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**GROWTH, REPRODUCTION AND RECRUITMENT  
OF GREAT BARRIER REEF FOOD FISH STOCKS**

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***FINAL PROJECT REPORT***

*Fisheries Research and Development Corporation  
Project No. 90/18*

*Edited by*

I.W. Brown  
Southern Fisheries Centre  
Queensland Department of Primary Industries

July 1994



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GREAT BARRIER REEF FOOD FISH STOCKS**

FR&DC Project No. 90/18

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## EXECUTIVE SUMMARY

The population characteristics of two of the most important species of fish in the Great Barrier Reef (GBR) handline fishery were, until recently, poorly documented. These species - the coral trout *Plectropomus leopardus* and the red-throat emperor *Lethrinus miniatus* - have been fished extensively by both recreational and commercial sectors of the industry, and evidence which came to light in the mid 1980's suggested that fishing pressure, particularly around reefs in the vicinity of major centres of human population, was having a measurable effect on local stocks of these fish.

The development of a management strategy for the reef line fishery highlighted the paucity of knowledge about important natural processes which regulate the size and distribution of these important reef fish resources. Although some previous work had been done on the growth and mortality of the species, there was not a consensus amongst workers in the field as to the most appropriate methods to be used, nor in many cases to the interpretation of the results. Some evidence was starting to emerge about aspects of the coral trout's reproductive behaviour which would make it particularly vulnerable at certain times of the year to exploitation by the fishery, but neither the universality of this behavior nor the exact timing of the critical period was known. Furthermore, there was a dearth of useful information concerning patterns of distribution and the duration of larval stages of large commercially-important species such as the coral trout. This meant that the impact of the current regional (reef-by-reef) zoning strategy on the dynamics of the stock was very difficult to predict.

As a result of preliminary meetings between representatives of research organisation involved in research on GBR fishery resources, a collaborative project was developed involving James Cook University (JCU), the Australian Institute of Marine Science (AIMS), and the Queensland Department of Primary Industry's Northern and Southern Fisheries Centres (NFC and SFC respectively). The primary objectives of the project were to elucidate the particular characteristics of growth, reproduction and mortality in coral trout and redthroat emperor from various parts of the GBR, and to establish the spatial and temporal connection between spawning and juvenile recruitment of coral trout. An additional component to the project aimed to determine appropriate genetic systems and analytical procedures which could be used subsequently in analyses of the structure of stocks of these two species.

Appropriate methods for determining the growth rates and age structure of coral trout populations were developed by Project staff at NFC and JCU. These methods involved the use of otoliths either read whole after heat treatment to accentuate the growth bands, or sectioned. There was a tendency for whole otoliths to underestimate the age of older fish (>6 yr). Similar techniques were applied by SFC and JCU staff to the redthroat emperor, although there was no need for heat-treatment of the whole otoliths. Again the sectioning method was considered more accurate for older (3-4 yr) fish.

On the basis of these individual age estimates, rates of growth and total mortality could be estimated. There was some disparity in growth parameter estimates between collections from different localities, but this was probably due more to differences in collection technique or source of material than to real geographic differences in growth rate. The growth characteristics of coral trout from as far apart as Cairns and the Swain Reefs were considered to be homogeneous. The average lengths of coral trout between ages 1 and 4 are about 23,

29.5, 33.7, and 39.3 cm respectively. Ages in excess of 15 yr were recorded, corresponding to an "average maximum" (asymptotic) length of around 60 cm.

The growth rates of redthroat emperor taken from the Swain Reefs and the Capricorn-Bunker Group were essentially the same, apart from a bias in the first two age-classes due to different data sources (commercial and research catches respectively). Because of insufficient representation of young (1 and 2-yr old) fish in the collections from Cairns and Townsville, useful north-south comparisons of growth rates in redthroat emperor were not possible. Length-at-age data from catches taken in the Capricorn-Bunker Group are considered representative for this species. Young redthroat grow rapidly, reaching as much as 25 cm in their first year. Thereafter the growth rate declines, fish of ages 2-4 achieving lengths of about 31, 36 and 39 cm (fork length) respectively. Although ages of up to 17 yr were recorded (from sectioned otolith examination), the fish grow little after 10 yr, reaching an asymptotic length at about 52 cm FL. The von Bertalanffy growth model provided a very good fit to the observed redthroat length-at-age data. These growth estimates based on otolith readings were significantly different from previously-reported estimates based on scales.

Coral trout spawn during the period from early spring to summer - September-December in the northern part of the GBR and October-February in the south. During the reproductive season lunar cues result in the formation of aggregations of fish at particular sites on the shallow coral slope surrounding the reefs. These aggregations were observed by divers with SCUBA gear, and are most concentrated during the new moon periods in October and November. Courtship displays between pairs of fish, the males with characteristic darkened fin edges, usually precede "spawning rushes" when the pair swims rapidly from the bottom high into the water column then turns abruptly, releasing the eggs and sperm.

In addition to the primary aggregation site identified by divers at each of the two monitored reefs, other seemingly less important "secondary" aggregating sites were located. It is not known whether every reef on the GBR supporting a population of coral trout has a geographically-identifiable spawning aggregation site, or indeed whether the larger reefs may have several. These issues, of particular significance in view of the developing live-market fishery for coral trout and the increasing use of precise navigational aids to locate fishing "hot spots", are (among others) the subject of ongoing studies by one of the Project staff.

Light-traps were used successfully to identify the presence and relative abundance of postlarval (pre-settlement) stages of reef fish at reefs close to those at which spawning aggregations were known to occur. This component of the study established a link during the first two seasons between the spawning event and subsequent appearance of coral trout postlarvae in the water column, a link which was validated by ageing the fish using daily growth rings in their otoliths and which suggests the possibility of a stock-recruitment relationship at a regional scale. Pelagic juveniles were most abundant in the near-surface water layer (at least at night, when the light-traps were effective), which may be of significance in the interpretation of larval dispersal patterns. Spawning and recruitment were "decoupled" during the third year of sampling; the cause of this is not known but may have been due to altered environmental conditions (e.g. current direction) at critical periods.

Densities of juvenile (post-settlement) coral trout were monitored (by SCUBA) at the reefs where pelagic juveniles were being sampled by light-trapping. The densities of juveniles were considerably lower than expected, considering the size of the adult population. This

is believed to be mainly because the young fish inhabit areas of broken coral rubble and are easily frightened into the coral. Some of the observed patterns of juvenile abundance were in accord with patterns of abundance of pre-settlement larvae, but the low observation rates precluded detailed analysis.

Both coral trout and redthroat emperor were confirmed histologically to be serial hermaphrodites with a protogynous strategy (i.e. starting life as a female then later developing male characteristics).

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The size (and age) at which coral trout change sex spans a considerable range. In the Cairns region, for example, coral trout were found to undergo sex reversal at lengths ranging from 22.5 to 61.5 cm FL, the average being a little over 42 cm. This means that while virtually all length-classes of fish contain individuals of either sex, most of the small fish will be females and most of the larger fish males. The size at which coral trout first become mature (capable of spawning) also varies considerably, with females as small as 26 cm FL observed in spawning condition. At a fork length of approximately 32 cm 50% of the female fish are reproductively mature. This length corresponds to an age between 2 and 3 yr, and a total length of 38 cm, the recommended minimum legal size for this species in Queensland.

During the currency of the Project, results have been drawn upon to assist with the development of management policies for the GBR reef line fishery. This is a very satisfactory outcome, and it should be noted that the minimum legal sizes already in place for coral trout and redthroat emperor were derived directly from this research. The Project's major recommendations include the retention of these minimum legal sizes and consideration of seasonal closures to protect spawning aggregations. Ongoing studies to determine the generality of the coral trout's spawning aggregative behaviour, and the specific patterns of dispersal of eggs and larvae from spawning reefs, should be supported.

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# 1. GENERAL INTRODUCTION

## 1.1 PROJECT BACKGROUND

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The handline fishery on the Great Barrier Reef represents a major part of Queensland's commercial scale-fish production, contributing over 3,000 t to the annual catch (Brown 1993). The catch consists primarily of a group of relatively sedentary demersal species belonging to the families Serranidae, Lethrinidae and Lutjanidae, and a migratory pelagic species - the Spanish mackerel (*Scomberomorus commerson*).

The serranid coral trout (*Plectropomus leopardus*) comprises the bulk of the demersal species (Craik 1981, McPherson 1989, Gwynne 1990, Trainor 1991), with annual catches in the vicinity of 1,200 t (Qld SUNFISH data) worth some \$10 million. The next most important demersal species is the redthroat emperor (*Lethrinus miniatus*), a lethrinid previously referred to as *L. chrysostomus*, and known in different parts of coastal Queensland as sweetlip emperor, lipper, or tricky snapper. Most of the annual commercial catch of this species (about 470 t, and valued at \$3.8 million) is taken from the southern part of the Great Barrier Reef (Brown 1994).

The recreational handline fishery on the Great Barrier Reef involves the use of very similar fishing gear to that employed in the commercial fishery. In fact there are no regulations applying to catching apparatus that can be used to distinguish between the two sectors. While an upper limit to the number of commercial fishing licences in Queensland has been set through fisheries legislation, and the Reef Line Fishery itself has recently been declared a limited entry fishery requiring special endorsement, there are no upper bounds on the size of the recreational fishery.

Effort in this fishery has risen over the years, partly as a result of increases in the size of the recreational component, and partly from significant technological advances in echolocating and navigational equipment. This has led to a steady increase in recreational catch, estimated to be about 7% per annum Craik (1986). Concern about the effects of this effort inflation on the stocks of reef fish (especially coral trout) have been the subject of discussion for a number of years, and contributed significantly to the establishment of the "Effects of Fishing" research programme, originally under the auspices of the Great Barrier Reef Marine Park Authority (GBRMPA) and now a sub-programme within the Reef Research CRC based at James Cook University, Townsville.

Early investigations by Craik (1981) showed that populations densities of coral trout on reefs close to major human population centres were lower than those at more distantly-situated reefs. This suggested a direct influence of exploitation pressure, and provided the basis for subsequent large-scale underwater visual surveys of fish densities (e.g. Ayling 1984, 1986, 1991(b)) and smaller-scale experiments on the effects of specific-use zoning on abundance (Beinssen 1989 a&b) and population age-structure and mortality rates (Ferreira and Russ 1992; Brown *et al.* 1992) of important reef-associated species.

