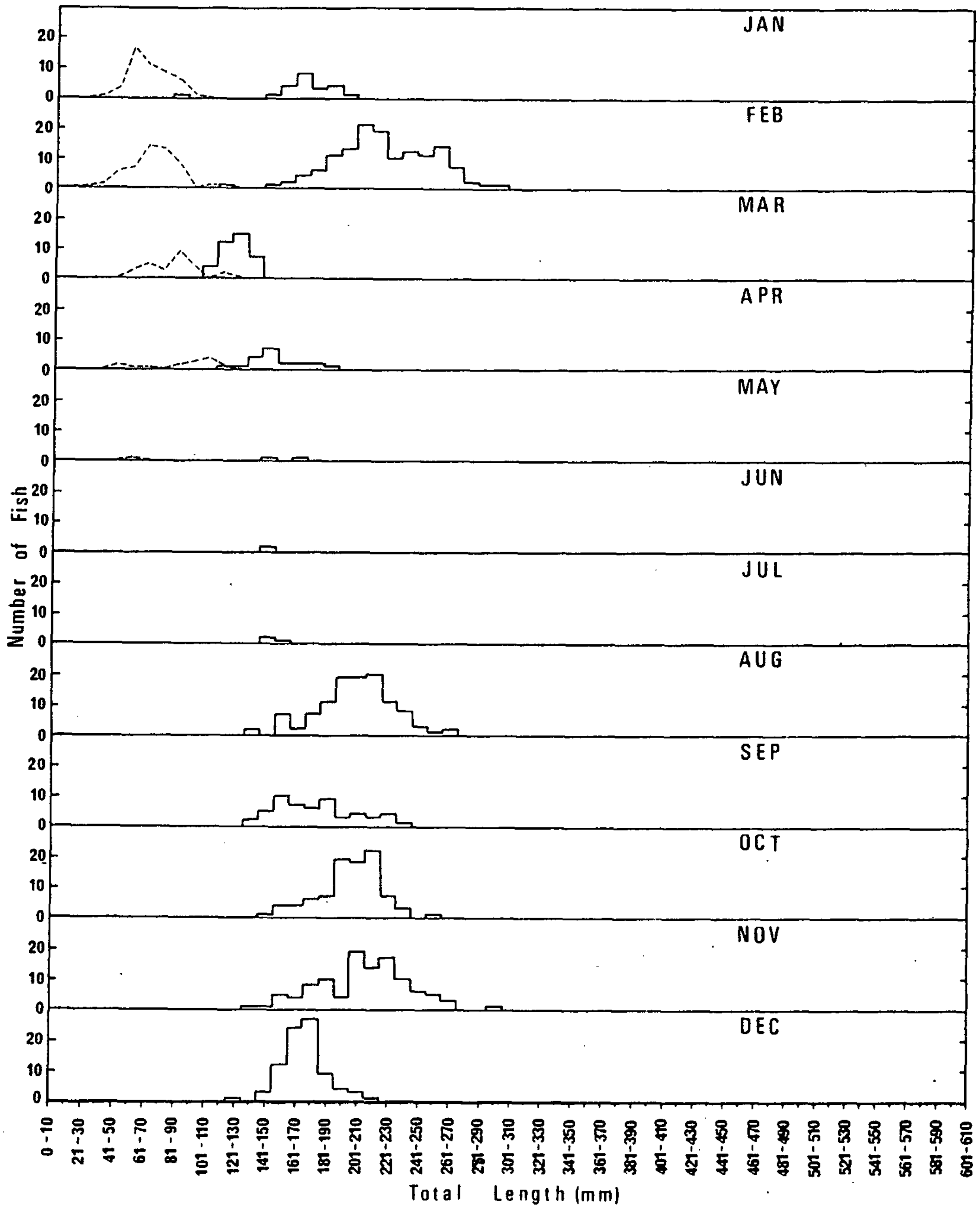

Fig. 37. Length frequency histograms of *P. argenteus* trawled from Cleveland Bay each month in 1982 (——), and collected by small mesh beach seine from Pallarenda in 1985 (----).

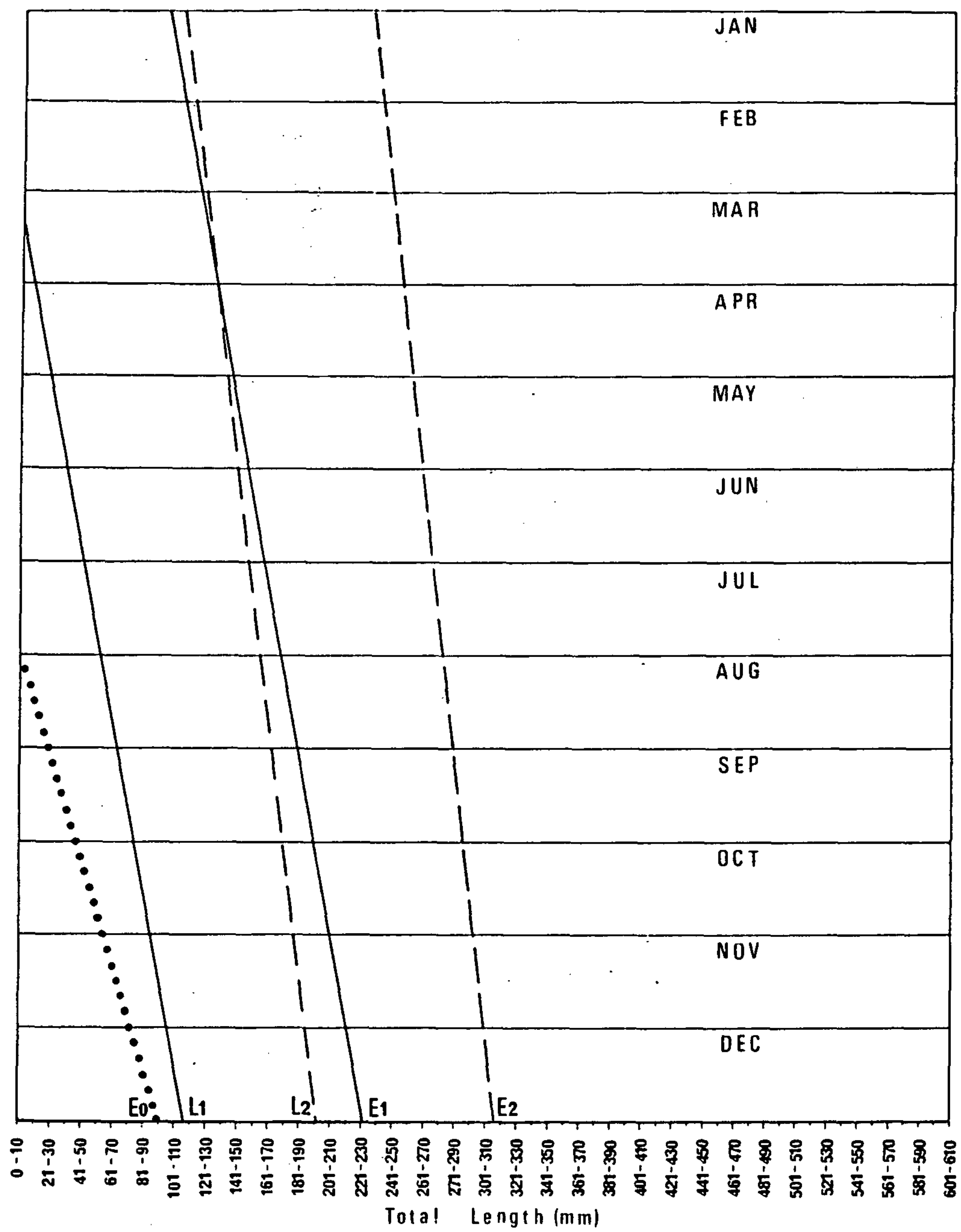

Fig. 38. Likely separation of year classes for *P. argenteus* from Cleveland Bay.

0 to E0 = young of the current (n) breeding season

L1 to E1 = fish from the previous (n-1) breeding season

L2 to E2 = fish from the (n-2) breeding season

Very few *P. argenteus* were sampled in June, July or August and, as discovered also from the Barramundi Creek sampling, this species seems to 'disappear' from the study site in those months.

Figure 38 shows a separation of the two age classes in the Cleveland Bay samples, with lines for early and late spawned fish of each breeding season fitted by eye.

As noted for the other species studied, the data for trawled fish from Cleveland Bay and seined fish from Pallarenda do not represent contemporaneous information, but a comparison of them provides an indication of growth from settlement to the size taken by trawling. Thus, from Figs. 36 and 37 it can be seen that very small *P. argenteus* were first caught at Pallarenda in October at lengths of 20mm to 50mm, and progression of the length frequency modes over the following months suggests that these fish are growing at about 10-20mm per month. The largest fish in these samples, taken from October through to April, would comprise individuals spawned early in the breeding season, whereas the smaller ones being continuously recruited over the period represent progressively later spawned individuals. The fact that some small fish were taken right through to April and May indicates that a late spawning occurred in Cleveland Bay, as was noted for *P. kaakan*, probably as late as February or March. It is postulated that, by the following March or April, these late spawned fish would overlap the size range of early spawned fish of the next spawning, as was noted earlier.

(b) Scale Reading:

The scale reading results for *P. argenteus* from Cleveland Bay (Fig. 39) show a similar pattern of lengths at mark formation, over the size range examined, as that observed for Barramundi Creek fish. The modal back-calculated lengths at mark formation for Cleveland Bay fish are however a little larger than for Barramundi Creek samples in the first two years. In Cleveland Bay fish the modal back-calculated length range at formation of the first mark is between 131-140mm, compared with 101-110mm for Barramundi Creek fish, and that of the second mark (the first 'birthday' mark) is 161-170mm compared with 141-170mm (cf. Fig. 32). The modal back-calculated length range at formation of the third mark is 201-210mm compared with 201-230mm for Barramundi Creek fish, and that of the fourth mark (the second 'birthday' mark) is 261-270mm compared with 241-270mm. The widths of the size ranges at mark formation are very similar for the two sites, though the size range at formation of the fourth mark in the Cleveland Bay sample may be somewhat truncated because of low numbers of larger fish sampled in this age class.

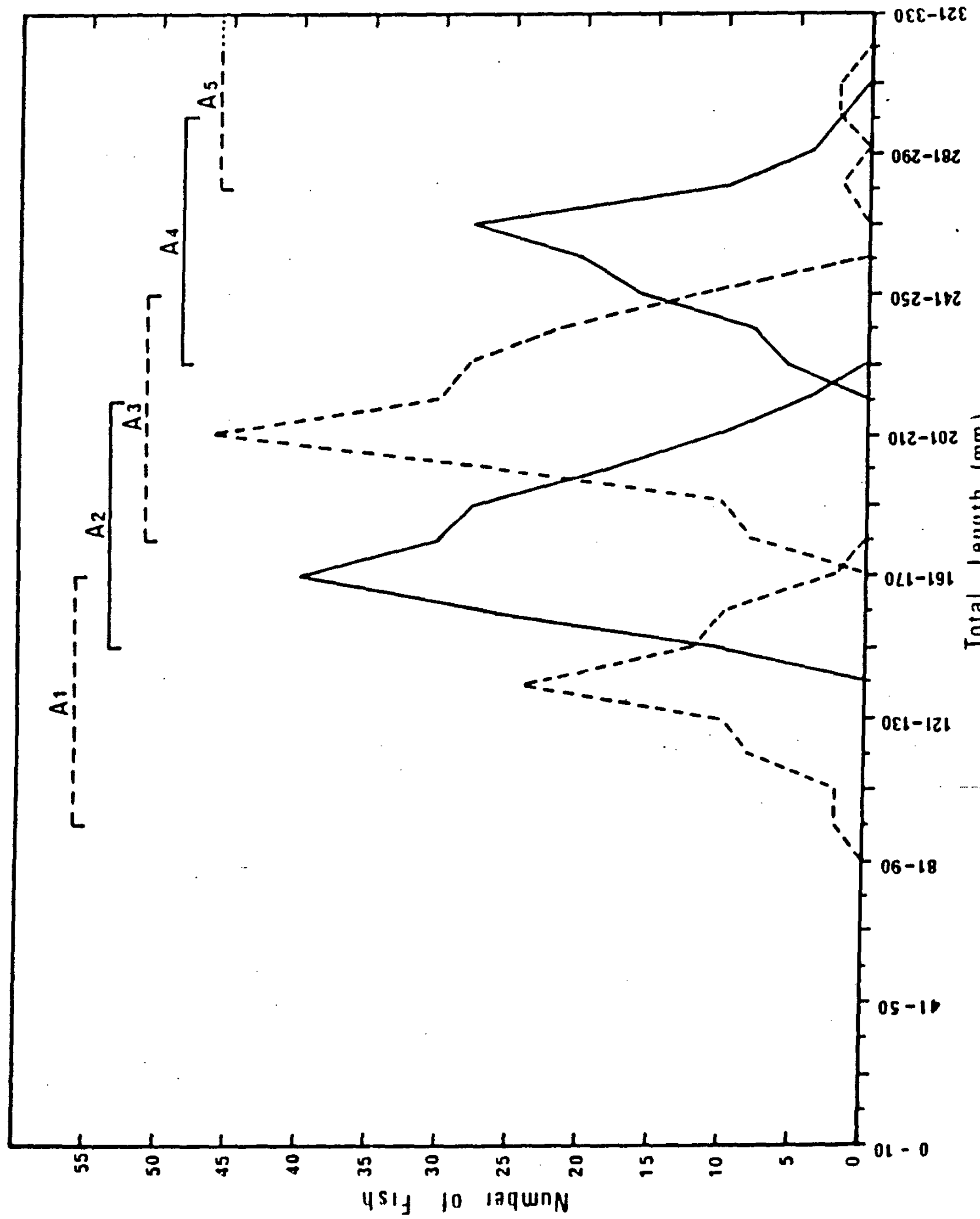

Fig. 39. Back-calculated lengths at mark formation on the scales of 275 *P. argenteus* from Cleveland Bay.