It has also stimulated investigations into the size of the recreational catch and analysis of angling club records to determine the extent and direction of long-term changes in catch rates. In a major study using telephone and boat-ramp survey techniques Blamey and Hundloe (1993) estimated that there are presently over 36,000 privately-registered boats in the GBR region, of which around 24,300 participate in the reef line fishery, at an average trip rate of between 210,000 and 270,000 trips yr<sup>-1</sup>. As a result of this effort the "private" (i.e. non-charterboat) sector of the fishery is estimated to land between 2.6 and 3.2 million fish (weighing between 3,500 and 4,300 tonnes) each year.

The size of the catch from the charterboat sector (i.e. other than game-fishing charterboats) has not yet been estimated *in toto*. Hundloe (1985) estimated that the charterboat catch in 1980 would conservatively have been around 700 tonnes. A voluntary logbook system recently established jointly by the Queensland Fish Management Authority (QFMA) and the Queensland Department of Primary Industries (QDPI) indicates that charterboats each landed, on average, 1.68 t of reef fish during the third quarter (July-September) of 1993 (Anon. 1993). Assuming the GBR line-fishing charterboat fleet numbers 250 vessels (A. Magee, QFMA, pers. comm.), then the annual catch from this source might be in the vicinity of 1,700 tonnes.

The combined annual commercial and recreational reef fish catch from the Great Barrier Reef may thus be in the region of 8,000 tonnes, of which coral trout and redthroat emperor probably comprise as much as 2,300 and 1,000 t respectively. Despite their obvious economic importance, relatively little was known until recently about the processes driving populations of these species on the Great Barrier Reef. Prior to the establishment of this Project, several Queensland research institutions (both State and Commonwealth) had been involved in studies on various aspects of the biology, behaviour and population processes of demersal reef fish (mainly serranids, lethrinids and lutjanids). In order to focus the research effort more clearly on current management issues (dealt with in more detail in Section 1.3) and to foster a greater degree of communication between research staff in various parts of the State it was agreed to develop a project in which two of QDPI's main laboratories (in Cairns and Deception Bay) collaborated with the Australian Institute of Marine Science (Townsville) and the Marine Biology Department of James Cook University (Townsville) in a major study of the age, growth, reproduction and recruitment of the two most important demersal food-fish species on the Great Barrier Reef.

## 1.2 OBJECTIVES

The aim of this collaborative project was to estimate essential population parameters which would facilitate the management of Great Barrier Reef fish stocks. The project concentrated on the coral trout (Family Serranidae) and the red-throat or sweetlip emperor (Family Lethrinidae), the two most important components of the Great Barrier Reef demersal handline fishery. The Project's specific objectives, as set out in the project documentation, were:

- a) To determine the extent of geographical differences in growth and reproductive patterns along the GBR
  - b) To identify the temporal and behavioural characteristics of coral trout spawning aggregations and assess their management significance
  - c) To determine the relationships between spawning stock abundance, pelagic larval density, and recruitment of juveniles.
  - d) To determine the duration of the pelagic larval stages.
- 

Two additional objectives were added after the project started, when we realised that certain other very valuable information could be obtained without significant change to either the format or costing structure of the project. These objectives (below) were to do with preliminary aspects of probable future genetic investigations of reef fish stock structure:

- e) To determine optimum conditions for allozyme electrophoresis for a number of reef species including *P. leopardus* and *L. miniatus*.
- f) To begin to collect material that could be incorporated into a study of the genetic makeup of the stocks of commercially important reef fish species.

One of the most important aspects of the Project was to bring together and focus all the studies being undertaken on coral trout and redthroat emperor on Queensland by the various research agencies. It was hoped that this would, where possible, result in a consensus view among scientists as to the estimation and interpretation of important population parameters and associated methodologies.

### 1.3 TECHNICAL BACKGROUND TO THE RESEARCH NEED

Coral trout of the genus *Plectropomus* are the dominant species of the demersal line fishery in Great Barrier Reef (GBR) waters (QDPI SUNFISH Database). This study focussed on *Plectropomus leopardus*, the most common of the five Australian species of coral trout (Randall and Hoese, 1986), which occurs, and is fished, throughout the GBR.

Commercial fishing effort in the reef line fishery has remained relatively steady (around 15,000 boat-days yr<sup>-1</sup> since the introduction in 1988 of the compulsory SUNFISH logbook system. Long-term trends in the fishery cannot be judged from the commercial data, as it spans only 5 years. However an indication of the magnitude and direction of these trends can be derived from angler perceptions of changes in catch rate over considerably longer periods, as documented by Blamey and Hundloe (1993). These authors reported that

58.5% of their interview respondents believed their catches had declined in the last five years. Species for which the decrease was most marked were coral trout, mackerel and sweetlip. Slightly more than 35% of the respondents said their catches had remained constant, and 6% reported an increase. A somewhat different result is gained from the work of Higgs (1991), who analysed the trip records of a number of angling clubs in an attempt to clarify trends in catch rate (numbers and weight of fish per angler-day) and mean size of fish caught over periods of up to 35 yr. Higgs (1991) reported considerable latitudinal variation in some of these indices of stock "health", but found little evidence of consistent declines over the time scale involved, in any of the four major GBR regions examined (Cairns, Townsville, Mackay and Rockhampton).

While the total Queensland commercial landings of coral trout have remained fairly stable over the past four years, there is evidence that catches in certain areas (particularly northern Qld) have increased quite substantially. This may be in part the result of a geographic shift of some fishing operations from the Mackay area to Cairns and further north in the last couple of years.

Many reef fish species have a marked seasonal reproductive period; spawning may occur for only a few weeks of the year (Thresher 1984). Some species, including those of the Serranidae (groupers), aggregate in large numbers at specific sites during their spawning season (Johannes 1980 and 1981, Thresher 1984, Colin *et al.* 1987, Shapiro 1987), presumably to facilitate spawning success. The importance of understanding spawning behaviour and aggregations for the management of fish stocks has been recognised for many years (Johannes 1980, Parrack & Huntsman 1982, Sadovy in press), but little attention has been given to this phenomenon on the Great Barrier Reef. Species that aggregate are easy for fishers to target if aggregation sites and timing are known. Unless controlled, this activity can lead to severe overexploitation. Stocks have been depleted in this manner in Palau (Johannes 1981), Puerto Rico, Virgin Islands, St Croix and Belize (Bohnsack 1989, Sadovy in press). Recently anglers in the northern GBR region have become concerned that spawning aggregations of coral trout are being overfished (Samoilys pers. obs.).

Anglers and fishermen in the Cairns region have observed *P. leopardus* aggregating between September and November, which coincides with the months of peak reproductive activity (McPherson *et al.* 1988). On the other hand there is an opinion among fishermen working the southern part of the GBR (G. Clark, pers. comm.) that the species does not aggregate to spawn in that region; at least they have not seen any evidence of such aggregations.

Despite the importance of coral trouts to the commercial and recreational fisheries of the Great Barrier Reef, remarkably little is known about their recruitment. The main reasons appear to be the apparent rarity and invisibility of the newly-settled stages. Like other serranids, coral trout are cryptic after settlement and juveniles are not amenable to standard visual census protocols until they are several months old.

Despite these operational difficulties, there is no reason to believe that the population dynamics of large food fishes are qualitatively different from those of the small sessile species, which are greatly affected by spatial and temporal variations in replenishment

(Doherty and Williams 1988, Doherty 1991, Doherty and Fowler in press a,b). In practical terms, this means that natural levels of replenishment, and hence resilience to fishing pressure, may vary among reefs and geographic regions; in which case, stocks could be conserved or managed more effectively through the use, alongside more traditional tools, of numerical hydrodynamic models incorporating sink-source relationships among reef populations.

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In contrast, Ayling *et al.* (1992) reported that juvenile coral trout are more common on reefs open to fishing compared with protected controls and they inferred a form of population regulation through cannibalism. If correct, this would have equally great, albeit opposite, implications for the most effective management of these stocks. The difficulty with assessing their claim is that juveniles were defined as fish <35cm which includes individuals up to two years old (Ferreira and Russ in press). These are pre-recruits to the fishery but are clearly not recently settled fish. To assess the management implications of these observations, it is necessary to have independent estimates of abundance closer to settlement to determine whether the differences detected among reefs were caused by variations in larval supply or by differential postsettlement mortality.

Doherty (1987) described an alternative technique to visual surveys for monitoring the replenishment of reef fish, based on fishing with light. He described an automated light-trap design that attracts the pelagic juveniles of a broad range of reef fishes and that has been shown capable of monitoring spatial and temporal variations in the larval supply of common damselfishes (Milicich *et al.* 1992). We considered it would be particularly useful to assess the value of light-traps as a tool for monitoring the relative density of the larvae of commercially and recreationally valuable fish species as well.

The redthroat emperor *L. miniatus* (Bloch & Schneider, 1801) was previously known to taxonomists as *L. chrysostomus* (Richardson) (Randall *et al.* 1990). This lethrinid is found associated with tropical and equatorial coral reefs in the western Pacific and eastern Indian oceans (Carpenter and Allen 1989, Walker 1975, Loubens 1978), and is the basis of an important handline fishery around Norfolk Island (Church 1985). Previous studies on the growth and reproductive characteristics of *L. miniatus* by Walker (1975), Loubens (1978 and 1980) and Church (1985) have revealed differences in growth parameters and sex ratios which may have been due to differences in research methodology or to ecological differences between their study areas (central Great Barrier Reef, New Caledonia and Norfolk Is. respectively). This cast some doubt on the accuracy of the only documented estimates of age and growth for GBR stocks of *L. miniatus*. As the age estimates were in doubt, so too were the estimates of total mortality which had been derived from age-structured catch curves. Questions also remained unanswered about the reproductive strategy of this species, as none of the previous studies had demonstrated protogyny conclusively, although it had been alluded to.

The uncertainties surrounding some of the most fundamental biological and population processes in the second most important species of fish in the demersal reef line fishery on the GBR identified a clear research need. This was reinforced at the time by the initiation of a review by the Queensland Fish Management Authority of the Reef Line Fishery.

During the consultation phase of this review (Gwynne 1990), concern was expressed by

fishing and processing sectors about the potential effect on the resource of the price differential favouring "plate-size" coral trout close to the (then) minimum legal size of 35 cm TL. A Minimum Legal Size Working Group established in 1991 to advise the Management Authority was responsible for reviewing minimum (and maximum) legal size (mls) legislation relating to a range of species, but initially primarily those targetted by the recreational and commercial reef line fishery. Among a number of changes to the legislation, this working group recommended that the minimum legal sizes of coral trout and redthroat emperor be increased from 35 and 30 cm TL to 38 and 35 cm TL respectively. These changes were based largely on unpublished information relating to the size at maturity in both *L. miniatus* and *P. leopardus* obtained during the early stages of this Project, and on other available reproductive data for *P. leopardus* (e.g. McPherson *et al.* 1985).

Yield-per-recruit (YPR) models have often been used in helping to determine appropriate minimum legal sizes. However Bannerot *et al.* (1987), in a review of fisheries population models for serranids, demonstrated that such models can be inappropriate for hermaphroditic species - i.e. those which undergo a sex change or "reversal" at some stage in their life. Many coral reef fish (including the serranids and lethrinids, but not lutjanids) are known or suspected to be hermaphrodites - the predominant form being protogyny, with the animals starting out life as females then changing into males. *P. leopardus* is a known protogynous hermaphrodite (Goeden 1978, McPherson *et al.* 1985), and some limited research on the reproductive strategy of *L. miniatus* suggested that the same may be the case for this species (Walker 1975, Young and Martin 1982, Church 1985). Thus it was clear that for YPR to be used effectively in modelling the responses of coral trout and redthroat emperor populations to fishing, this reproductive characteristic would have to be taken into consideration.

The question of dispersal of eggs and larval fishes from their natant reef has a direct bearing on the response of populations on a given reef to fishing. Are the larvae distributed more or less randomly over a wide area encompassing many reefs? Or are they entrained in a definite direction by prevailing currents so that the progeny from one reef recruit only to a limited number of "downstream" reefs? To what extent are reefs "self-supporting"? These questions are fundamental to the "source-sink" hypothesis, and represent one of the major uncertainties about stock-recruitment relationships which the Effects of Fishing Programme (as proposed by Walters and Sainsbury 1990) was to have addressed.

An alternative approach to gaining an understanding of these dispersal and recruitment processes is through an investigation of the temporal and spatial links between the spawning population and pre- and post-settlement stages. If a direct link could be established, for instance, between spawning events at one reef and the subsequent appearance of larvae and juveniles at neighbouring reefs, some definite conclusions about dispersal processes could be drawn. One of us (PD) had previously developed a novel method for the effective and efficient sampling of pelagic fish larvae, involving the use of floating light traps (Doherty 1987), and evidence had been gained that this method could be used for estimating the relative abundance of postlarvae of large predator species such as serranids, lethrinids and lutjanids. Another of the Project team (MS) had identified the preferred near-reef habitat of juvenile coral trout, from many hours of SCUBA-based

searching and observation, and had developed underwater visual census (UVC) protocols for estimating their abundance. The methodology for conducting investigations into larval dispersal at the scale of the individual reef was therefore known, and required little further development.

Management of the stocks of coral trout and other reef fish on the Great Barrier Reef is hampered by a limited understanding of the stock structure of the species involved. In addition to coral trout and redthroat emperor referred to above, the gold-band snapper *Pristipomoides multidens* contributes significantly to commercial and recreational fish catches in tropical Australian waters. Gold-band snappers comprised about 70% of the 428 tonne trap and drop line catch in the Northern Territory during 1991. The catch of this species has increased rapidly from 23 tonnes in 1987 to 289 tonnes in 1991, with a GVP of approximately \$2.03 million. Kramer *et al.* (1994) have suggested that this species may form a component of a potential deep reef slope fishery off the Great Barrier Reef.

One of the pressing issues for management of the reef line fishery is that of larval dispersal. From GBRMPA's point of view it is essential to know the geographical scale over which recruitment of reef fish takes place, so that access to reefs and associated resources by various user-groups can be more effectively managed through zoning legislation. The issue of recruitment scale translates ultimately into stock definition - if recruitment is very localised, there is an increased probability that genetically distinct stocks of fish occur over the geographical range of the GBR. Detection of such genetic differences, or the lack thereof, could provide important insights into the scale of dispersal and recruitment processes, and complement the investigation of links between spawning events and recruitment of juveniles to the reef habitat as described above.

## 1.4 STUDY AREAS

The research results described in this report are based on material collected from sites spanning three-quarters of the length of the Great Barrier Reef, a distance of some 12000 km. There were five major geographical areas represented in the study, representing three of the four "Sections" of the Great Barrier Reef Marine Park (GBRMP). The Study Areas, which ranged in size from a few reefs surrounding a single island (Lizard Is.) to a vast complex of many hundreds of reefs covering an area of 4500 n.mi<sup>2</sup> (Swains), are as follows:

- . **Lizard Island** (extreme northern boundary of the Cairns Section)
- . **Cairns region** (centre of the Cairns Section)
- . **Townsville region** (northern part of the Central Section)
- . **Swains Reefs** (centre of the Mackay-Capricorn Section)
- . **Capricorn-Bunker Group** (southern part of the Mackay-Capricorn Section)



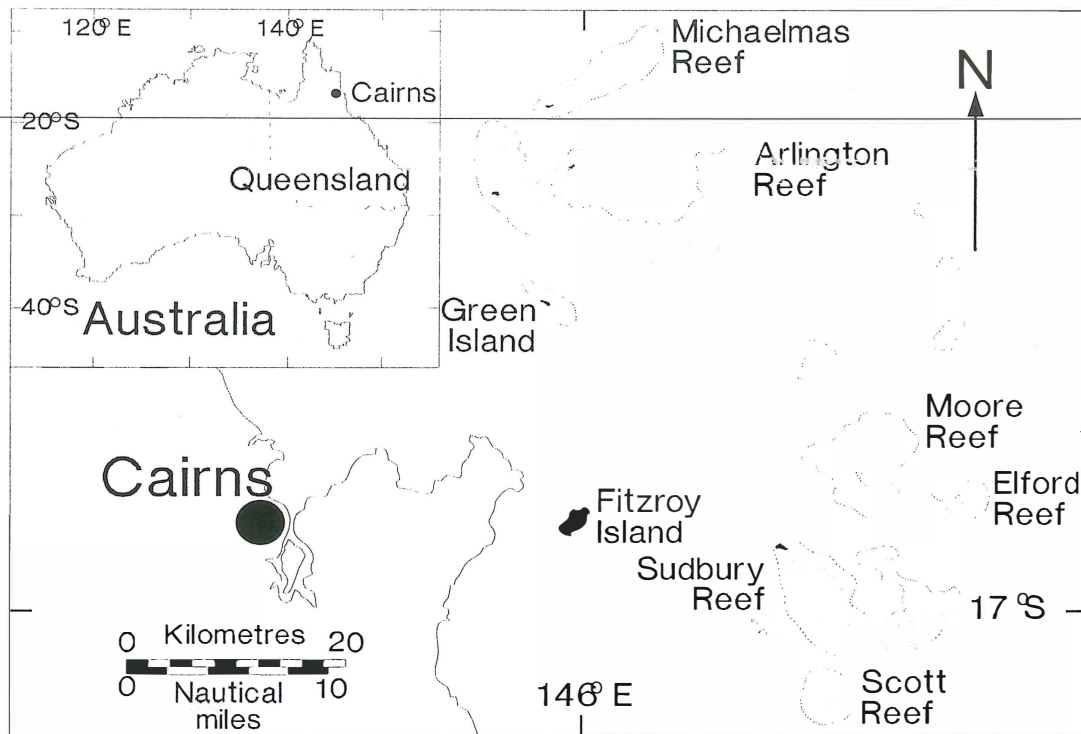


Figure 1 Location of study sites at Scott and Elford Reefs south of Cairns, northern Great Barrier Reef.

The **spawning behaviour** study was based near Cairns at Scott (17°05'S 146°11'E) and Elford (16°55'S 146°15'E) Reefs (Fig. 1). On each reef one area of reef slope was selected for monitoring. The areas selected were sites in which apparent seasonal aggregations had been regularly observed by local fishers over the past 12 years (L.C. Squire pers. comm.). After preliminary observations, sites were mapped and reproduced on underwater paper (Fig. 2 & 3). These maps were used as proformas to standardise observations collected during censuses.

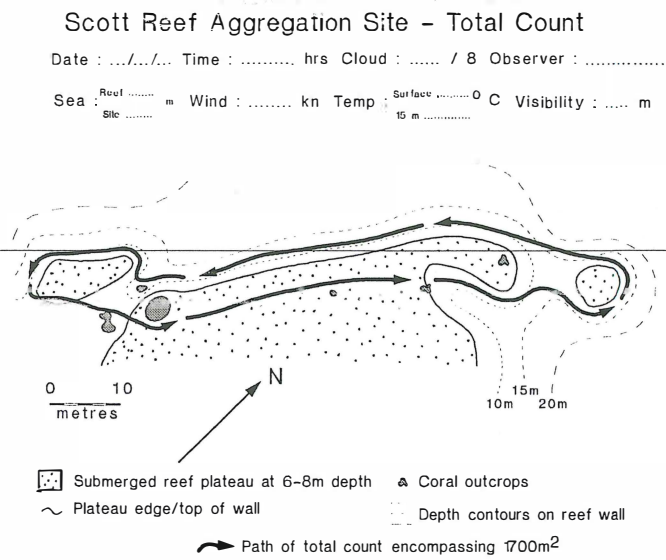
Because of the need for daily clearance of the light-traps used in the **larval recruitment** study, this work was limited to reefs reasonably close to a land base. The QDPI Field Station on Green Island, Cairns Section, provided an excellent choice with ready access to Arlington and Green Reefs (Fig. 1) in proximity to research facilities, including aquaria for maintaining live material from the light-trap collections. Limited growout of live specimens was done in the first year to positively identify the pelagic juveniles referred to *Plectropomus*. An additional advantage of the Green Island location was that it is situated within 40 km of reefs where project staff from QDPI were monitoring coral trout spawning aggregations. Although our limited knowledge of the hydrodynamics of this area suggests that the spawning sites (Scott, Elford Reefs) lie downstream of the reefs where recruitment was monitored (Wolanski and Pickard 1985), the close proximity

nevertheless allowed us to seek (and indeed find) temporal linkages at regional scales.