7.3.5 Pomadasys maculatus - Cleveland Bay

(a) Length Frequency:

Figures 40 and 41 show the length frequency distributions of *P. maculatus* captured by trawl sampling in Cleveland Bay on a monthly basis through 1981 and 1982 respectively. Also included on these figures are length frequencies of small *P. maculatus* taken by small mesh beach seine at Pallarenda on the shores of Cleveland Bay in 1984 and early 1985.

From Figs. 40 and 41 it can be seen that there are two major size groups in the trawl samples; larger fish from approximately 120mm to 190mm and a smaller size group less than 100mm, for most of the year. The April 1981 and June 1981 samples indicate some fish of intermediate size which may be the result of a successful late spawning in the previous year.

In general the lengths of fish comprising the smaller size group tend to increase over the year, and apparently merge with the larger size group from about October to December. By December the new small size group is being sampled in the trawl catch and is the result of recruitment from the immediate breeding season, which would have begun by August and would continue through to about February or March (as noted in the Reproduction chapter). Thus, these new recruits are up to 5 months old for fish spawned in early August and may be up to about 60mm in total length. The slightly larger fish (70-80mm) in this new recruit group in December may be

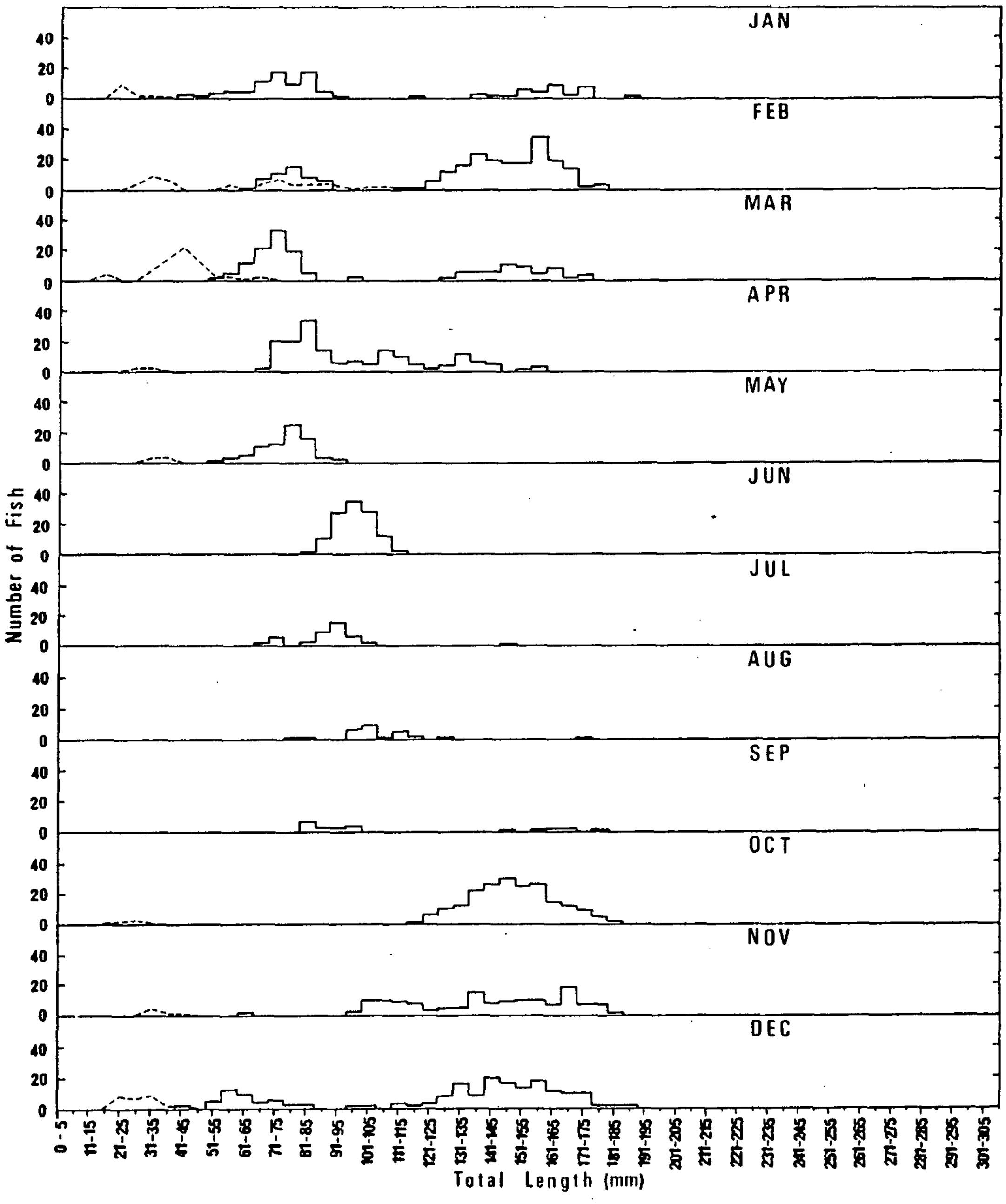

Fig. 40. Length frequency histograms of *P. maculatus* trawled from Cleveland Bay each month in 1981 (———), and collected by small mesh beach seine from Pallarenda in 1984 (- - -).

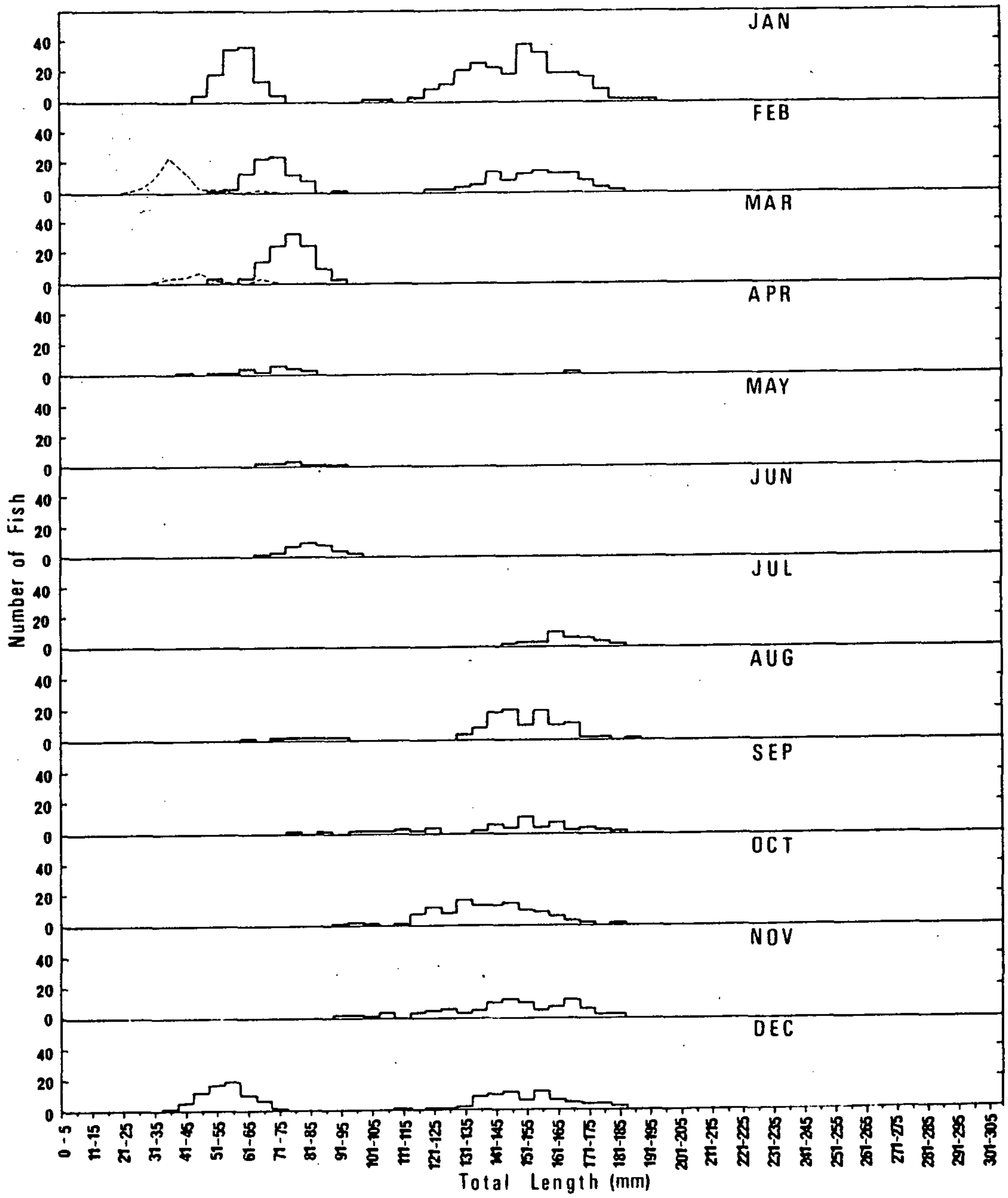

Fig. 41. Length frequency histograms of *P. maculatus* trawled from Cleveland Bay each month in 1982 (——), and collected by small mesh beach seine from Pallarenda in 1985 (----).

either fast growing fish of this spawning, or remnants of a late spawning and/or slow growing fish from the previous breeding season. It would be expected that fish spawned late would be slower growing since their early growth would be through the winter months.

Therefore, if the first spawnings during the breeding season occur in August, the larger fish of the small size group captured by trawl in that month, of approximately 120-125mm TL, will comprise individuals approximately 12 months old together with some late spawned fish from the previous season which may be up to 18 months old. By December when new recruits from the immediate spawning are being taken in the trawl samples, the largest fish of the previous small size group would be about 16 months old and up to 150mm TL, ranging down to 90mm and smaller for later spawned fish (say December - February) of 10-12 months old. Thus, in Fig. 40, the new recruit group first taken in the trawls in December 1981 forms the basis of the small size group in the 1982 samples (Fig. 41). By December 1982 the largest of these new recruits would, as in the previous year, be approaching 150mm, while the small size group from 1981 would now make up the group of fish larger than 150mm. The largest of these could be up to 190mm and 28 months old (or even 40 months old depending on the longevity of this species, as will be discussed later). Figure 42 indicates the likely separation of the year classes for this species.

When the Pallarenda samples are taken into account (the broken line in Figs. 40 and 41) it is obvious that spawning and

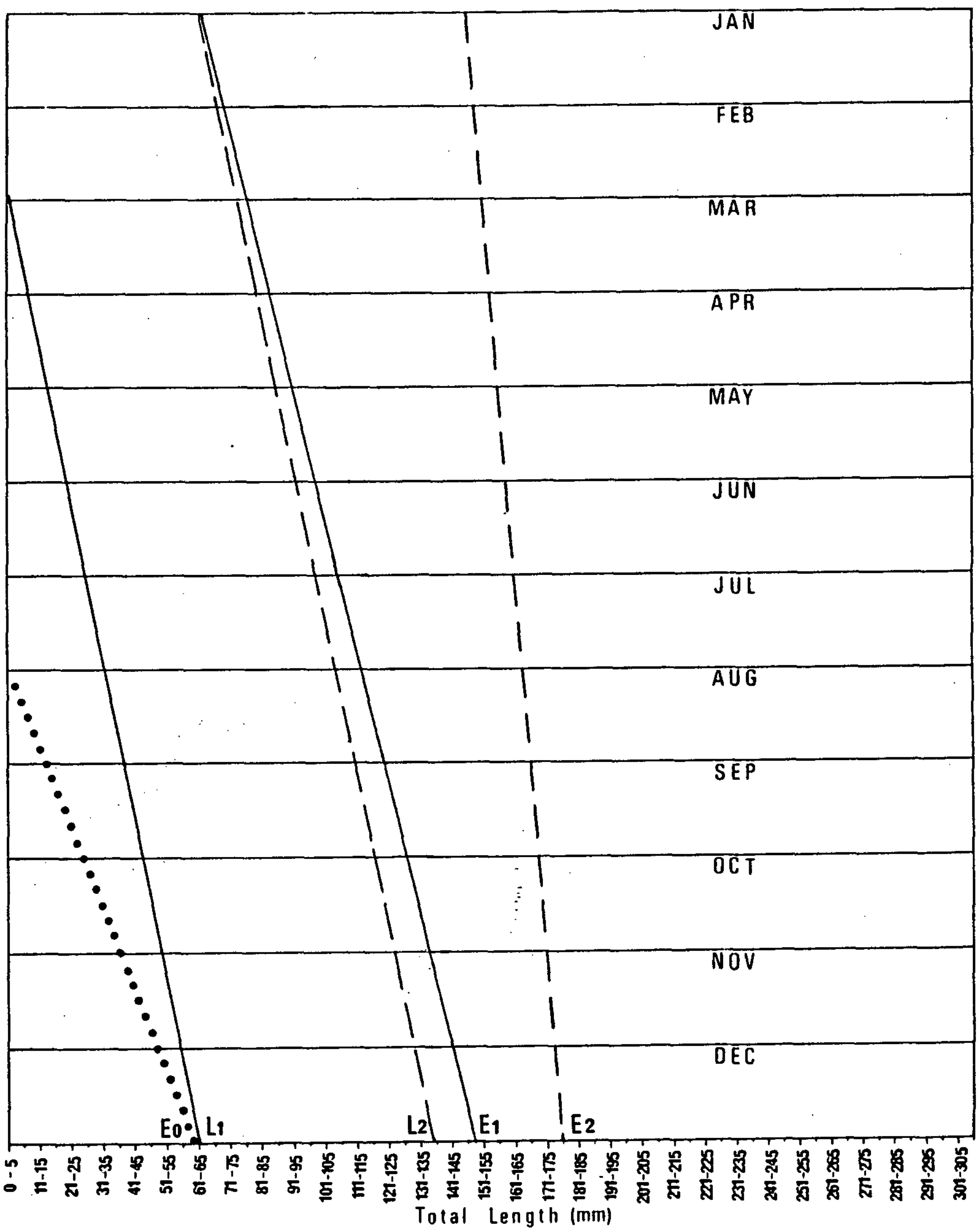

Fig. 42. Likely separation of year classes for *P. maculatus* from Cleveland Bay.