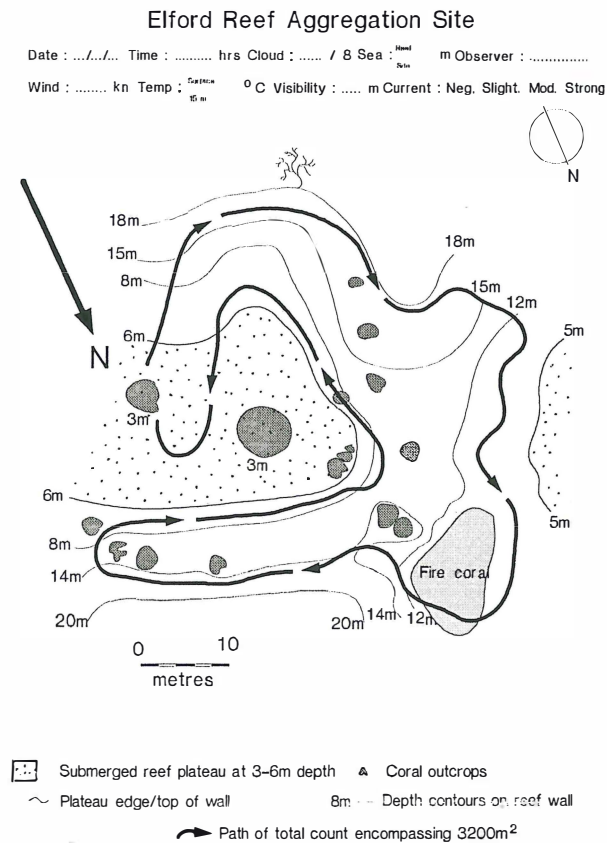
The density and distribution of benthic juveniles was investigated at Arlington (16°04'S 146°04'E) and Green (16°46'S 145°59'E) Reefs (Fig. 1) to correspond with the larvae light traps.

At Scott Reef the study site (hereafter called the "primary aggregation site") measured approximately 1700m<sup>2</sup> and was located on an extensive submerged patch reef, separated from the main reef (Fig. 2). The area is approximate since it corresponds to a two-dimensional surface area, measured underwater with 50m tapes. The site was long and narrow in shape, consisting of an upper plateau area submerged at approximately 6-8 m depth, with a steep wall to seaward, dropping to a gently sloping sandy bottom at approximately 17-25 m depth. Moderate to strong currents were a regular feature of the area particularly on the full and new moons.

The "primary aggregation site" on Elford Reef measured approximately 3,200 m<sup>2</sup>, and was located at a channel which cut right through the main reef from north to south (Fig. 3). The channel was approximately 10m in width at the aggregation site, but opened into much wider lagoon to the north (leeward).



**Figure 2** Data sheet used for underwater censuses of coral trout at Scott Reef off Cairns.



**Figure 3** Data sheet used for census counts at Elford Reef showing diagram of aggregation site and physical parameters recorded.

The site, though larger than Scott in area, was more compact and consisted of shallow reef top at approximately 3-6m depth on either side of the channel; with steep walls to seaward (south) dropping to a gently sloping sandy bottom at approximately 20-25m depth. To leeward (north) the reef sloped at approximately 45° into the protected lagoon area which had a sandy bottom of approximately 16-20m depth. Moderate to strong currents were frequently encountered in the channel, running either north or south.

## 1.5 RESEARCH RESPONSIBILITIES

Four laboratories, representing three major research organisations, were involved in this collaborative project. Factors such as the geographical location of these laboratories, their recent history of involvement in particular aspects of reef fish research, different skills bases and logistic considerations were responsible for determining the role that each was to play in the project. An outline of the research responsibilities, identifying the relevant Sub-project Leaders, is given in Table 1.

As far as possible material in this report is presented in such a way as to avoid unnecessary repetition of details common to the various sub-projects. However when methodologies, results etc differ between different laboratories, appropriate annotations (e.g. JCU, NFC) have been used to identify the relevant source.

Table 1. Division of research responsibilities between laboratories and organisations.

RESEARCH TASK	STUDY AREA				
	LIZARD IS.	CAIRNS	TOWNS -VILLE	SWAINS REEFS	CAPRICORN-BUNKERS
Coral trout - collection of material	JCU <sup>1</sup>	NFC <sup>2</sup>	JCU <sup>1</sup>	SFC <sup>3</sup>	SFC <sup>3</sup>
Coral trout - age/reprodn processing	JCU <sup>1</sup>	NFC <sup>2</sup>	JCU <sup>1</sup>	NFC <sup>2</sup>	NFC <sup>2</sup>
Coral trout - reproductive behaviour		NFC <sup>4</sup>			
Coral trout - larval recruitment		AIMS <sup>5</sup>			
Redthroat - collection of material		NFC <sup>2</sup>	JCU <sup>1</sup>	SFC <sup>3</sup>	SFC <sup>3</sup>
Redthroat - age/reprodn processing		SFC <sup>3</sup>	JCU <sup>1</sup>	SFC <sup>3</sup>	SFC <sup>3</sup>

<sup>1</sup> Dr G. Russ

<sup>2</sup> Mr G. McPherson

<sup>3</sup> Dr I. Brown

<sup>4</sup> Ms M. Samoilys

<sup>5</sup> Dr P. Doherty

## 2 CORAL TROUT

### 2.1 SPECIFIC OBJECTIVES

Prior to the initiation of this Project there was some information available on the age, growth and longevity of the common coral trout. On the Great Barrier Reef, Goeden (1978) estimated the growth rate of this species at Heron Island from length-frequency data. Loubens (1980) and McPherson *et al.* (1988) used whole otolith annulus counts to estimate age and growth in populations of coral trout from New Caledonia and Cairns respectively.

The objectives of this part of the study were

- i) to validate age estimates for coral trout
- ii) to estimate growth parameters for the species from Lizard Island, Cairns, Townsville, the Swains Reefs and the Capricorn Bunker Group.
- iii) to determine size and age at first maturity, and assess the appropriateness of present minimum legal size legislation
- iv) to determine the size and/or age at which this hermaphroditic species changes sex from female to male, and assess the implications of this on present management strategies relating to the reef line fishery
- v) to estimate the instantaneous proportion of the adult stock actually spawning
- vi) to confirm the occurrence of seasonal aggregations of mature coral trout
- vii) to observe and document actual spawning thus confirming the aggregations as spawning events
- viii) to identify the temporal and behavioural characteristics of coral trout spawning aggregations and assess their management significance.

## 2.2 MATERIALS AND METHODS

### 2.2.1 Collection and processing of materials

Coral trout were sampled from a variety of reefs in the Townsville region (18-19°S) (JCU). These samples were obtained from commercial and recreational line fishermen but most of the fish used for otolith examination in this study came from a systematic line sampling of 4 mid-shelf reefs (two open to fishing and two closed) in June-July and September-October of 1990 and 1991 by a team of recreational fishermen using standard fishing methods (Table 2). These field operations were funded by the Australian Research Council (ARC).

**Table 2.** Dates and number of *P. leopardus* collected on a one day trip to each of four reefs at 2 times per year for 2 years.

YEAR	PERIOD	CLOSED		OPEN	
		GLOW	YANKEE	GRUB	HOPKINSON
1990	June/July	52	18	8	14
	Sept/Oct	50	42	11	16
1991	June/July	74	54	13	28
	Sept/Oct	28	11	15	13
TOTAL		180	119	47	71

These reefs were Grub and Hopkinson (General Use reefs open to fishing) and Glow and Yankee (Marine Park B reefs closed to fishing since 1987). Coral trout were sampled in the Lizard Island area (14° 40'S; 154° 28'E) between March 1990 and February 1992 (Table 3). Fish were caught by recreational and commercial fishermen using hook-and-line (n=184) and by recreational spearfishermen (n=94). Individuals smaller than 20 cm total length are usually not vulnerable to line fishing, and were caught around Lizard Island by SCUBA divers using fence-nets (n=32). The fork length (cm), standard length (cm) and total weight (g) of each fish were measured. Fork length is defined as the length from the front of the snout to the caudal fork, and standard length is defined as the length from the front of the upper lip to the posterior end of the vertebral column. Additional samples, in the form of carcasses kept frozen after filleting, were obtained from local commercial and recreational fishermen.

The gonads were removed, weighed and staged macroscopically. Sex determination could be done macroscopically only if gonads were active. In this case, individuals were classified as ripe females or males and the information used to determine periodicity of spawning. The gonosomatic index (GSI) was calculated as the ratio of gonad fresh weight to total weight of the fish. As total weight was not available for the commercial samples,

estimated values were obtained through the relationship between fork length and total weight (Ferreira and Russ, 1992).

Sampling in the Cairns area (NFC) began in September 1989, before the commencement of this study. Biological material was collected mainly from reef fishing charter boats operating from Cairns and working in the area between latitudes 16°20' and 17°30'S, approximately 30 nautical miles north and south of Cairns, and from 12 to 35 nautical miles due east of Cairns. Two vessels engaged in daily fishing operations provided deck space and access to recreational hook-and-line catches. While *Plectropomus leopardus* was a highly prized and sought after component of the day charter industry, other species such as 'redfish' of the genus *Lutjanus* also formed a large component of the catch (McPherson 1989). Additional samples of *P. leopardus* were obtained from spear collections made at study sites in the Cairns area by QDPI staff engaged on this project. Sub-adult and adult fish were taken during the spawning months, while young of year fish were collected during juvenile surveys each year.

**Table 3.** Number of fish collected per month from Townsville and Lizard Island reefs from 1990 to 1992.

MONTH	TOWNSVILLE			LIZARD ISLAND		
	1990	1991	1992	1990	1991	1992
Jan	-	-	-	-	-	10
Feb	-	-	-	-	8	14
Mar	-	6	-	5	4	-
Apr	9	2	-	-	20	-
May	3	2	-	-	-	-
Jun	-	25	-	-	-	-
Jul	21	10	-	5	61	-
Aug	5	-	35	36	5	-
Sep	-	10	-	-	2	-
Oct	18	28	83	-	20	-
Nov	16	-	-	6	161	-
	-	-	-	-	73	-
Total	60	83	118	52	354	24

Samples were taken when possible once per week during the first and fourth weeks of each month, and twice per week during the second and third weeks of each month. During spawning periods, samples were taken on two or three days each week. Sampling days were selected randomly to distribute sampling effort throughout the moon cycles, especially during the spawning season. Weather, anglers' preferences for species in the inter-reef fishery, and last minute charter cancellations influenced the actual frequency of sampling. Fishing operations usually took place between 0800 and 1500 hr, as the travel time from Cairns to the fishing grounds was between 2 and 2.5 hr. Two charter vessels maintained a length/frequency record of their total catch of *P. leopardus* during 1990 and 1991.