0 to E0 = young of the current (n) breeding season

L1 to E1 = fish from the previous (n-1) breeding season

L2 to E2 = fish from the (n-2) breeding season recruitment of post-larvae and juveniles to inshore weed beds was taking place over a prolonged period. From the March 1984 Pallarenda sample (Fig. 41) it is obvious that there was a second peak of spawning activity in the prolonged breeding season as there was recruitment of very small fish of 15-20mm at that time, resulting from spawning probably in January or February. However, this late spawning and recruitment indicated in March 1984 does not appear to have occurred in 1985. Thus, although the breeding season will extend over about the same time each year, its precise duration and the success of recruitment may undergo some variation, and this must be taken into account when interpreting the data, and especially when comparing the Pallarenda data with the trawl data. Also, the prolonged recruitment to each age class adds to the difficulty of interpreting the length frequency data, particularly for older age groups.

The Pallarenda data show that very small juveniles of *P. maculatus* are being sampled as early as October at less than 25mm TL. These are the result of the earliest spawnings, probably as early as the beginning of August. The mode of this size group progresses at approximately 10mm per month but with some fish growing somewhat faster, as might be expected. Thus, it is reasonable to expect that by December some of these fish could have obtained the size of those forming part of the new recruit group noted earlier in the trawl samples *i.e.* between about 40mm and 75mm.

(b) Scale Reading:

Neither scales nor otoliths were found to be useful for ageing this species. The otoliths were very crystalline in nature and showed no clear growth rings, while the scales from fish larger than approximately 100mm were almost totally replacement scales (Plate 13). Some fish had a few original scales remaining under the pectoral fin, very close to its base, and when present these scales were removed and mounted along with a selection of replacement scales from the same fish. Preparations of this type were examined for 76 fish for which more than two reasonable non-replacement scales were obtained. The proportion of growth from the point of scale replacement was calculated, in addition to a back-calculation of the lengths at formation of any marks, on original scales. Length increments since scale loss, calculated from different scales from the same fish, were very similar indicating that most of the original scales had been lost simultaneously, or at most over a fairly short period of time, or alternatively at a time when little growth was occurring. The results of these analyses are shown in Fig. 43. Replacement scales formed on fish at lengths between 45mm and 105mm, and most original scales had a single mark which corresponded with a back-calculated length between 145mm and 175mm.

It is indicated from the length frequency data that the 45-105mm group would be recruits from the last spawning but still too small to breed themselves (see Reproduction chapter), while the

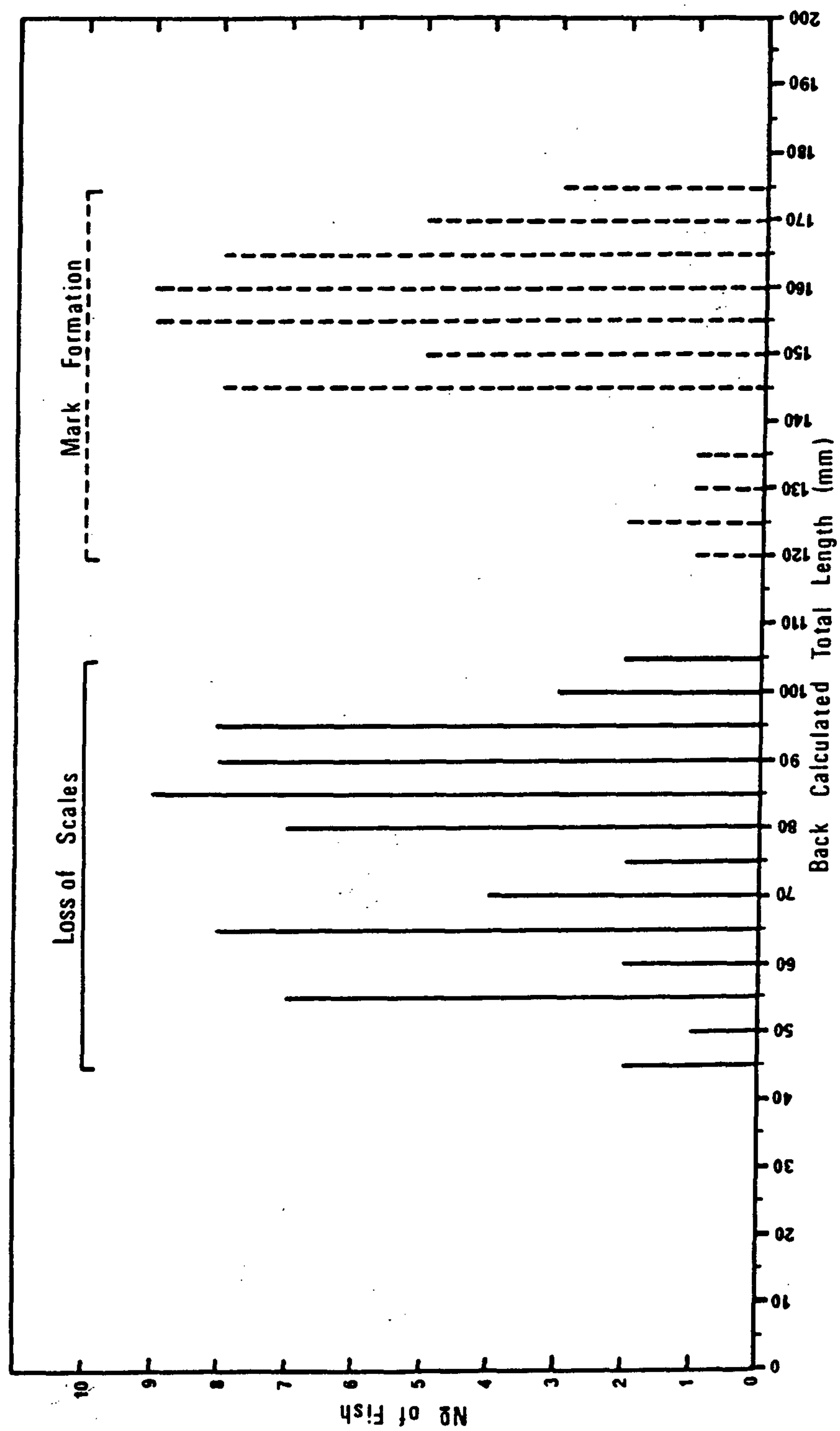

Fig. 43. Back-calculated lengths, at the time of scale loss and of mark formation, for 76 *P. maculatus* from Cleveland Bay.

145-175mm group were about two years old and of a reproductive size. Thus, the mark on the scales of the latter group may be a spawning mark, or more likely a pre-spawning mark associated with reproductive development. This has been postulated for *P. kaakan* and *P. argenteus*. The loss of scales in the smaller size group may have been associated with some similar hormonal or physiological change. Another possible explanation is that the mark on the scales may have been a response to movement out of Cleveland Bay by the larger fish during the winter months, while the loss of scales in the smaller fish may have been a response to adverse conditions, including reduced temperatures, encountered by remaining in the Bay over the winter months. A further explanation should not be overlooked, however, where the loss of scales in smaller fish may be due to 'predation' by scale picking fish, such as *Terapon jarbua* and *T. theraps*, which occur within the Bay - the latter in very large numbers (N. Milward, pers. comm.). The occurrence of scale feeding in *T. jarbua* has been noted by other workers (Whitfield and Blaber, 1978; Whitfield, 1979) and it is possible that species of other families occurring in the area may have the habit also (eg. Carangidae - Stickney and White, 1973, and Triacanthodidae - Mok, 1978).

7.3.6 Determination of Asymptotic Lengths by Walford Plots

Using the calculated values for mean length at 'birthday' mark formation, a Walford Plot of length at age t+1 against length at age t was drawn for each of the three species studied (Fig. 44), in order to obtain a first approximation of their asymptotic lengths (l_∞). Data derived from scale reading of Barramundi Creek fish were used for *P. kaakan* and *P. argenteus*. These gave the best indications of age over the greatest size ranges, though lengths derived from length frequency analyses would have been more appropriate if they had spanned a greater age range (see Discussion 7.4.1).

The mean lengths at age used for *P. kaakan* for the first five years were 160mm, 285mm, 390mm, 475mm, and 530mm respectively. When plotted these values yielded an estimate for the asymptotic length of *P. kaakan* of 750mm. A similar plot for *P. argenteus* using the values 155mm, 255mm, 335mm, 380mm, and 410mm for mean lengths at ages 1-5 respectively yielded an estimate of 480mm as the asymptotic length.

For *P. maculatus* from Cleveland Bay the best indication of length at age is given by the length frequency data, since scale reading was not very useful for ageing. This resulted in a mean length of 120mm at one year old and 165mm at two years old. Since the largest fish caught was 190mm, and because it was impossible to confidently separate fish in the larger size group in the length frequency data, an estimate of 185mm at three years old was used.

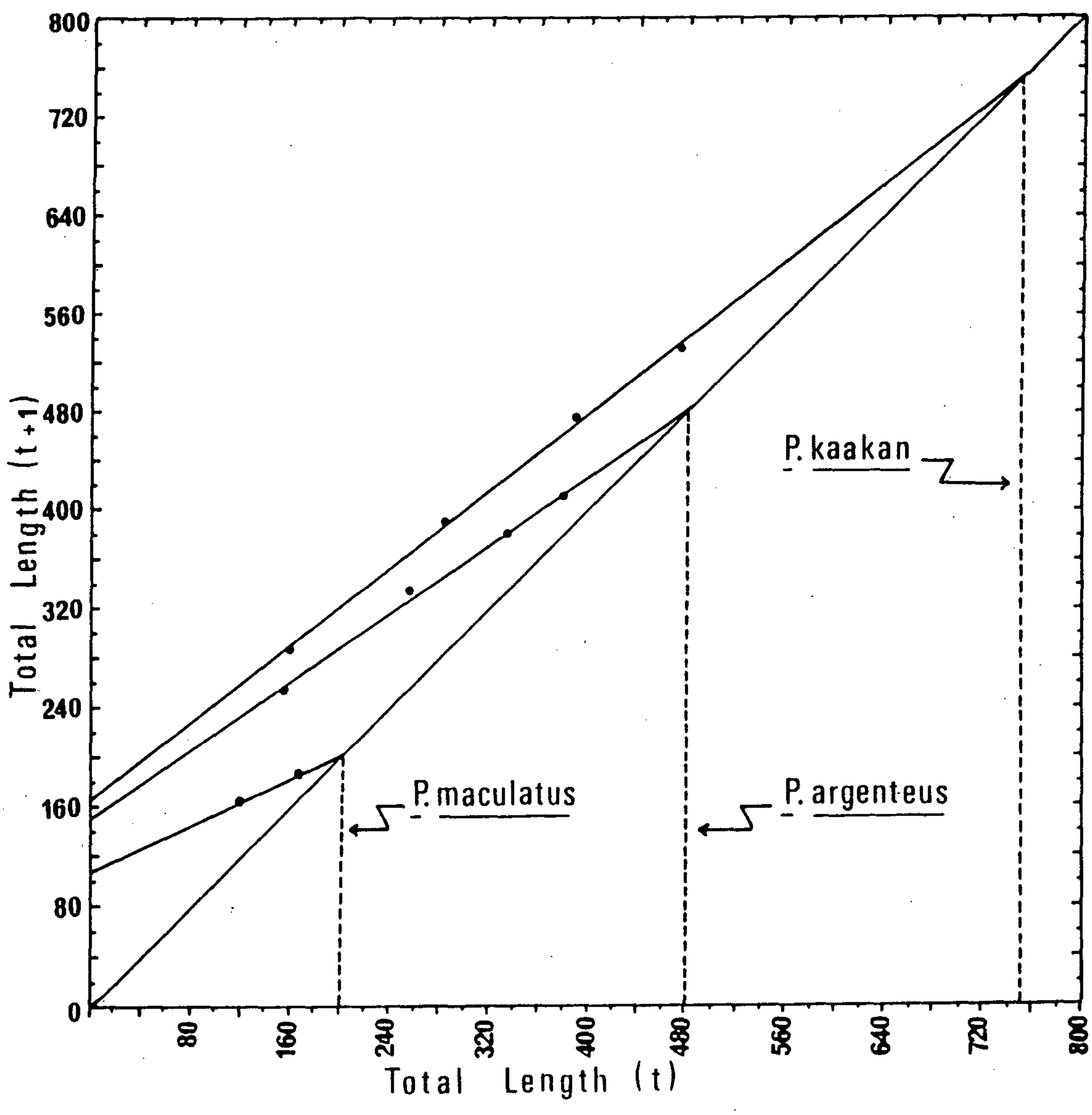

Fig. 44. Walford Plot of length at age (t + 1) against length at age (t), for *P. kaakan*, *P. argenteus*, and *P. maculatus*.