The sampling location, in terms of its distance from the nearest reef crest, was recorded as one of three categories ( $\leq 500$  m,  $> 500$  m to  $\leq 1000$  m, and  $> 1000$  m). A number of

recreational anglers also provided length-frequency estimates or frames from their catches. In all, 4,745 fish were sampled from the recreational charter boat and angling sectors of the fishery. All fish sampled represented either the entire catch or a random subsample (e.g. the first 20 landed) of the daily catch.

Fork lengths were routinely measured to the nearest 0.5 cm. In more than 2000 fish total lengths (the distance from the snout to the maximum extension of the caudal fin, as defined in Queensland fisheries legislation) were also measured to enable the calculation of length conversion factors. Unless otherwise stated, fork length is used throughout this report.

Total weights were recorded in the field to the nearest 0.1 kg, and in the laboratory to the nearest gramme. Time of landing was recorded to the nearest 15 min on board charter vessels, and for some of the speared samples.

The absolute size-frequency of fish sampled by line and spear from the Cairns and southern GBR areas are shown in Fig. 4. The length distributions of the line and spear samples do not substantially differ for adult fish, but spearing yielded the smallest fish.

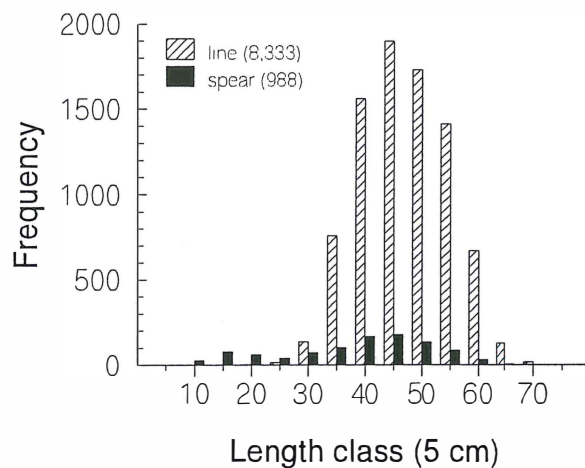


Figure 4 Length frequency distribution of coral trout sampled from the Cairns area and from southern GBR.

## 2.2.2 Reproductive Behaviour

### 2.2.2.1 Aggregation behaviour

The following protocol was adopted for assessing primary aggregation sites. Coral trout were counted on the aggregation site during a standard underwater census (UVC) using SCUBA (see Samoilys and Carlos 1992), and their individual fork lengths estimated. Each census was conducted by one trained observer, although different censuses were done by one of three persons. Training involved estimating fish size using wooden models (see Bell *et al.* 1985, Samoilys and Carlos 1992). The observer adopted a fixed search pattern following a route swum in a set time of 25 minutes. This took the observer around the site at a slow but steady pace. The observer searched a path width of approximately 10 m, with some minor variation caused by visibility. The route was designed to allow the observer to view the whole aggregation site by the end of the census giving a total count rather than a transect count. The observer swam at approximately 1.5 m off the bottom, following a route that ensured no overlap in search path. Since trout move, there may have been inaccuracy in the counts (either over or under-estimation) associated with taking 25 minutes to complete the count (Watson *et al.* in press) but any bias should have been consistent among censuses. Trout numbers were recorded by noting the location and size (in 5 cm size classes) of each fish and marking them on the topographical map. Fish sex was recorded by noting courtship colours and display

behaviour, which is only exhibited by males, and noting females as those individuals which males courted. Sex was confirmed by spearing and dissecting selected fish (Rimmer *et al.*, 1994).

Weekly or fortnightly visual census surveys were conducted throughout the spawning season (August/September to December) each year. In 1991 and 1992 surveys were conducted outside the spawning season every other month. At Scott Reef sampling was conducted for three years (1990-1992), and at Elford Reef for two years (1991-1992). The majority of UVC counts were completed just before sunset. Another set of UVC counts were conducted during the day, between 0830 and 1600 AEST, to determine the stability of aggregations. Table 4 summarises the total number of censuses conducted at Scott and Elford Reefs from 1990 to 1992. On each census in 1990 water temperature was measured with a handheld mercury thermometer at 15 m depth. In 1991 and 1992 temperatures were measured at the surface and at 15 m depth with a hand held red spirit thermometer. An approximate estimate of visibility was made using a fibreglass tape measure to confirm conditions were appropriate for visual surveys.

**Table 4.** Total number of UVC counts at primary aggregation sites on Scott and Elford Reefs, 1990-1992.

YEAR	SCOTT REEF			ELFORD REEF		
	< 1230 hr	1230- 1600 hr	> 1659 hr	< 1230 hr	1230- 1600 hr	> 1659 hr
1990	6	5	24	0	0	0
1991	7	4	21	7	2	14
1992	9	5	21	8	6	21
TOTAL	22	14	66+1*	15	8	35+1*

\* Two counts were done outside the listed time periods: one at 16:40 at Scott (1990), and one at 16:54 at Elford (1992). These are included as dusk censuses.

### 2.2.2.2 Spawning behavioural observations

Following completion of the census count on the primary aggregation site, the observer remained on the site to watch for spawning activity. Observations were conducted from a stationary position in an area with the most trout. These observations were carried out for 15-30 minutes or until darkness. Behavioural observations were based on the ethogram and observation period of 15 min developed by Samoily (1987), and were structured as follows: Where available a dominant male trout was observed for 15 minutes, and his activities recorded by the minute. Observations focussed on recording the occurrence of spawning behaviour which was defined after initial observations in 1990: (i) courting; (ii) male-male aggression/territorial displays, and (iii) spawning rushes. Non-spawning behaviour (moving, swimming, cleaning etc. see Samoily 1987) were recorded, but not in detail. At the same time the observer noted the male's territory area and the number and sizes of females within the territory. The females are predominantly inactive during spawning time, except when about to spawn, and therefore it was relatively easy to keep



track of individuals. If a male fish was not found, the first adult trout located was selected for observation.

Behavioural observations commenced on 17 Oct 1990, the 19th day of censusing at Scott Reef. Thereafter, observations were conducted after most of the dusk censuses, including those at Elford Reef from 1991 onwards.

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### 2.2.2.3 Secondary aggregation site identification

Neighbouring areas on Scott Reef, up to 2 km in all directions from the primary aggregation site, were surveyed on snorkel during daylight hours to search for additional aggregations. This included the reef edge (slope) and separated reef patches. Similar searches were done at Elford Reef, covering an area of approximately 2 km<sup>2</sup> around the primary aggregation site. Additional searches were done at the southwest end of Elford Reef which is characterised by the presence of several channels in the reef edge, similar to the main channel at the primary site.

### 2.2.2.4 Analytical procedures

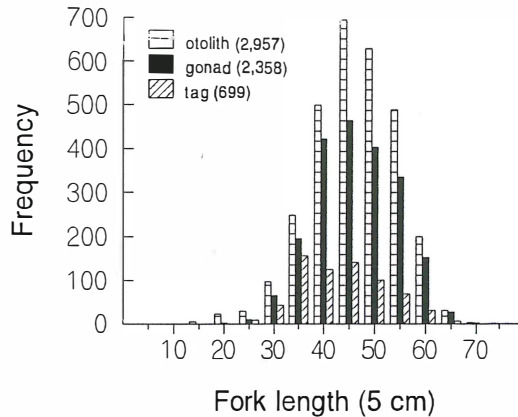
*Dusk counts:* Total numbers of trout on the aggregation sites at dusk were plotted against time, moon phase and water temperature.

*Daytime counts:* Visual census counts on the aggregation sites from different times of the day were compared using the following time periods: morning = < 1201 hours; afternoon = 1230-1600 hours; dusk = > 1659 hours. Only the data collected from days on which trout were aggregating were used. To define these records, i.e. the minimum total number of trout on site which constitutes an aggregation, an arbitrary three-fold multiplier was used. On both reefs this gave a minimum of 18 because both aggregation sites had a mean density of 6 trout outside the spawning periods. Thus all censuses with a total number of 18 fish or more were used in analyses. In addition, only data from those days on which more than one census was conducted were used in analyses. Since counts were conducted twice a day (dusk and morning or dusk and afternoon), the dusk counts were split into two groups for analysis. Data were pooled across all years. At Elford Reef tagging disrupted the counts in 1992. Only those counts from days where there was no fishing are graphed. A paired t-test was used for comparisons at Scott Reef, having first tested for normality.

## 2.2.3 Reproductive development and chronology

### 2.2.3.1 Macroscopic staging

Ovaries of coral trout from the Cairns region were staged macroscopically using the scheme of McPherson (1992a in press). Gonads were removed, weighed to the nearest 1 or 5 g depending on the size of the sample and preserved in 10% neutral buffered formalin (Hunter 1985). Mature ovaries were injected with preservative whenever possible to enhance rapid fixation. The length distribution of 2,358 fish from which gonads were preserved and analysed is given in Fig. 5.



**Figure 5** Length frequency distribution of coral trout from the Cairns and southern GBR tagged or sampled for otoliths and reproductive data.

### 2.2.3.2 Condition (mesenteric fat content)

The amount of fat deposited in the mesenteries was estimated for the Lizard Island sample (JCU) on a relative scale from 0 to 1, with 6 categories which indicated the proportion of fat covering the viscera (0=no visible fat; 0.2= thin threads of fat; 0.4; 0.6; 0.8 increasing amounts of fat, and 1.0= fat completely covering the viscera). This scale was chosen after observing the seasonal variation in the relative amounts of mesenteric fat for a year, and estimations were always made by the same observer (BPF).

### 2.2.3.3 Histological processing

Gonads from 230 fish from Lizard Island and 131 from Townsville were preserved in FAAC (formaldehyde 4%, acetic acid 5%, calcium chloride 1.3%) for later sectioning (JCU; L. Winsor, pers. comm.). Middle portions of the two gonadal lobes were embedded in paraffin and sectioned transversely at 5 microns thickness and stained with Mayer's haematoxylin-eosin.

Preserved tissue samples from Cairns and Southern GBR fish were embedded in paraffin and sectioned at 6  $\mu\text{m}$  (testis and non-mature ovary) or 6-10  $\mu\text{m}$  (mature ovary) and stained with Harris haematoxylin-eosin. In 82% of samples, slides were prepared from proximal, medial and distal areas of one gonad lobe.