The plot using these values suggests an asymptotic length of 200mm for this species.

7.3.7 von Bertalanffy Growth Equations

(a) P. kaakan:

The Walford growth transformation of plotting length at age t+1 against length at age t produced a least squares regression relationship of -

$$l_{t+1} = 163.131 + 0.7843 l_t \quad (r = 0.999)$$

for *P. kaakan*.

From this equation a more accurate estimation of the asymptotic length of fish in the population can be determined since L_∞ = intercept ÷ (1 - slope) = 163.131 ÷ (1 - 0.7843) = 756mm TL. An estimate of the growth coefficient, K, can also be determined, where

$$K = -\log \text{slope} = -\log 0.7843 = 0.24296$$

The von Bertalanffy growth equation

$$l_t = L_\infty (1 - e^{-K(t-t_0)})$$

describes growth of fish where a Walford Plot produces a straight line (Everhart *et al*, 1975), and the values derived above are integral parts of it.

Similarly, a linear regression of $(L_\infty - l_t)$ against age t allows t_0 to be calculated. The equation of this regression is

$$L_\infty - l_t = 6.639 - 0.2451 l_t \quad (r = 0.999)$$

and

t_0 = (intercept - log L_∞) ÷ K = (6.639 - log 756) ÷ 0.24296 = 0.041

Therefore the von Bertalanffy growth equation for *P. kaakan* from Barramundi Creek is

$$l_t = 756\ (1 - e^{-0.243(t-0.041)}).$$

From this equation, predicted lengths for the first 10 'birthday' marks, which can be equated with annuli, have been calculated . These are

1 year old	(A2)	157mm	6 year old	(A12)	578mm
2 year old	(A4)	286mm	7 year old	(A14)	616mm
3 year old	(A6)	387mm	8 year old	(A16)	646mm
4 year old	(A8)	467mm	9 year old	(A18)	670mm
5 year old	(A10)	529mm	10 year old	(A20)	689mm

which are plotted in Fig. 45.

These values agree well with the lengths at 'birthday' mark formation determined from scale reading, which were

1 year old (A2) = 160mm

2 year old (A4) = 285mm

3 year old (A6) = 390mm

4 year old (A8) = 475mm

5 year old (A10) = 530mm

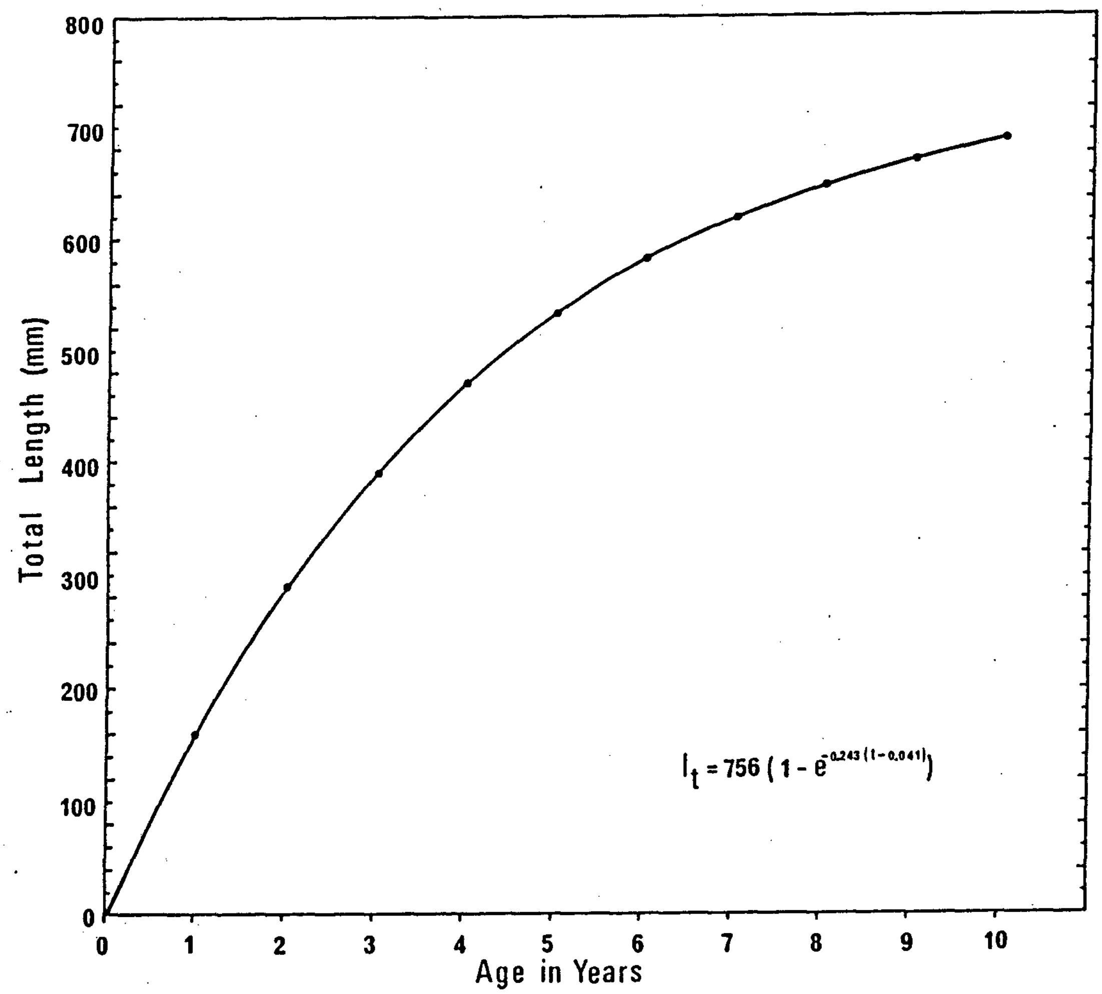

Fig. 45. von Bertalanffy growth curve for *P. kaakan* from Barramundi Creek.

(b) *P. argenteus:*

For *P. argenteus*, the Walford growth transformation produced a least squares linear regression relationship of

$$l_{t+1} = 153.536 + 0.6811_{t} \quad (r = 0.997)$$

The asymptotic length determined for fish in the population was

$$L_{\infty} = 153.536 \div (1 - 0.681) = 481\text{mm TL.},$$

and the growth coefficient (K) calculated was

$$K = -\log 0.681 = 0.38419.$$

The value for t_o was calculated in the same way as for *P. kaakan* and resulted in t_o = 0.012.

Therefore the von Bertalanffy growth equation for *P. argenteus* from Barramundi Creek is

$$l_t = 481 \ (1 - e^{-0.384(t-0.012)}).$$

From this equation, predicted lengths for the first 10 'birthday' marks were calculated. These are

1 year old (A2)	152mm	6 year old (A12)	433mm
2 year old (A4)	257mm	7 year old (A14)	448mm
3 year old (A6)	328mm	8 year old (A16)	459mm
4 year old (A8)	377mm	9 year old (A18)	466mm
5 year old (A10)	410mm	10 year old (A20)	471mm

which are plotted in Fig. 46.

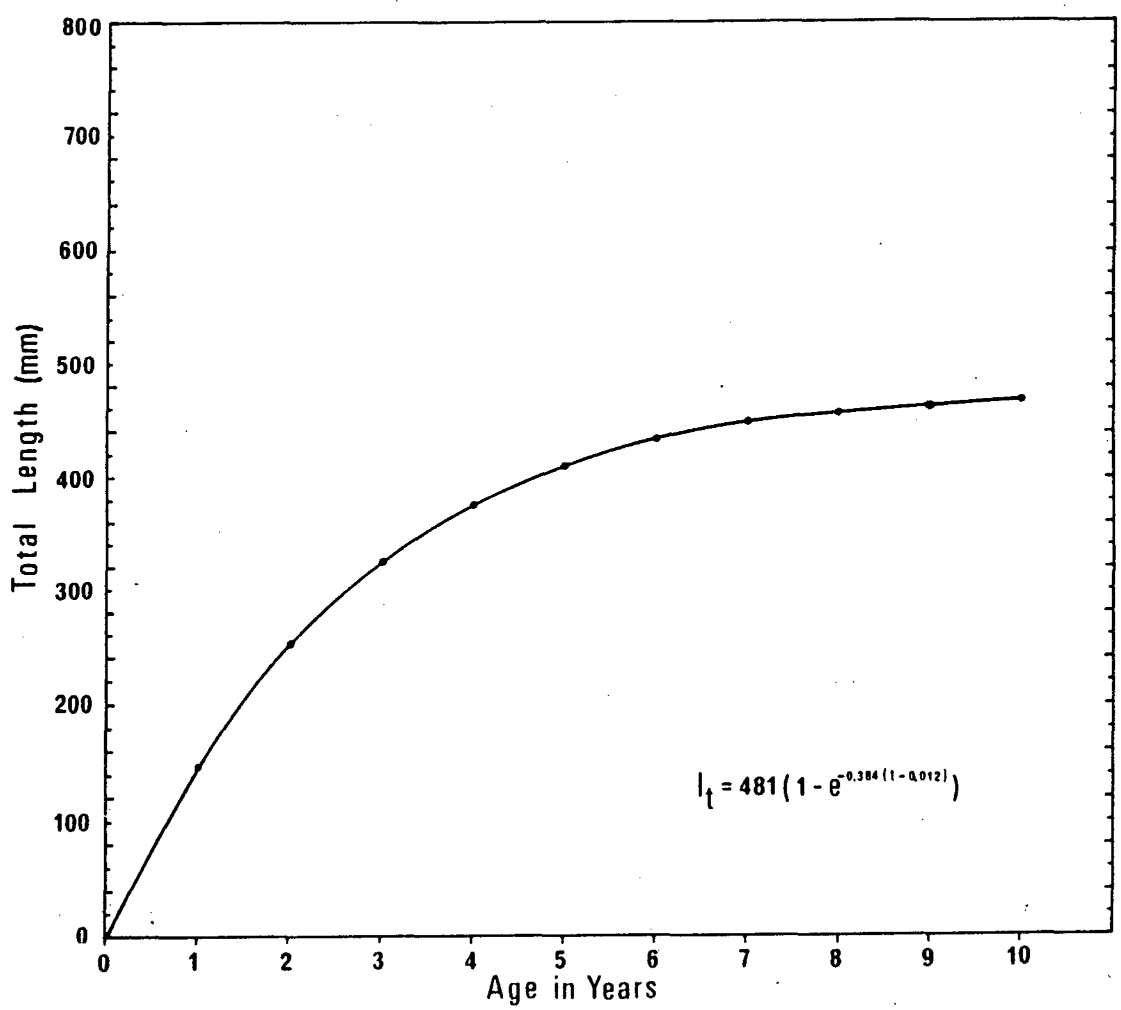

Fig. 46. von Bertalanffy growth curve for *P. argenteus* from Barramundi Creek.

These values agree well with the lengths at 'birthday' mark formation determined from scale readings of

1 year old (A2) = 155mm

2 year old (A4) = 255mm

3 year old (A6) = 335mm

4 year old (A8) = 380mm

5 year old (A10) = 410mm

for the first five years.

(c) *P. maculatus*:

For *P. maculatus* the Walford growth transformation produced a regression relationship of

$$l_{t+1} = 109.81 + 0.4586 l_t \qquad (r = 0.999)$$

however it should be noted that only three values were available to calculate this relationship. Values determined for L_∞, K, and t_0 were

$$L_\infty = 203\text{mm}$$

$$K = 0.77947$$

$$t_0 = -0.148$$

Therefore the von Bertalanffy equation is as follows

$$l_t = 203(1- e^{-0.779(t+0.148)})$$

Estimated values for length at age for the first five years, using the equation above, are

1 year old = 120mm

2 year old = 165mm

3 year old = 186mm

4 year old = 195mm

5 year old = 199mm

which are plotted in Fig. 47.

Despite the few values available to calculate the Walford regression, the values determined from the von Bertalanffy relationship, together with the determined value of L_∞ of 203mm, suggest that the von Bertalanffy equation effectively describes growth in this species.

7.3.8 Length-Weight Relationship

The equations given below describe the relationship between total length (TL) and whole weight (W), and were derived from least-squares regression analysis of log transformed data. In all cases the correlation coefficients of the relationships were greater than 0.995 indicating a very close relationship between length and weight which would allow one to be determined from the other confidently.

The relationships were initially calculated separately for both sexes for each species, and separately for the two sites, Barramundi Creek and Cleveland Bay, in the cases of *P. kaakan* and *P. argenteus*.

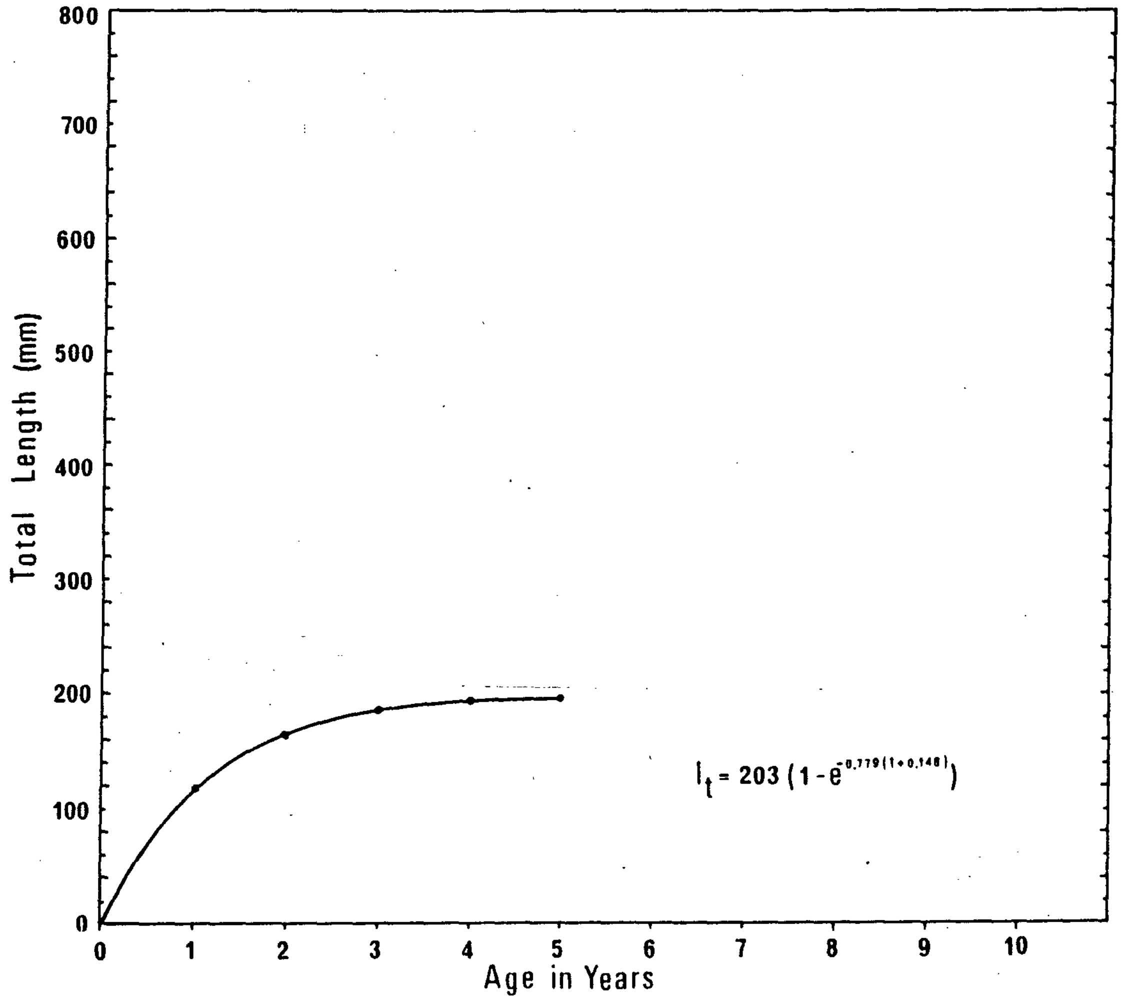

Fig. 47. von Bertalanffy growth curve for *P. maculatus* from Cleveland Bay.

(a) *P. kaakan*:

There was only an extremely small difference between the length-weight relationship of female and male *P. kaakan*, with less than 3% variation in the weight for a particular length for the two sexes. The relationship for fish (males and females pooled) from the two sites was also very similar. Thus, only a single equation has been presented below since it is a predictive equation and individual differences could easily account for small deviations from the relationship.

The equation describing the length-weight relationship is -

$$\text{Log } W = 2.8565 \text{ Log } TL - 10.3783$$

Thus for the estimated asymptotic length of 756mm the corresponding asymptotic weight would be approximately 5.2kg.

(b) *P. argenteus*: -

Similarly to *P. kaakan*, negligible difference between the length-weight relationship of females and males, and between sites, was found for *P. argenteus*.

The equation describing the relationships is -

$$\text{Log } W = 2.9063 \text{ Log } TL - 10.5724$$

Thus the asymptotic weight, corresponding to the estimated asymptotic length of 481mm, is approximately 1.6kg.

(c) P. maculatus:

For this species there was a difference in the length-weight relationship for females and males, with males having a lower weight than females.

These relationships, for fish all taken from Cleveland Bay, are -

Log W = 3.0687 Log TL - 11.3389 for females

and Log W = 2.9124 Log TL - 10.6287 for males.

The asymptotic weights corresponding to the estimated asymptotic length of 203mm are 143g for females and 127g for males.

7.3.9 Length-Length Relationships

Least squares linear regressions were calculated to allow transformation of total length (TL) values, which have been used in this study, into standard length (SL) or length to caudal fork (LCF) values.

As with the length-weight relationship, the length-length relationships were very predictable. For each species, the relationships for fish from different sites were almost identical, as were the relationships for the different sexes.

The equations for each species are -

P. kaakan

SL = 0.83 TL - 5.44 (r = 0.999)

LCF = 0.95 TL + 0.52 (r = 0.999)

P. argenteus

$$SL = 0.83\ TL - 5.14 \quad (r = 0.999)$$

$$LCF = 0.95\ TL + 0.97 \quad (r = 0.999)$$

P. maculatus

$$SL = 0.81\ TL - 1.07 \quad (r = 0.999)$$

$$LCF = 0.92\ TL + 2.86 \quad (r = 0.925)$$

7.4 DISCUSSION

7.4.1 *P. kaakan:*

The results from sampling at Barramundi Creek and Cleveland Bay give a good indication of growth in this species and the three methods of age determination correlate with each other very well. This gives a good degree of confidence in the interpretation of the data.

The fine details of the cut-off points of a particular age group may vary slightly with the three methods of age and growth determination but generally there is good agreement between them. For example, the length frequency data for Barramundi Creek fish suggest an average size of 160-180mm for one year old fish in the population, whereas the scale reading data point to the average size at formation of the second mark (A2), which has been interpreted as the 'birthday' mark, as being 140-180mm. It has been reported in most studies where lengths have been back-calculated from scales using a direct proportion method, that the back-calculated lengths are less than empirical lengths for a given age group. This is referred to as Lee's phenomenon (Lee, 1920) and four possible causes for it have been suggested as listed by Bagenal (1978). These are; (1) incorrect back-calculation procedure; (2) non-random sampling of the stock, for example, if the sampling tends to select the larger members of the younger ages; (3) selective natural mortality, favouring greater survival of the smaller fish of a given age group; and (4) selective fishing mortality, similarly biased. It is not possible to positively determine the underlining cause in this case and, indeed, another alternative explanation for the small disparity noted between back-calculated lengths derived from scale reading and those derived from length frequency analysis in this study, is that the 'birthday' marks on the scales were pre-spawning marks. As such, these marks may have been laid down when the fish were a little less than 12, 24, 36, etc. months of age, while results from the length frequency analysis are based on the average size of fish at 12, 24, 36 etc. months old. Thus it would have been slightly more accurate to use length at age values derived from length frequency analyses to determine the von Bertalanffy relationship, but the difficulty in using these was the few values that could be confidently determined, due to small sample numbers of large fish and variable growth rates. The differences, however, between lengths derived from the two methods are only marginal and would not alter the conclusions drawn from the data.

From the data then a generalised view of the growth of this species in the local area can be ascertained, at least for the first few years of life.

This species breeds over a prolonged period between August and March and because of this has a prolonged recruitment of juveniles to the population. Young of the year that are spawned early in the breeding season grow rapidly over the spring and summer months and reach a larger size, almost double in fact by 12 months old, than young of the year that are spawned late and are growing initially through the autumn and winter months. The major spawning is the early one occurring in spring and the largest proportion of the future year class results from this spawning. From the von Bertalanffy equation then, an 'average' fish spawned in this major spawning period would be approximately 157mm TL at one year old, 286mm at two years old, 387mm at three years old, 476mm at four years old and approximately 529mm at five years old. It should be borne in mind, of course, that the von Bertalanffy equation provides a simplified picture of the annual growth of the population (as exemplified in Fig. 45 for *P. kaakan*, and Figs. 46 and 47 for *P. argenteus* and *P. maculatus* respectively) and that in reality there are marked seasonal and individual variations in growth as evidenced by the tag recovery data (Figs. 12 and 13). These types of variability have been considered by Gerking (1966), Lockwood (1974) and Cloern and Nichols (1978). In particular, the "average" growth rate will be affected by the faster growth rate over the spring - summer months, as against the winter months, an effect which will be compounded in its complexity depending on whether individual fish were spawned early or late in the breeding season. It is also probable that growth rate will vary from year to year, depending on environmental conditions and therefore, especially in long lived fish, there seems little point in building in accuracies on which to base a generalised model of growth. As noted by Lockwood (1974), it seems necessary in most cases to acknowledge simply that regressions fitted to growth data are predictive regressions. Also, where variations of the von Bertalanffy model have been used to take into account changes in seasonal growth rate, growth has been restricted to one season or a short period of time with little or no growth outside that period. Growth was occurring in pomadasyids over the entire year.

The lengths of 246mm, 346mm and 465mm, at 1, 2 and 3 years old, respectively, given by Deshmukh (1973) for *'P. hasta'* are somewhat larger than those determined for *P. kaakan* in the present study. The fact that the Indian *'P. hasta'* spawns in the autumn and grows initially during the winter suggests that the growth may not correspond with that of the fish in North Queensland, which spawns primarily in the spring and summer, even if they were the same species. However, the growth rate of the Indian fish would be expected to be lower than that observed locally, especially in the first year, since initial growth would have been at a time of cooler water temperatures. This was not the case. Results from the present study also indicate that the maximum size of 600mm given by Konchina (1978) for *'P. hasta'* is considerably less than the estimated asymptotic length for *P. kaakan*, though the asymptotic weight of 6kg indicated is a little larger than the 5.2kg determined in this study. This points to considerable variation in the growth of *P. kaakan* in different parts of the world if indeed '*P. hasta*' is the same species, or that the '*P. hasta*' studied in other localities is not conspecific with *P. kaakan*.

It is known that tagging can have a major adverse effect on the growth rate of tagged fish. In the present study, however, the overall similarity in growth rates for the majority of tagged fish compared with the length frequency data and results from scale reading, and the fact that many of the tagged fish grew at close to 20mm per month while tagged, which would be close to maximal growth, suggest that the tags (and in particular the 'clothes' tags) had a minimal effect on growth. Thus, most of the variability in growth rates observed was more likely to have been largely due to other factors, as noted above.

Very few fish larger than 400mm were caught during the study, suggesting that most of the population is less than 3 years old. This is good evidence of the heavy exploitation of this species by anglers, since most of the fish are caught by the time they are little more than half their maximum size and about one third of their attainable age. It also appears that most of the large fish that were caught in this study were fast growing fish, with maximum increments between successive age lengths and that they were close to the maximum size for their age group. Therefore it is not that these fish were surviving longer, but rather that they were growing faster than other members of the same cohort.

7.4.2 *P. argenteus*:

The discussion for this species is largely based on Barramundi Creek data, since these give the clearest indication of growth using length frequency analysis, scale reading and tagging methods. Also, in the years when sampling was undertaken there was a somewhat longer spawning period in Cleveland Bay (up to 8 months) compared with Barramundi Creek (about 6 months). This prolonged period would have produced less discrete year classes in the length frequency data, due to more overlap in lengths of the late spawned fish of one year with the early spawned fish of the next.

The results suggest that *P. argenteus* is a moderate sized fish, attaining an asymptotic length of 481mm, which would be approached in approximately 10 years. Fish of this species were less common in catches than *P. kaakan* for most of the year, and sample sizes were generally smaller.

These fish grew fairly rapidly in their first two or three years and thereafter the growth rate was much slower. On average, individuals of this species grew to about 152mm by the end of their first year, to 257mm by the second, 328mm by the third, 377mm by the fourth, and 410mm by the fifth year. Early spawned fish would grow in length somewhat faster than this and later spawned fish somewhat slower.

Similarly to *P. kaakan* this species spawns over a prolonged period during the spring and summer months, which tends to complicate the interpretation of the growth data. By employing the three different methods of studying growth, however, a good indication of growth in this species can be attained, and as with *P. kaakan* the three sets of data result in very similar conclusions.

Comparison of data from the two sampling sites, Barramundi Creek and Cleveland Bay, suggests overall similarity in growth of the two populations, but enough differences to indicate distinctiveness between bay and estuarine populations (see General Discussion - Growth).

Konchina (1978) gives a maximum length for this species of 500mm, but no further information is given. The present study indicates that this is a reasonable value, with the estimated asymptotic length of *P. argenteus* from North Queensland being 481mm. Fish of this species attain a much smaller mass than *P. kaakan*, with an estimated asymptotic weight of 1.6kg compared with 5.2kg for *P. kaakan*.

The major problem with studying this species was sampling large enough numbers, particularly from Barramundi Creek but also from Cleveland Bay. This species could not be caught in any number, either by line fishing or trawling, from either of the two sites over the winter months of June and July. This could be accounted for in a number of ways, for example if fish moved out of the estuaries. However, there would then be an expected increase in numbers of fish inshore such as in Cleveland Bay. This was not the case. It may be that the fish moved out of the study area toward the lower reaches of the estuary, perhaps in preparation to spawn, but not into the bays. This does not explain the absence of fish from the trawl samples in the bay unless fish are also moving from the bay into the lower reaches of the estuaries, or are moving further offshore. There is evidence that the latter strategy is employed by *P. maculatus* but not for *P. argenteus*. The fact that a number of *P. argenteus* were tagged before winter and recaptured at the same site after winter suggests that if the fish move from the study area in winter, they home to the same area in the spring. A more likely possibility is that changed behaviour, with reduction of feeding in winter may explain the low numbers of captures from Barramundi Creek. However, this still does not explain the absence of fish in the trawl samples from Cleveland Bay. This aspect requires further study.