#### 2.2.3.4 Histological staging

The nomenclature for description of the stages of oogenesis and spermiogenesis followed Yamamoto *et al.* (1965). Classification of males and females into ontogenetic stages (stages) and developmental stages (stadia) followed the adaptation by Ferreira (1993) from Moe (1969). Developmental stages of ovaries were determined according to the most advanced oocyte stage present in the gonad (Ebisawa, 1990).

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<b>Immature female:</b>	Ovaries that showed no evidence of prior spawning. Lamellae filled with previtellogenic oocytes in early and late perinucleolus stages and abundant oogonium and chromatin nucleus stages.
<b>Mature female:</b>	<p><i>Resting:</i> Lamellae filled with previtellogenic oocytes in early and late perinucleolus stages, oogonium and chromatin nucleus stage oocytes. Evidence of prior spawning in the form of yellow-brown bodies.</p> <p><i>Ripening:</i> oocytes in early stages of vitellogenesis, from yolk vesicle stage to primary yolk globule stage.</p> <p><i>Ripe:</i> oocytes in late stages of vitellogenesis from tertiary yolk globule stages to hydrating stages.</p> <p><i>Spent:</i> lamellae disrupted and disorganised, with extensive vascularization. Vitellogenic oocytes in atresia. Follicular cells, remnants of post-ovulatory follicles, present throughout the gonad. Proliferation of oogonium and chromatin nucleus stage oocytes.</p>
<b>Transitional:</b>	Transitional individuals were defined as having gonads that showed proliferating testicular tissue in the presence of degenerating ovarian tissue, but in which sex-transition had not yet proceeded to the point at which the dorsal sperm sinuses were formed and filled with spermatozoa (Hastings 1981).
<b>Young male:</b>	Post-transitional, newly transformed testis. Ovarian tissue dominating the lamellae that had not assumed the typical lobular form of the mature testes. Presence of sperm crypts in all stages of development.
<b>Mature male:</b>	<p><i>Resting:</i> testis dominated by stromal tissue and early stages of spermatogenesis.</p> <p><i>Ripening:</i> later stages of spermatogenesis and spermiogenesis, spermatozoa starting to fill the dorsal sinus.</p> <p><i>Ripe:</i> testis dominated by spermiogenesis. Most crypts containing spermatids and spermatozoa. Crypts of spermatozoa ruptured and joined within the testicular lobules, forming large intralobular or "central" sperm sinuses. Dorsal sinuses filled with spermatozoa.</p> <p><i>Spent:</i> active development of crypts of spermatogonia and primary spermatocytes throughout the testis. Stromal tissues well developed between crypts.</p>

To estimate the percentage of remaining female tissue in transitional and male gonads, the whole gonad was observed under low magnification (40x), the percentage area occupied by oocytes estimated twice independently, and the results averaged.

Spawning frequency was estimated using the postovulatory follicle and hydrated oocyte methods of Hunter and Macewicz (1985) (Hunter *et al.* 1986; McPherson, in press). The spawning fraction by the postovulatory follicle method was calculated as the total number of post-spawning females with POF's divided by the total number of mature females. The mean spawning fraction by the hydrated oocyte method (Hunter and Macewicz 1985) was calculated as the ratio of pre-spawning females to all mature females. The variance of the ratio of spawning fraction estimates was calculated according to Cochran (1977) as recommended by Hunter *et al.* (1986). Spawning frequency is the inverse of spawning fraction.

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#### **2.2.3.5 Size and age at maturity and sex change**

Only individuals of age  $\geq 2$  years old were included in the comparisons between Lizard and Townsville, as younger individuals were only represented in the Lizard Island sample where fishing gear other than hook and line was employed.

Length at 50% maturity was estimated from the logistic model of Saila *et al.* (1988) using the proportion of mature ovaries in fish grouped by 5 cm length class.

The size and age range in which individuals changed sex was estimated from the zone in which size and age distributions of females overlapped with size and age distributions of transitional, young or mature males. The range of overlap was calculated as a percentage of the total range of sizes and ages observed. To compare if sex-change occurred at the same time for the two locations the distributions of size and age of individuals within the overlap range were compared using analysis of variance (Shapiro 1984).

For the calculation of sex ratio, only reproductively active (i.e. mature) individuals were included. The age and size of first spawning for females was determined as the age or size class in which 50% of females were mature.

#### **2.2.3.6 Analytical procedures**

One, two and three-way analyses of variance including post-hoc tests (Tukey-Kramer) were used for comparisons. The assumptions of normality and homoscedascity were examined and data were transformed if needed (transformed data indicated in tables). Level of significance used was  $p < 0.05$ . Spearman-Rank correlation was used to analyse the relationship between gonad weight and fat (Lizard Island data only) and between gonad weight and age and size of fish. The overlap of distributions of size and age of males and females were compared by t-test.

## 2.2.4 Spawning, Larval Supply and Recruitment

Regular sampling with light-traps was designed to monitor daily, seasonal and interannual variations in the supply of pelagic juveniles to reef environments. Juveniles were collected to validate any trends seen in trap catches. By counting daily increments in their otoliths, this method provides an independent hindcast estimate of settlement throughout each season. Correspondence between the two time series would validate the light-traps as an alternative method for monitoring replenishment in a valuable species where settlement cannot be monitored by conventional means.

A fixed array of light-traps was located within 100 m of shallow reef slope on the downstream side of Arlington Reef and various locations around the smaller adjacent Green Reef. The downstream locations were emphasized because earlier sampling around the entire perimeters of several reefs off Townsville had shown that traps are more efficient when fished in this orientation (Doherty and Carleton unpubl. data). This seems to result from retention eddies which play a part in trapping and retaining larval fish from the mainstream currents.

Due to a restriction on the number of light-traps available at the start of the study, there were some small changes in the intensity and distribution of sampling effort between the first and subsequent seasons. In 1990/91, 12 light-traps were deployed in a depth-stratified (0 & 20 m) design covering the southern ends of Arlington and Green Reefs. Soon after the start of sampling, one trap (A0) on the western end of Arlington was relocated to a new location near the SE corner and redesignated A3 for the rest of that season.

In 1991/92, four additional traps were introduced at two new locations on the SE face of Arlington. These were located equidistant on both sides of the trap previously designated A3 and the entire sequence renumbered. No additional effort could be put into the sampling around Green but G3 was relocated from the SW to the more productive SE corner.

In 1992/93, all 16 traps were maintained in the same locations as in the previous year to assess interannual variation in larval supply.

All traps were located on wire moorings, marked with flags and radar reflectors, and anchored with 250 kg railway wheels. Individual traps were hung from 300mm poly floats on short or long ropes to determine their fishing depth. On each night of fishing, all traps were lit simultaneously during three periods (2100-2200, 0000-0100, 0300-0400 hr EST) to spread any unwanted effects of time of night or tidal currents on trap efficiency. While it would have been ideal to sample every day of the entire summer, practical constraints limited sampling to approximately half of each lunar month. This effort was centred around consecutive new moons since continuous sampling in other locations has shown that this is the most productive time (Milicich 1992). Sampling was generally done between September and January.

*Recruitment* was assessed at the end of each summer by collecting representative samples of juvenile coral trout from reef slope habitats adjacent to the traps. In 1990/91, these fish were collected only from Arlington Reef. In both other years, fish were collected from both reefs.

Otoliths were removed from these fish and prepared for microscopic examination to hindcast settlement patterns for comparison with the light-trap records. The techniques of preparation and interpretation are detailed elsewhere (Doherty *et al.* in press).

*Spawning effort* was monitored concurrently by M. Samoilyls and other staff from the QDPI Northern Fisheries Centre on two reefs to the south of our study area (see elsewhere for details). It is worth recording here that we assume (1) that actual spawning release from the monitored aggregations was proportional to the number of trout counted on the aggregation sites, and (2) that any correlations between the spawning and recruitment time series would reflect global entrainment of both processes. The latter follows from the relative positions of the two sites in the mainstream flow (i.e. spawning was monitored downstream from the reefs where recruitment was measured).

Having established when trout were recruiting to the reef from the light trap catches, long swim searches on SCUBA were carried out around the perimeter of Arlington Reef to look for new coral trout recruits. These survey swims ranged from 15 minutes to over two hours, with a mode of 60 minutes. Surveys searched a swath of approximately 5m in width, swimming at a slow but steady speed, for distances of approximately 600-1400m on the reef slope at Arlington, and 300 m in all other habitats (per 60 minutes). Initially, in January 1991, surveys were conducted by two observers swimming in pairs, each searching a separate 5 m transect. These data were pooled and presented as effort data per single observer, i.e. divided by 2. All subsequent surveys were conducted by single observers.

Surveys were initiated late in January (1991), approximately two months after the appearance of coral trout larvae in the light traps, at which time they were considered to be just large enough to see in the benthic environment. Surveys were stratified across three major habitats: reef slope, reef crest and bommie field, and in two depth ranges: shallow (<7 m) and deep (7-12 m). A total of 38 surveys were conducted in January-February, March and May-June 1991. The sites surveyed are shown in Table 5 and Figure 6. Trout up to 20 cm FL were recorded, which would have included some slower-growing 1+ fish (mean FL for 1+ fish = 21.9 cm). Observers were trained in visual estimation of fish size from a concurrent project (Samoilyls and Carlos 1992). However, the training involved a minimum size of 11 cm FL, and therefore estimates of the smaller juveniles would have been approximate. After the visual surveys, juveniles were speared for ageing purposes. Spearing provided an excellent opportunity for training in length estimation for subsequent visual surveys. Training in Years 2 and 3 improved further since fish were speared after visual estimation of size and therefore actual lengths were measured. These data are currently being worked up into a paper on visual census training (Samoilyls and Carlos in prep.).

In 1992 and 1993, surveys were conducted at both Arlington and Green Reefs. The survey design was modified to adopt a more stratified approach, targeting habitats and depths which yielded higher densities in 1991 (Tables 6-9). Since very few juveniles were found in the deeper stratum or on the reef crest, these strata were not surveyed in 1992 and 1993. Surveys consisted of a fixed 1 hr SCUBA swim search by trained observers. Fish up to 20 cm FL were included in 1992. In 1993 surveys were restricted to fish up to 15 cm FL. To sample for early and late recruits in 1992, surveys were conducted in January-February and April-May, to correspond with the spawning and light trap larval catches of 1991. In 1993 surveys were conducted only in February.

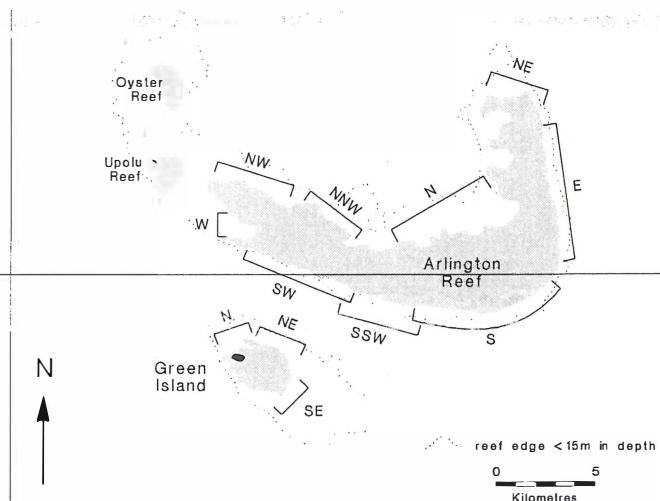


Figure 6 Location of study sites on Arlington and Green Reefs off Cairns, northern Great Barrier Reef. NW, NE etc refer to location of visual census surveys.

All visual surveys in 1992 and 1993 were modified so that observers concurrently sampled juvenile trout. Observers counted and then speared the juveniles. This differs from straight visual surveys in terms of the time taken to spear and any disturbance caused, and therefore such surveys are not strictly comparable with the non-sampling surveys of 1991. However, it was considered a high priority to obtain samples for ageing by AIMS staff.

Table 5. Number of visual census surveys conducted at Arlington Reef by habitat and depth, 1991. Compass points refer to orientation of reef face at sampling site, as shown in Figure 6.

DEPTH	LEEWARD					WINDWARD				
	SLOPE		BOMMIES		CREST	SLOPE		CREST		
<7m	NW	2	NNW	3	NE	2	E	4	SW	2
	NNW	2	NE	2			S	3		
	N	3	NW	4			SSW	6		
	NE	1	W	2			SW	1		
>6m	NE	1			NE	1	S	2		
							SW	1		

**Table 6.** Number of visual census surveys conducted at Arlington Reef by habitat in 1992. Compass points refer to orientation of reef face at sampling site as shown in Figure 6.

LEEWARD				WINDWARD	
SLOPE		BOMMIES		SLOPE	
N	3	N	7	S	8
NW	3	NW	7	SW	8

**Table 7.** Number of visual census surveys conducted at Green Reef by habitat in 1992. Compass points refer to orientation of reef face at sampling site as shown in Figure 6.

LEEWARD				WINDWARD			
SLOPE		BOMMIES		SLOPE		BOMMIES	
NE	2	NE	4	SE	8	SE	4
N	6	N	4				

**Table 8.** Number of visual census surveys conducted at Arlington Reef by habitat in 1993. Compass points refer to orientation of reef face at sampling site as shown in Fig. 6.

LEEWARD				WINDWARD	
SLOPE		BOMMIES		SLOPE	
N	4	N	4	S	4
NW	4	NW	4	SW	4

**Table 9.** Number of visual census surveys conducted at Green Reef by habitat in 1993. Compass points refer to orientation of reef face at sampling site as shown in Figure 6.

LEEWARD				WINDWARD			
SLOPE		BOMMIES		SLOPE		BOMMIES	
NE	2	N	4	SE	4	SE	4
N	2						



## 2.2.5 Age estimation and validation

### 2.2.5.1 Otolith preparation

Otoliths were removed, cleaned and allowed to air dry before being stored (NFC). This drying process is important, as Loubens (1978) reported that otoliths freshly extracted from a variety of reef fish species were clear and lacked discernable internal structure, and (from experiments with *Lethrinus nebulosus* otoliths) recommended a drying time of around one week. McPherson (1992b) found that if otoliths were not properly dried (as can happen when the sampling is done at sea), they were often translucent or clear, resulting in a high rejection rate. The length distributions of coral trout from the Cairns and southern GBR regions is given in Fig. 5.

A sub-sample of otoliths that were difficult to interpret, and a sample that were readily aged by traditional methods for comparison, were embedded in Beuhler 'Castolite' resin. A thin (0.45 mm) section was taken by cutting transversely on either side of the focus with a Beuhler 'Isomet' low speed saw. Temporary sections were mounted on a glass microscope slide in histological mounting fluid.

### 2.2.5.2 Otolith reading and interpretation

Sagittal otoliths were removed, cleaned, weighed and stored dry (JCU). Left and right sagittae, when intact, were weighed to the nearest milligram. Otoliths were prepared and read as described by Ferreira and Russ (1992, 1993). To increase contrast between bands, whole otoliths were burned lightly on a hot plate at 180°C (Christensen, 1964). Both right and left sagitta were read whole under reflected light using a dissecting microscope at 16x magnification. The otoliths, with the concave side up, were placed in a black container filled with immersion oil. The left sagitta was prepared for reading by embedding in epoxy resin (Spurr, 1969) and sectioning transversely through the core with a Buehler Isomet low-speed saw. Sections were mounted on glass slides with Crystal Bond 509 adhesive, ground on 600 and 1200 grade sand paper, polished with 0.3 $\mu$  alumina micropolish and then examined under a dissecting microscope at 40x magnification with reflected light and a black background.

Whole otoliths were immersed in aniseed oil and examined at least three times under reflected light against a black background (NFC). Otolith radius and check measurements were taken on the concave proximal face from the focus to the dorsal margin on an axis perpendicular to the *sulcus acousticus*. Otolith checks were measured to the border between the outer edge of the opaque zone and the inner edge of the translucent zone. A check was not considered to have been formed until a translucent margin was visible around the entire otolith margin. Otoliths that were difficult to interpret were heated as described above, to enhance the banding pattern.

Terminology for otolith readings followed definitions by Wilson et al. (1987) (JCU). Two experienced readers independently counted opaque zones (annuli) in each whole and sectioned otolith of a random subsample (n=136) to assess the precision and accuracy of

countings obtained through the two methods. The precision of age estimates was calculated using the Index Average Percent Error (IAPE) of Beamish and Fournier (1981). The results obtained from whole and sectioned otoliths were compared by plotting the difference between readings obtained from whole and sectioned otoliths (section age - whole age) against section age. The results of this comparison indicated that whole otolith readings tended to be lower than readings from sectioned otoliths when more than 6 rings occurred in the otolith. Therefore, remaining otoliths were read whole first and, if the number of rings was higher than 6, or the whole otolith was considered unreadable, the otolith was sectioned and counts were repeated. Two readers independently counted annuli in each otolith. The results were accepted and used in the analysis when the counts of the two readers agreed. If the counts differed, the readings were repeated once and if the counts still differed, the fish was excluded from the analysis.

### 2.2.5.3 Validation procedures

Tagging operations (NFC) were conducted by QDPI staff and vessels in association with the Cairns Rod and Reel Fishing Club over two weekends in 1990 (October and November) and one weekend in 1991 (October). Funding for these tagging exercises was provided by QDPI Recreational Fishing Enhancement Programme. Anglers provided their own vessels and gear while QDPI provided food, ice and bait as well as a specially commissioned t-shirt in recognition for their efforts. The length distribution of the 699 *P. leopardus* tagged is given in Fig. 5. Of these, 369 were injected with oxytetracycline hydrochloride at a minimum dose of 50 mg/kg of body weight. A total of 148 coral trout were anaesthetised upon landing and their sex determined by cannulation.

Ages were assigned based on annulus counts and knowledge of the spawning season (JCU). The periodicity of annulus formation was determined with the use of tetracycline labelling. From August 1990 to February 1992, 80 fish were caught in a trapping program at Lizard Island fringing reef (Davies, in prep.), tagged with T-bar anchor tags and injected with tetracycline hydrochloride before being released. The fish were injected in the coelomic cavity under the pelvic fin with a dosage of 50 mg of tetracycline per kg of fish (McFarlane and Beamish, 1987), in a concentration of 50 mg per ml of sterile saline solution. Five fish were recaptured after periods of at least one year at large. Two of those fish were reinjected at the time of recapture and kept in captivity for periods of 3 to 4 months. To determine the time of formation of the first annulus, five young-of-the-year were captured with fence-nets. Three of these fish were injected with tetracycline at the time of capture, and all five fish were kept in captivity for periods of 3 to 17 months. The otoliths of the fishes treated with tetracycline were removed, sectioned and observed under fluorescent light. To determine time of formation of the translucent and opaque zones, the distances between events for which time of occurrence was known (i. e.. between two tetracycline bands or between a tetracycline band and the margin of the otolith) were measured on otolith sections and plotted against the corresponding time interval. The relative positions of the translucent and opaque zones to these marks were then measured and plotted on the same scale. While this method does not provide real distances, it standardises the measurements allowing for comparison between fishes of different ages.

## 2.2.6 Growth parameter estimation and regional comparison

The growth models were fitted to the data (JCU) and their coefficients and standard errors estimated using standard non-linear optimisation methods (Wilkinson 1989). As the plot of the length-at-age data indicated some form of asymptotic growth, Schnute's (1981) reformulation of the von Bertalanffy growth equation for length in which  $a \neq 0$  was fitted to the data:

$$L_t = y_1^b + (y_2^b - y_1^b) \left\{ \frac{1 - e^{-a(t - t_1)}}{1 - e^{-a(t_2 - t_1)}} \right\}^{b-1}$$

where  $L_t$  is length-at-age;  $t_1$  and  $t_2$  are ages fixed as 1 and 14 respectively;  $y_1$  and  $y_2$  are estimated sizes at these ages; and  $a$  and  $b$  are the parameters which indicate if the appropriate growth curve lies closer to a three or two parameter sub-model. By limiting parameter values the data were used directly in selecting the appropriate sub-model, namely the generalised von Bertalanffy, Richards, Gompertz, Logistic, or Linear growth models. Subsequently, the original von Bertalanffy (1938) growth equation for length

$$L_t = L_\infty (1 - e^{-k(t - t_0)})$$

was fitted to the data.  $L_t$  is length-at-age;  $L_\infty$  is the asymptotic length,  $K$  is the growth coefficient,  $t$  is age, and  $t_0$  is the hypothetical age at which length is zero.

To evaluate the effects of use of gear selectivity (and consequently varying age composition) on the estimates of growth parameters, results obtained using only the sample collected by line and spear fishing were compared with that obtained using the same data complemented by the fence-net sample composed of younger fish.