7.4.3 *P. maculatus:*

The determination of growth rate in *P. maculatus* relies heavily on the length frequency analysis, since neither scales nor otoliths proved useful for ageing and tagging was not feasible on the fish obtained only by trawl from Cleveland Bay. Fortunately the numbers of *P. maculatus* collected by trawl sampling were fairly large and comprised the entire size range of fish in the area, except for the very small ones which could be sampled by seine netting. Thus, the length frequency data could be used confidently to determine growth in this species.

The results show that the 'young of the year' size class form a group that is fairly distinct from the larger size classes for most of the year; though there may be some overlap of the group with late spawned, slow growing fish from the previous breeding season. Therefore it is possible to obtain a good indication of growth over the first 12 to 16 months of life. After this time there is increased merging of the small size group with the larger adult component of the population and it is more difficult to distinguish different age classes within this larger size group. However the length frequency data do suggest three, or perhaps four, age classes within the population, with the larger size group being composed of 1+, 2+ and perhaps 3+ year old fish, depending on the longevity of the species.

The results suggest that at one year old most fish from the major spawning, which takes place from August to November, are approximately 120mm TL and at two years old are approximately 160-170mm TL. There appears to be little growth in length after the second year of life since the largest fish caught was less than 190mm TL. Grant (1982) records that *P.maculatus* grows to 18 inches (400mm) in length and Konchina (1978) records 450mm, but no fish of that size has been captured locally. It would be expected that if fish larger than 190mm were in the area they would have been sampled by the trawl, since other species up to 300mm in length were captured regularly, including congeners *P.kaakan* and

P. argenteus. There is no evidence of larger ones being caught by any other methods in this area either. It is interesting to note that Grant (1982) describes *P. maculatus* as an estuarine form, whereas in the local area this species is only rarely caught in the mouths of estuaries and is most common within bays and offshore.

The growth rate determined from length frequency analysis of the trawl data, of approximately 120mm in the first year, is consistent with the length frequency analysis of the Pallarenda samples which show an increase in the modal length of small fish of approximately 10mm per month. It has been shown that there is a prolonged breeding period with probably two peaks of spawning activity in this species and so considerable variation in growth rate would be expected for fish spawned early in the season compared with those spawned late. It may be assumed that, at any particular point in time, early spawned fish would be larger than those spawned later, and that the former, therefore, would have an advantage in feeding and general survival in such a schooling species. In groups of juveniles kept in aquaria the larger fish were more aggressive and consumed more of the food than the smaller fish. The advantage gained by early spawned fish would most likely continue during the juvenile phase, leading to a better growth rate of these compared with the rest of the age class.

The estimated average growth rate of 10mm per month during the first year is also consistent with data from trawl samples collected in December, when the young of the year were first being sampled at about 50-60mm. If these fish were spawned early in

August they would be about 5 months old. The larger fish in this group may have been either slightly faster growing than average fish from the present spawning, or could have been late spawned and therefore slower growing fish from the previous spawning. It is most likely that the largest individuals of these samples are derived from both sources. This would account for the small numbers of intermediate sized fish sampled, for example, in April and June 1981 (Fig. 40).

The lack of the larger size group in trawl samples over the winter months of both years suggests that these fish move offshore at this time. This is confirmed by catches from commercial prawn trawlers working outside Cleveland Bay in these months. The larger fish disappeared from Cleveland Bay about April and reappeared in catches towards the end of July. It is not clear why these fish move offshore since the smaller fish remain in the bays over the winter months, but it may be associated with temperature and/or food availability. The smaller fish may perhaps be more constrained by predation pressures in deeper waters. As has been noted, this overwintering in the bay may be one explanation of the marked loss of scales from the smaller fish and resultant high proportion of replacement scales on larger fish. From Fig. 43 it can be observed that the back-calculated length at scale loss corresponds to the size of the 'young of the year' fish over the winter months.

7.4.4 GENERAL DISCUSSION - GROWTH

It has often been found very difficult to study growth of wild fish populations in the tropics, since the conventional ageing techniques that have been developed for temperate water species are not always reliable and invariably lead to data that are hard to interpret.

In this study, while there was initially some difficulty in interpreting the marks on the scales of *Pomadasys* species, eventually these could be used quite confidently to age fish of the two species, *P. kaakan* and *P. argenteus*, at least over the first five years. However, it would have been almost impossible to interpret the scale data without information from the other two methods employed, namely length frequency analyses and tagging. It is likely that any study based solely on ageing tropical fish species from marks on hard structures may be difficult.

The combination of the three methods used to determine growth in *P. kaakan* and *P. argenteus* enabled a good indication of growth in these species. The fact that the scales of *P. maculatus* were unreliable as an ageing tool, together with the difficulty of carrying out an effective tagging program with this species, led to a reliance on interpretation of length frequency data for this species. It was fortunate that this species was accessible to trawl capture and that fairly large samples over almost the entire size range could be taken, as these are important criteria for effective length frequency analysis. These facts allow confident interpretation of the results for this species.

As noted in the Introduction to this chapter, very little work on the growth of pomadasyids had been previously undertaken, and no studies had been conducted in Australian waters on these species, even though the genus *Pomadasys* includes highly sought after angling species and some that are also taken commercially in small quantities.

The results of the present study suggest that the three species are markedly different in their growth patterns, with *P. kaakan* being the largest species, attaining an estimated asymptotic total length of 756mm and an age in excess of 10 years, while *P. argenteus* also may live to about 10 years old but attains an estimated asymptotic length of only 481mm. These two species grow quite fast in the first year of life, attaining lengths averaging 150 to 160mm, but thereafter *P. kaakan* continues to grow rapidly while in *P. argenteus* growth slows quite markedly. Individuals of the *P. maculatus* population studied also grew fast in their first year, attaining a length of about 120mm, but growth attenuated very rapidly so that there was very little growth after the second year of life, and these fish probably only live for a maximum of four or five years. Reports in the literature suggest that this species grows up to 500mm (Anon, 1974; Konchina, 1978; Grant, 1982), but there is no evidence for this locally.

As has been noted, a complicating factor in the study was the considerable variation in growth rates of individual fish, not only between early spawned and late spawned fish, but also probably related to individual differences in physiological attributes and response to environmental influences. Certainly, in suitable conditions this species is capable of rapid growth with 20mm per month often being observed. This variability would ensure a range of fish sizes in the population to take advantage of 'spaces' in ecological niches made available perhaps by poor recruitment of an ecologically similar species (Lowe-McConnell, 1979) or to minimise the chances of leaving an ecological space if some catastrophe drastically reduced the numbers of a particular cohort. Similarly, such high growth rates would help to maintain a population of reasonably sized fish in the sampling area, in the face of fairly heavy fishing pressure.

While there were no differences of any consequence in growth rates of fish from Cleveland Bay compared with those from Barramundi Creek, the sizes at maturity in the two areas were quite different. It is suggested that these differences between the two populations may have been largely attributable to the different environmental conditions existing at the two study sites. It must be recognised that while, in this study, Barramundi Creek and Cleveland Bay have been used as examples of two different environments inhabited by these species, the two sites are geographically separated (see Fig. 1). Barramundi Creek flows into Bowling Green Bay whereas Cleveland Bay is the next bay to the north and is separated from Bowling Green Bay by Cape Cleveland and adjacent deeper water than in most of the bays. This may serve as a deterrent to interchange of fish between the two bays. Thus, if it was occurring, interchange between estuary and bay would be more likely between Bowling Green Bay and Barramundi Creek, or Cleveland Bay and say Ross River, than between Barramundi Creek and Cleveland Bay unless there is a concerted longshore migration. While there may be some movement of larger fish within inshore and estuarine environments, particularly in relation to spawning, the findings of the study have provided no evidence for gross intermingling of the inshore and estuarine fishes, nor for longshore movements from bay to bay or estuary to estuary. It is possible that the difference in length at maturity is due to population differences resulting from two populations with relatively little interchange. Other explanations may be that food type, which was shown to be different in the two study sites, or food availability, may have resulted in earlier maturity in Cleveland Bay. Less equitable temperature and salinity regimes in Barramundi Creek may also have influenced the rate of reproductive development (Gerking, 1982) at that site.

The implications of the results from this study are that the two species *P.kaakan* and *P.argenteus* should be able to withstand high fishing pressures, since they both grow to a reproductive size in their second year of life and most would have spawned at least once before reaching the current minimum legal length of 300mm. The effect of heavy fishing pressure will be a reduction in the proportion of larger fish in the populations, as appears to be the case in Barramundi Creek where most of the fish captured in this study were less than 4 years old and of a relatively small size.

Only a few larger fish were caught from Barramundi Creek and as noted earlier, these appeared to be fast growing, rather than much older fish. Therefore it appears that a large proportion of the population is being removed each year, either by fishing or by natural deaths due to predation, etc.

P. maculatus is not exploited either commercially or by amateur fishermen at the present time, though large numbers are often taken in the by-catch of commercial prawn trawlers.

From the results it is apparent that fish spawned early in the breeding season have a marked advantage over those spawned later in the season. It is clear that early spawned fish grow much more rapidly in their first year of life compared with later spawned fish, and that this faster growth rate is carried through into later years. This phenomenon leads to considerable differences in the growth rate of individuals within a year class, though it is not known whether growth compensation (Gerking, 1966) may occur in late spawned fish in later life. The advantage gained by being spawned early probably results from a longer period of favourable growing conditions during the spring and summer months and less competition for food. Having grown larger than later spawned fish, the early spawned fish would maintain dominance in feeding since the species studied school when young, and larger fish may obtain more food by being faster and more aggressive. Thus, in future studies of these species, fish derived from the late spawning period (February to March) should perhaps be considered separately from the majority of the population, derived from the main spawning period between August and November, if possible.

It has been suggested that the marks on the scales of *P. kaakan* and *P. argenteus* are possibly the result of physiological or hormonal changes associated with gonad development, since the time of mark formation corresponds with just prior to and over the two peaks of spawning activity in the breeding season. This would explain the fact that marks are being laid down over a prolonged period for the population as a whole, whereas if an environmental event was responsible, a much more discrete time period of mark formation might be expected. Also, the marks observed were recognised by cutting over of the circuli, suggesting a cessation of growth at some point in time. Transfer of food utilization to gonad development and gamete production, rather than somatic growth, may account for this in adult fish. However, this cause does not hold for explaining the marks on the scales of juveniles, unless there is some metabolic change in small fish during the spawning periods also, even though the gonads do not develop at this time.

Whatever the cause of the marks on scales, it is clear that they were not produced by spawning *per se*, since marks were laid down on the scales of pre-spawning sized fish. Further, it appears that they do not result from low temperatures, since they were formed on scales during most months of the year and least during the cooler months. Chevey (1934) noted that a drop in temperature of 4°C to 5°C was enough to cause mark formation on the scales of

P. argenteus in China, but apparently this is not occurring locally. The high salinity values recorded in Barramundi Creek from about April/May through to October/November may have some effect on the fish but it is unlikely that these conditions are directly responsible for mark formation either, since the salinity is high over the mid winter months when mark formation is at a minimum. Also, salinity in Cleveland Bay remains fairly constant over the year yet marks still form on the scales of fish from this site.

The presence of additional marks noted on the scales of Cleveland Bay fish as against those from Barramundi Creek is worthy of note. Environmental factors have been observed during trawling operations to have a major influence on the behaviour of *Pomadasys* and associated species (N. Milward - pers. comm.), with calm, clear seas acting to aggregate the fishes into large concentrations, and rough, turbid seas tending to disperse them. Such influences may affect other aspects of the biology such as feeding, predator/prey interactions etc., that in turn may be reflected in growth changes. However, the extra marks were often close to the typically disposed marks and as such could be related to the timing of a subsequent breeding event. A further possibility is that marks on scales were laid down corresponding to the beginning and end of the wet season, though failure of the wet season in the years during which the study was carried out would suggest this is not the case.

The important point is that two recognisable marks are being laid down each year correlating with the two periods of peak reproductive activity, and as such one may be considered a 'birthday' mark while the other corresponds with the other spawning peak. It is worth noting that Suzuki and Kimura (1980) also determined that two marks were laid down per year on the scales of the related *Parapristipoma trilineatum* from Japan, though these were laid down in summer and winter. Blake and Blake (1981) indicated only one mark per year was laid down on the scales of *P. macracanthus*, at the time of the rains. Thus, it appears that the cause of mark formation on the scales is variable for different species and different geographic regions.

Deshmukh (1973) concluded that one mark per year was laid down on the scales of '*P. hasta*' in India, though, as has already been noted, it is unlikely that the species studied by him was the same as any in the present study. If the Indian and North Queensland fish are the same species, the differences in growth data warrant further investigation, to determine whether they reflect varying growth patterns in the two areas or result from inconsistencies in analysis.

The values for length at age given by Ovens and Salekhova (1970) for '*P. hasta*' are very different from those found in the present study and again suggest that a different species was studied, or that their ageing methods were unreliable. The fact that they report a 213mm '*P. hasta*' as 6 years old and close to its maximum size strongly points to the former.

The absence of larger *P. argenteus* in samples over the winter months, both from Barramundi Creek and Cleveland Bay, is still a mystery. A similar absence of larger *P. maculatus* from samples over the winter months can be explained by larger fish moving out of the bays to deeper water and there is evidence to support this from observations of commercial trawlers. There is no such evidence for *P. argenteus* and other possibilities have previously been discussed. Thus, while questions relating to the ultimate cause of the marks on the scales and where individuals of *P. argenteus* spend the winter months have scope for further investigation, the growth aspects of the three *Pomadasys* species studied are confidently defined.

CHAPTER 8 - CONCLUDING COMMENTS AND RECOMMENDATIONS

The aim of this study was to provide basic biological information on fishes of the genus *Pomadasys*, which are important components of the estuarine and inshore communities of North Queensland. It was recognised that these fishes, like many other species in these systems, were coming under increasing pressure from rapidly expanding fishing exploitation, as well as habitat degradation due to competing land use, raised levels of pollutants, and other environmental changes.

Although only of minor importance in Australia as commercial species at this time, *Pomadasys* species make a large contribution to the recreational fishery. They are among the most sought after and popular fishes, being highly regarded by local anglers for both their edible and sporting qualities. In order to conserve this valuable resource, the need to have a better knowledge of their biology was identified as an essential prerequisite to the formulation of management procedures.

The findings from this study on feeding, reproduction, and growth indicate that the *Pomadasys* species are well adapted to living in inshore and estuarine habitats of tropical regions. This undoubtedly accounts for their wide distribution and abundance in many areas.

The generalist and opportunistic feeding of these species enables them to utilize a wide variety of food resources. Their principal food is crustaceans, but their diet comprises a large number of different species within this taxon, together with a broad range of other organisms. These feeding habits allow for maximum utilization of prey, which may spatially or temporally vary in availability within the habitats or be subject to influences of environmental change.

The reproductive mechanisms of the *Pomadasys* species studied can be related to their sub-tropical and tropical distributions. The prolonged breeding period is common to many tropical species (Lowe-McConnell, 1979; Moore, 1982; Thresher, 1984). In northern Australia the breeding season of many estuarine and inshore species occurs over the spring and summer months (Grant and Spain, 1975a, 1975b; Beumer, 1978; Russell and Garrett, 1982; Davis and Kirkwood, 1984) and small juveniles of many species were caught regularly while seine netting in Cleveland Bay over this period in the course of this study. For the *Pomadasys* species, breeding extends over the warm spring-summer-autumn months, with a major peak of spawning in September-November and a minor one in February-March. Consequently, most fish in the population are spawned in spring and have the opportunity for optimal feeding and growth over the warmest period of the year. At the same time, however, the extended period and second peak of spawning provide for a reserve recruitment should the input from the spring spawning for any reason fail or be decreased, and also to take advantage of the continuing niche that is being vacated as the earlier spawned fish grow. The high fecundities of the *Pomadasys* species indicate low survival rates of early life stages, but, together with the extended spawning season, would permit maximum utilization of favourable conditions at the times that they occur.

The noted preponderance of females in the larger fish cannot be ascribed to differential growth or mortality rates, or movements, between the sexes, nor to the occurrence of protandry. For the moment the difference in sex ratio must remain unexplained. Its occurrence, however, together with the early maturation typical of each of the species, would also tend to favour reproductive success.

While the sizes attained by the *Pomadasys* species studied are markedly different, they are all characterised by rapid growth rates, especially during the early part of their lives. Individuals of the larger species *Pomadasys kaakan* and *P. argenteus*, having asymptotic lengths of 756mm and 481mm respectively, are capable of an average growth close to 20mm per month over the first year. Those of *P. maculatus* may attain 60% of the asymptotic length of 203mm in the first year, this relatively higher early growth rate presumably acting to reduce vulnerability to predation prior to maturation in this smaller and shorter life-span species. Though *P. kaakan* and *P. argenteus* are sought after species, *P. maculatus* and *P. trifasciatus* are not exploited in Australian waters at the present time. However, these latter two species do form a considerable part of the 'trash' fish caught by commercial prawn trawlers and discarded. As they could be used as a food resource in the future, the effects of such operations on the populations of these species warrants further investigation.

The relationship between size and age in *Pomadasys* species is complex, due to the extended spawning season and the differential rates of growth resulting from fish bred at different times in the season. Thus, fish within any year group may differ greatly in size. This complexity necessitated careful analyses and comparisons of the length frequency and scale reading data, supported and confirmed by results from the tagging study. These different growth rates may influence other aspects of the biology of these fishes, and this fact will need to be taken into account in future studies of North Queensland *Pomadasys* species.

Many aspects of the biology of the *Pomadasys* species indicate their dependence upon inshore and estuarine habitats, with both young and adults being particularly associated with seagrass beds and mangrove areas. One of the major threats to these species, therefore will undoubtedly be degradation of these coastal environments. This degradation is occurring at an ever increasing rate, as a result of urban and other 'developments', often involving clearing of mangroves, and the effects of pollution. Such environmental changes can be expected to have severe impact upon the survival of *Pomadasys* species. The need to protect the coastal environments is gradually gaining community acceptance but recognising that changes will take time, there is an urgent need for improved knowledge of the tolerence limits of these species to man-made changes in environmental variables.

It has been suggested that fish populations living in aseasonal environments such as the tropics may be less resiliant than those from seasonal environments (Lowe-McConnell, 1979). From the results of this study it is apparent that the *Pomadasys* species may be considered to be resiliant fishes, in the sense that their feeding, reproductive, and growth features may enable them to cope with fluctuations or changes in their natural environment. However, to counter the effects of increased fishing pressures and habitat degradation, it is clear that well founded management procedures will be essential for their long term protection. In formulating these procedures particular attention will need to be given to the reproductive and growth patterns as revealed in this study, supplemented by further research on the aspects of sex ratio and fish movements.

Thus, the results of this study have raised some questions and therefore will provide a framework for more detailed studies of specific aspects of *Pomadasys* biology. More importantly, this study has provided basic biological information which was lacking for this group of fishes and gives the basis for the formulation of suitable management policies in the future.

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APPENDIX 1 : TAG RECOVERY DATA FOR *P. kaakan* AND *P. argenteus* FROM BARRAMUNDI CREEK.

Note:

- For Release and Recovery Sites see Fig. 2.
- '*' after recovery site denotes movement from release site. Number following indicates approximate distance moved, in kilometers, from the tagging site.
- Tags recovered more than once are underlined
- Tag Types:

  F = Floy FD67-C anchor tag

  M = Monel opercular tag

  G = Floy FD68-BC anchor tag

  C = Modified 'Clothes tag'

Table A1: *P. kaakan* TAG RECOVERY DATA.

Tag Nº	Tag Type	Release Date	Recovery Date	Days Free	TL Rel.	TL Rec.	Growth (mm)	Rel. Site	Rec. Site
042 000	F	02.07.81	07.09.81	67	190	205	15	B	B
065 000	F	26.07.81	06.09.81	41	203	213	10	B	B
067 000	F	26.07.81	08.08.81	13	180	183	3	B	B
069 000	F	26.07.81	08.08.81	13	176	178	2	D	D
073 000	F	08.08.81	03.10.81	56	255	265	10	B	G*11
142 000	F	05.09.81	21.09.81	16	185	189	4	B	B
161 000	F	21.09.81	23.09.81	2	172	172	0	B	A*1½
161 000	F	21.09.81	19.10.81	28	172	175	3	B	B
183 000	F	07.10.81	19.10.81	12	170	170	0	B	B
206 000	F	19.10.81	19.11.81	31	206	214	8	E	E
219 000	F	06.11.81	19.11.81	13	168	171	3	B	B
228 000	F	19.11.81	07.12.81	18	159	166	7	B	B
252 000	F	06.01.82	22.01.82	16	166	172	6	B	B
255 000	F	06.01.82	04.02.82	30	181	195	14	B	B
259 000	F	22.01.82	04.02.82	14	174	182	8	B	B
259 000	F	22.01.82	18.02.82	27	174	194	20	B	B
287 000	F	18.02.82	05.03.82	15	189	192	3	B	B
291 000	F	18.02.82	06.03.82	16	238	238	0	E	E
000 749	M	21.03.82	17.04.82	27	150	156	6	B	B
000 753	M	21.03.82	03.04.82	12	138	145	7	B	B
303 754	MF	21.03.82	03.04.82	14	181	187	6	B	B
304 758	MF	21.03.82	17.04.82	27	171	187	16	B	B
306 879	MF	21.03.82	03.05.82	43	242	254	12	D	D
307 756	MF	21.03.82	03.04.82	14	152	159	5	B	B
309 882	MF	21.03.82	03.05.82	43	210	226	16	B	B
323 778	MF	17.04.82	01.06.82	45	166	173	7	B	B
324 779	MF	17.04.82	18.05.82	31	156	165	9	B	B
325 780	MF	17.04.82	03.05.82	16	154	157	3	B	B
326 781	MF	17.04.82	03.05.82	16	168	172	4	B	B
329 784	MF	17.04.82	03.05.82	16	157	159	2	B	B
343 000	F	18.05.82	16.06.82	29	150	154	4	B	B
344 000	F	18.05.82	01.06.82	14	144	151	7	B	B
349 000	F	18.05.82	01.06.82	14	148	150	2	B	B
349 000	F	18.05.82	04.09.82	109	148	155	7	B	B
351 000	F	18.05.82	01.06.82	14	138	140	2	B	B
354 000	F	18.05.82	16.06.82	29	156	159	3	B	B
376 000	F	01.06.82	30.06.82	29	145	149	4	B	B
376 000	F	01.06.82	14.08.82	74	145	156	11	B	B
376 000	F	01.06.82	04.09.82	96	145	158	13	B	B
381 000	F	01.06.82	13.07.82	43	136	138	2	B	B
381 000	F	01.06.82	04.09.82	96	136	143	7	B	B
382 000	F	01.06.82	16.06.82	15	157	157	0	B	B
395 000	F	16.06.82	04.07.82	18	156	156	0	B	B
395 000	F	16.06.82	04.09.82	80	156	160	4	B	B
403 000	F	16.06.82	30.06.82	14	151	154	3	B	B

Table A1 cont'd -*P. kaakan*

Tag Nº	Tag Type	Release Date	Recovery Date	Days Free	TL Rel.	TL Rec.	Growth (mm)	Rel. Site	Rec. Site
404 000	F	16.06.82	28.07.82	42	140	142	2	B	D*2
413 000	F	16.06.82	14.08.82	59	145	147	2	D	D
430 000	F	13.07.82	04.09.82	53	141	150	9	B	B
431 000	F	13.07.82	04.09.82	53	166	172	6	B	B
432 000	F	13.07.82	28.07.82	15	136	137	1	B	B
432 000	F	13.07.82	30.08.82	48	136	141	5	B	B
433 000	F	04.07.82	04.09.82	62	162	176	14	E	E
437 000	F	04.07.82	11.09.82	69	131	144	13	B	B
437 000	F	04.07.82	27.09.82	69	131	144	13	B	B
441 000	F	30.06.82	04.09.82	66	131	137	6	B	B
444 000	F	30.06.82	04.07.82	4	152	152	0	B	B
446 000	F	30.06.82	16.07.82	16	176	177	1	B	B
482 000	F	28.07.82	14.08.82	17	140	140	0	D	D
492 000	F	28.07.82	30.08.82	33	164	172	8	B	B
492 000	F	28.07.82	11.09.82	45	164	173	9	B	B
493 000	F	28.07.82	14.08.82	17	123	124	1	B	B
496 000	F	13.07.82	08.11.82	118	150	169	19	B	B
497 000	F	13.07.82	04.09.82	53	158	165	7	B	B
498 000	F	13.07.82	28.07.82	15	163	164	1	B	B
005 005	GC	14.08.82	01.10.82	48	159	?	?	D	G*9
012 014	GC	30.08.82	06.09.82	7	168	?	?	B	B
013 000	G	30.08.82	09.12.82	101	147	176	29	B	B
061 073	GC	10.10.82	28.11.82	49	180	187	7	B	B
076 084	GC	10.10.82	08.11.82	29	189	210	31	B	B
102 000	G	08.11.82	09.12.82	31	143	154	11	B	B
113 000	G	08.11.82	11.12.82	33	322	330	8	B	F*8
127 000	G	09.12.82	23.12.82	14	142	149	7	B	B
151 000	G	23.12.82	25.01.83	33	153	166	13	B	B
154 000	G	23.12.82	25.01.83	33	127	148	21	B	B
184 137	GC	08.01.83	07.02.83	30	171	189	18	B	B
201 137	GC	08.01.83	23.02.83	46	171	191	20	B	B
185 000	G	08.01.83	25.01.83	17	147	152	5	B	B
986 143	GC	25.01.83	07.02.83	13	173	180	7	B	B
204 153	GC	07.02.83	20.05.83	102	189	224	35	B	B
000 159	C	07.02.83	23.02.83	16	123	129	6	B	B
948 164	GC	23.02.83	08.03.83	13	208	213	5	B	B
935 186	GC	23.03.83	08.04.83	15	220	228	8	B	B
000 208	C	08.04.83	10.05.83	32	133	147	14	B	B
000 208	C	08.04.83	07.06.83	60	133	150	17	B	B
000 210	C	08.04.83	02.09.83	147	142	189	47	B	B
000 226	C	08.04.83	26.04.83	18	157	166	9	B	B
000 227	C	08.04.83	20.05.83	42	135	154	19	B	B
000 233	C	26.04.83	07.06.83	42	146	155	9	B	B
905 245	GC	26.04.83	20.05.83	24	164	170	6	B	B
904 246	GC	26.04.83	10.05.83	14	163	169	6	B	B
000 266	C	20.05.83	24.05.83	4	128	130	2	B	B
000 287	C	20.05.83	07.06.83	18	131	140	9	B	B

Table A1 cont'd - *P. kaakan*

Tag Nº	Tag Type	Release Date	Recovery Date	Days Free	TL Rel.	TL Rec.	Growth (mm)	Rel. Site	Rec. Site
000 294	C	24.05.83	22.10.84	517	174	356	182	B	C*1
000 301	C	24.05.83	07.06.83	14	164	168	4	B	B
000 308	C	07.06.83	18.10.83	133	120	166	46	B	B
000 309	C	07.06.83	08.07.83	31	152	160	8	B	C*1
000 323	C	22.06.83	18.10.83	118	126	163	37	D	D
000 338	C	08.07.83	02.09.83	56	122	133	11	C	C
000 341	C	08.07.83	05.08.83	28	147	152	5	C	B*1
000 341	C	08.07.83	29.11.83	144	147	203	56	B	B
000 345	C	24.07.83	18.10.83	86	172	185	13	B	B
000 351	C	24.07.83	17.09.83	55	159	173	14	B	B
000 356	C	05.08.83	21.09.83	47	154	168	14	B	B
000 366	C	16.08.83	14.11.83	90	136	173	37	D	D
000 368	C	02.09.83	21.11.83	80	159	196	37	B	B
000 370	C	02.09.83	17.09.83	15	166	169	3	C	C
877 374	GC	17.09.83	18.10.83	31	175	184	9	B	B
875 377	GC	17.09.83	10.04.84	206	174	287	113	B	B
000 400	C	18.10.83	21.11.83	34	137	160	23	D	D
873 402	GC	18.10.83	21.11.83	34	174	188	14	D	D
000 411	C	31.10.83	10.04.84	162	174	259	85	B	B
000 426	C	14.11.83	21.11.83	7	208	208	0	B	B
000 449	C	21.11.83	15.02.84	86	117	167	50	D	D
832 479	GC	29.11.83	30.12.83	31	198	214	16	B	B
000 495	C	30.12.83	16.01.84	17	150	159	9	B	B
000 495	C	30.12.83	28.01.84	29	150	166	16	B	B
801 539	GC	16.01.84	15.02.84	30	174	186	12	B	B
000 541	C	28.01.84	25.02.84	28	123	140	17	B	B
783 558	GC	28.01.84	25.02.84	28	181	196	15	B	B
783 558	GC	28.01.84	28.04.84	91	181	223	42	B	C*1
000 574	C	25.02.84	14.03.84	18	144	151	7	B	B
000 576	C	25.02.84	14.03.84	18	118	129	11	B	B
000 579	C	25.02.84	14.03.84	18	133	141	8	B	B
000 579	C	25.02.84	27.03.84	31	133	144	11	B	B
000 579	C	25.02.84	25.04.84	59	133	150	17	B	B
000 610	C	25.02.84	27.03.84	31	160	182	22	B	B
000 618	C	14.03.84	27.03.84	13	157	160	3	B	B
000 623	C	14.03.84	27.03.84	13	155	163	8	B	B
000 660	C	27.03.84	24.04.84	28	110	117	7	D	D
000 669	C	27.03.84	28.05.84	62	120	131	11	D	D
000 693	C	10.04.84	24.04.84	14	127	130	3	B	B
000 693	C	10.04.84	30.08.84	143	127	138	11	B	B
000 695	C	10.04.84	09.05.84	29	135	144	9	B	B
000 695	C	10.04.84	09.09.84	152	135	171	36	B	B
000 697	C	10.04.84	24.04.84	14	165	172	7	B	B
719 707	GC	10.04.84	24.04.84	14	175	179	4	B	B
719 707	GC	10.04.84	09.05.84	29	175	180	5	B	B
000 707	C	10.04.84	20.12.84	254	175	255	80	B	B
718 708	GC	10.04.84	24.04.84	14	179	182	3	B	B

Table A1 cont'd -*P. kaakan*

Tag Nº	Tag Type	Release Date	Recovery Date	Days Free	TL Rel.	TL Rec.	Growth (mm)	Rel. Site	Rec. Site
000 709	C	10.04.84	25.06.84	76	146	152	6	B	B
717 712	GC	10.04.84	24.04.84	14	176	179	3	B	B
000 714	C	10.04.84	22.07.84	103	145	163	18	B	B
000 735	C	24.04.84	09.05.84	15	156	161	5	B	B
000 737	C	24.04.84	28.05.84	34	134	156	22	B	B
000 737	C	24.04.84	30.01.85	281	134	231	97	B	B
000 740	C	24.04.84	09.05.84	15	151	156	5	B	B
000 746	C	24.04.84	09.05.84	15	115	118	3	B	B
705 752	GC	24.04.84	09.05.84	15	195	197	2	B	B
703 754	GC	24.04.84	09.05.84	12	215	216	1	B	B
701 757	GC	24.04.84	05.11.84	195	203	213	10	B	C*1
696 762	GC	24.04.84	09.05.84	15	248	253	5	B	B
000 767	C	09.05.84	12.06.84	34	131	137	6	B	B
000 770	C	09.05.84	12.06.84	34	137	143	6	D	D
000 779	C	09.05.84	09.09.84	123	129	153	24	B	B
000 779	C	09.05.84	20.11.84	195	129	179	50	B	B
000 784	C	09.05.84	22.07.84	74	148	163	15	B	B
000 784	C	09.05.84	06.08.84	89	148	165	17	B	B
000 790	C	09.05.84	28.05.84	19	146	150	4	B	B
000 790	C	09.05.84	19.08.84	102	146	169	23	B	B
000 794	C	09.05.84	19.08.84	102	134	161	27	B	B
000 795	C	09.05.84	28.05.84	19	110	110	0	B	B
000 795	C	09.05.84	30.08.84	114	110	134	24	B	B
000 796	C	09.05.84	09.07.84	61	129	137	8	B	B
000 797	C	09.05.84	22.07.84	74	152	159	7	B	B
000 803	C	28.05.84	22.07.84	55	140	147	7	B	B
000 803	C	28.05.84	19.08.84	83	140	156	16	B	B
000 804	C	28.05.84	22.07.84	55	143	152	9	B	B
000 812	C	28.05.84	25.06.84	28	137	140	3	D	D
000 823	C	28.05.84	06.08.84	70	141	153	12	C	C
000 830	C	28.05.84	22.07.84	55	140	145	5	B	B
000 834	C	28.05.84	10.08.85	439	141	285	144	B	B
674 842	GC	12.06.84	30.06.84	18	207	207	0	B	B
000 861	C	12.06.84	21.09.84	101	117	134	17	C	C
000 861	C	12.06.84	05.11.84	146	117	146	29	C	C
000 868	C	25.06.84	05.11.84	133	138	180	42	D	D
666 873	GC	25.06.84	17.01.85	206	191	231	40	C	F*7
663 875	GC	25.06.84	22.07.84	27	170	170	0	C	C
000 875	C	25.06.84	08.10.85	472	170	280	110	C	C
000 882	C	09.07.84	05.11.84	119	112	147	35	D	D
000 882	C	09.07.84	20.11.84	134	112	151	39	D	D
000 882	C	09.07.84	20.12.84	164	112	167	55	D	D
000 892	C	09.07.84	19.08.84	41	145	151	6	B	B
000 893	C	09.07.84	09.09.84	62	141	144	3	B	B
000 900	C	22.07.84	21.09.84	61	134	147	13	B	B
000 900	C	22.07.84	16.04.85	268	134	265	131	B	B
650 905	GC	22.07.84	06.08.84	15	196	196	0	B	B

Table A1 cont'd -*P. kaakan*

Tag Nº	Tag Type	Release Date	Recovery Date	Days Free	TL Rel.	TL Rec.	Growth (mm)	Rel. Site	Rec. Site
650 905	GC	22.07.84	21.09.84	61	196	202	6	B	B
000 908	C	22.07.84	21.09.84	61	147	161	14	B	B
000 909	C	22.07.84	20.12.84	151	176	239	63	A	A
647 914	GC	06.08.84	30.08.84	24	191	194	3	C	C
645 916	GC	06.08.84	30.08.84	24	169	174	5	C	C
000 917	C	06.08.84	09.09.84	34	142	154	12	B	B
000 917	C	06.08.84	03.10.84	59	142	159	17	B	B
000 921	C	06.08.84	21.09.84	46	156	171	15	B	B
000 922	C	19.08.84	09.09.84	21	154	162	8	B	B
000 922	C	19.08.84	21.09.84	33	154	167	13	B	B
000 939	C	30.08.84	21.09.84	22	145	152	7	B	B
0001014	C	05.11.84	20.11.84	15	152	158	6	D	D
0001016	C	05.11.84	20.11.84	15	115	122	7	D	D
0001041	C	20.11.84	30.01.85	71	218	238	20	C	B*1
5491097	GC	15.02.85	04.03.85	17	208	215	7	B	C*1
0001127	C	13.08.85	23.11.85	92	162	208	46	B	B

TABLE A2: *P.argenteus* TAG RECOVERY DATA.

Tag Nº	Tag Type	Release Date	Recovery Date	Days Free	TL Rel.	TL Rec.	Growth (mm)	Rel. Site	Rec. Site
000 881	M	21.03.81	03.04.81	12	267	267	0	D	D
319 890	FM	03.04.82	03.05.82	30	236	240	4	D	D
192 000	G	25.01.83	08.03.83	42	151	172	21	B	B
991 000	G	25.01.83	23.12.83	29	168	185	17	B	B
938 180	GC	23.03.83	08.04.83	15	199	204	5	B	B
938 180	GC	23.03.83	24.05.83	62	199	210	11	B	B
000 290	C	24.05.83	30.12.83	220	132	207	75	B	B
000 299	C	24.05.83	21.09.83	120	161	183	22	B	G*11
000 316	C	07.06.83	15.02.83	253	142	215	73	D	D
000 320	C	22.06.83	31.10.83	131	134	167	33	B	B
000 327	C	27.06.83	16.01.84	202	150	205	55	B	B
000 375	C	17.09.83	21.11.83	65	171	194	23	B	B
876 376	GC	17.09.83	28.01.84	133	174	202	28	B	B
876 376	GC	17.09.83	25.02.84	161	174	210	36	B	E*3
000 383	C	30.09.83	30.12.83	91	163	188	25	B	B
000 383	C	30.09.83	27.03.84	178	163	210	47	B	B
680 383	GC	30.09.83	09.05.84	221	163	220	57	B	B
680 383	GC	30.09.83	25.06.84	268	163	221	58	B	C*1
000 385	C	30.09.83	21.11.83	52	149	171	22	B	B
000 405	C	31.10.83	21.11.83	21	156	160	4	B	B
000 405	C	31.10.83	28.01.84	89	156	192	36	B	D*2
000 420	C	31.10.83	16.01.84	77	129	169	40	D	D
000 444	C	21.11.83	16.01.84	56	146	180	34	B	B
848 454	GC	21.11.83	30.12.83	39	175	193	18	B	B
848 454	GC	21.11.83	28.01.84	68	175	204	29	B	B
834 474	GC	29.11.83	15.02.84	78	205	249	44	B	A*1½
000 477	C	29.11.83	25.02.84	88	161	193	32	B	B
000 478	C	29.11.83	25.02.84	88	191	223	32	B	B
826 485	GC	29.11.83	30.12.83	31	180	201	21	B	B
822 494	GC	30.12.83	28.01.84	29	169	187	18	B	B
814 510	GC	30.12.83	24.04.84	116	234	258	24	B	B
812 515	GC	30.12.83	14.03.84	74	177	193	16	B	B
810 519	GC	30.12.83	14.03.84	74	227	246	19	C	B*1
791 550	GC	28.01.84	25.02.84	28	196	209	13	B	B
791 550	GC	28.01.84	10.04.84	73	196	210	14	B	B
785 556	GC	28.01.84	15.02.84	18	217	223	6	B	A*1½
785 556	GC	28.01.84	25.02.84	28	217	234	17	B	B
000 588	C	25.02.84	10.04.84	45	160	169	9	B	B
764 590	GC	25.02.84	10.04.84	45	209	214	5	B	B
743 630	GC	14.03.84	27.03.84	13	200	200	0	B	B
739 636	GC	14.03.84	27.03.84	13	190	190	0	B	B
739 636	GC	14.03.84	24.04.84	41	190	191	1	B	B
000 654	C	14.03.84	30.06.85	473	198	300	102	A	F*10
000 694	C	10.04.84	28.05.84	34	120	131	11	B	B
000 698	C	10.04.84	09.05.84	29	153	160	7	B	B

Table A2 cont'd - *P. argenteus.*

Tag N°	Tag Type	Release Date	Recovery Date	Days Free	TL Rel.	TL Rec.	Growth (mm)	Rel. Site	Rec. Site
690 788	GC	09.05.84	20.12.84	225	254	271	17	B	A*1½
000 802	C	28.05.84	30.08.84	94	161	177	16	B	C*1
000 802	C	28.05.84	15.02.85	262	161	246	85	C	B*1
000 884	C	09.07.84	05.11.84	119	137	164	27	D	D
000 950	C	30.08.84	05.12.84	97	178	206	28	B	B
000 982	C	21.09.84	15.02.85	147	161	211	50	A	A
614 995	GC	22.10.84	15.02.85	116	188	232	44	B	B
0001056	C	05.12.84	15.02.85	72	163	189	26	C	B*1
0001070	C	20.12.84	30.01.85	41	161	182	21	B	A*1½
5681086	GC	30.01.85	15.02.85	16	187	192	5	B	B
0001113	C	29.05.85	19.08.85	82	180	190	10	B	C*1