Growth curve parameters were estimated (NFC) from length and otolith age data fitted to the growth models of Schnute and Richards (1990). Comparison of growth between females and males was performed least squares ANOVA for unbalanced data by the LSMLMW package (Harvey 1960), and curves fitted by the LMM minimisation routine (Osborne 1976, modified by A.J. Millar [CSIRO] and A.T. Lisle [QDPI] 1986). Parameters were estimated from data pooled across sexes or areas, with the change in the regression sum of squares being examined using an F-test. Tag recapture data was fitted to the von Bertalanffy model using the minimisation routine LMM (Osborne 1976; program modified by D.R. Jackett and A.J. Miller, CSIRO Division of Mathematics and Statistics, 1984).

### 2.2.7 Mortality rate estimation

Total mortality rates for coral trout populations in the Cairns area were estimated by NFC using the programme Catcurv (Restrepo *et al.* 1985). Estimates of Z (by JCU) for Lizard Is. and Townsville populations were derived from regression analysis of the age-frequency data.

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As this Project did not attempt to partition Z experimentally into F and M, a rough approximation of natural mortality (M) was derived from Raiston's (1987) formula relating M and the growth coefficient K, the latter having been estimated from the length-at-age data. Fishing mortality F was then estimated simply by subtraction, as  $Z - M$ .

### 2.2.8 Yield-per-recruit analysis

Yield-per-recruit analyses (NFC) used an integrated model (T. Quinn, University of Alaska, pers. comm.) which incorporates a survival probability function for undersized fish returned to the water (Waters and Huntsman 1986).

### 2.2.9 Length-weight relationship and length-conversion factors

A simple linear regression of the form  $FL = a + b.SL$  was used to describe the relationship between fork and standard length. The model  $W = aL^b$  (where W = weight [g] and L = fork length [cm]) was fitted by non-linear regression estimation (JCU) or by linear regression of log-transformed data (SFC and NFC) to describe the relationship between fork length and total weight.

## 2.3 RESULTS

### 2.3.1 Reproductive behaviour

#### 2.3.1.1 Aggregation behaviour

(i) *Dusk counts.* Figures 7-9 show the number of *P. leopardus* recorded in dusk counts on the primary aggregation site at Scott Reef in all three years. In each year a dramatic increase in trout numbers was recorded during the spawning season. The increase was sharp; for example numbers rose from 8 to 82 in twelve days in October 1992. Maximum numbers of trout ranged from 74 in 1991 to 128 in 1992. These peaks in trout density represent magnitude changes of up to 13-fold, 16-fold and 19-fold, respectively. Subsequently, numbers dropped equally dramatically. In 1991 and 1992 successive aggregations formed, with two major aggregations occurring in 1991. A smaller aggregation was recorded in December, giving a third aggregation to the 1991 season (Fig. 8). Three major aggregations were recorded in 1992, though the third was smaller in magnitude (Fig. 9). In 1990, only one major aggregation was observed, though two smaller aggregations were discernible, with maximum numbers of 20-22 fish (Fig. 7).

A similar pattern was observed at Elford Reef (Figs. 10-11). Three distinct aggregations occurred in 1991, with maximum numbers ranging from 24 to 53 (Fig. 10). In 1992 the aggregation site was disrupted by fishing to tag spawning trout, and therefore the counts were not directly comparable with 1991, or with Scott Reef. Two major aggregations occurred in 1992, with maximum numbers ranging from 32 to 57 (Fig. 11). A smaller aggregation occurred at the end of the season with maximum numbers ranging from 16-22. The peaks in trout density at Elford aggregation site in 1991 and 1992 represent magnitude changes of up to 7-fold and 9-fold, respectively.

The timing of the aggregations is clearly lunar, with peak numbers of trout

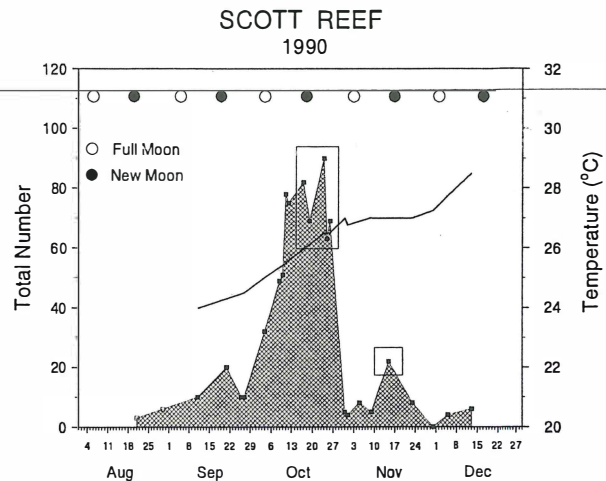


Figure 7 Numbers of trout at dusk at the Scott Reef site in 1990 showing water temp. at 15 m depth. Boxes show dates when spawning rushes were seen.

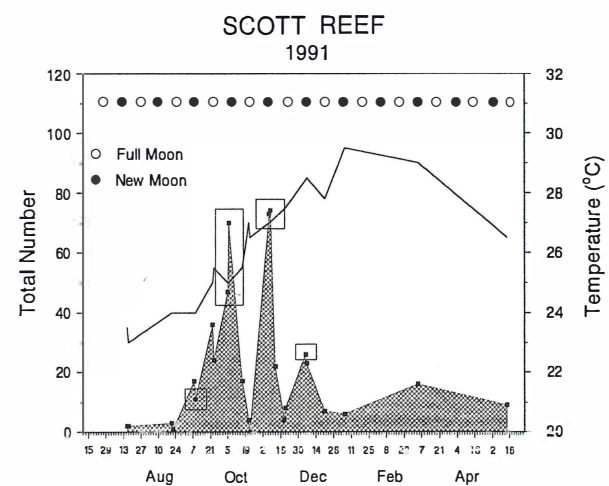


Figure 8 Numbers of coral trout seen at dusk on the Scott Reef aggregation site in 1991.

corresponding to the new moon, at which time spawning rushes (see below) were also observed (see boxed areas in Figs. 7-11). This lunar pattern is particularly apparent when major aggregations form again through the season as in 1991 and 1992 (Figs. 8-11). However the formation of the first aggregation of the season appears to be less precise in timing with respect to lunar phase. For example at Scott Reef in 1992 (Fig. 9), numbers of trout began increasing on the new moon in August, at which time spawning rushes were seen. Numbers then continued to rise through the full moon period of early September at which time spawning was also observed, with numbers peaking on the new moon in September. Thereafter aggregations corresponded closely with the new moon phase. This pattern of a more gradual build up of the first aggregation followed by more tightly defined second and third aggregations corresponding to the new moon is also apparent at Elford Reef in 1992 (Fig. 11) and at both reefs in 1991 (Figs. 8 & 10). The single major aggregation in October 1990, despite an apparent earlier aggregation in September, also reflects a gradual rise in numbers: from early October on the full moon, to numbers peaking around the new moon, spanning the third and first quarters (Fig. 7).

In general, the first increase in trout numbers for the season corresponded with water temperatures rising above 24°C as the winter season of southerly weather came to an end. Usually this occurred in September. This is particularly apparent in 1992 where temperatures rose earlier, in August, and a correspondingly early rise in trout numbers was recorded (Figs. 9 & 11). In both 1990 and 1991 temperatures did not exceed 24°C until September (Figs. 7 and 8).

The timing of formation of aggregations on the two spawning sites was very similar. Even though the site on Elford was disrupted in 1992 by tagging, three aggregations formed in a similar pattern to that observed at Scott Reef. In each year aggregations peaked in October-November. However the maximum number of fish in the aggregations differed considerably

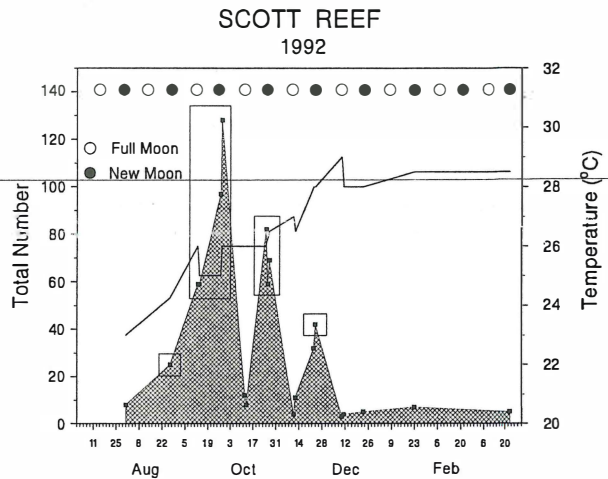


Figure 9 Numbers of coral trout seen at dusk on the Scott Reef aggregation site in 1992.

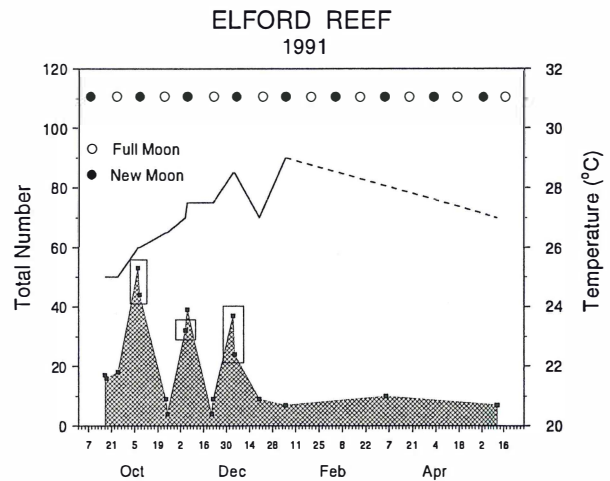


Figure 10 Numbers of coral trout seen at the Elford Reef aggregation site at dusk in 1991.

between the two reefs, with greater numbers recorded at Scott Reef. The highest number recorded was 128 trout at Scott, in 1992, and the highest number at Elford was 57, also in 1992.

(ii) *Daytime counts.* The stability of the aggregations was assessed by comparing visual census counts conducted at different times of the day (Figure 12). The data are sparse for Elford Reef ( $n = 2-3$ ) because tagging in 1992 disrupted the counts; they are included simply for completeness. The graph shows that the aggregations, at least at Scott Reef, were not well established in the morning. The average number of trout differed significantly between morning and dusk ( $t = -4.19$ ; d.f. = 10;  $p = 0.002$ ). By the afternoon the aggregations had stabilised, and there was little difference in the total number of fish between afternoon and dusk ( $t = -0.98$ ; d.f. = 7;  $p = 0.36$ ). Elford Reef data were not analysed because of the small number of replicates.

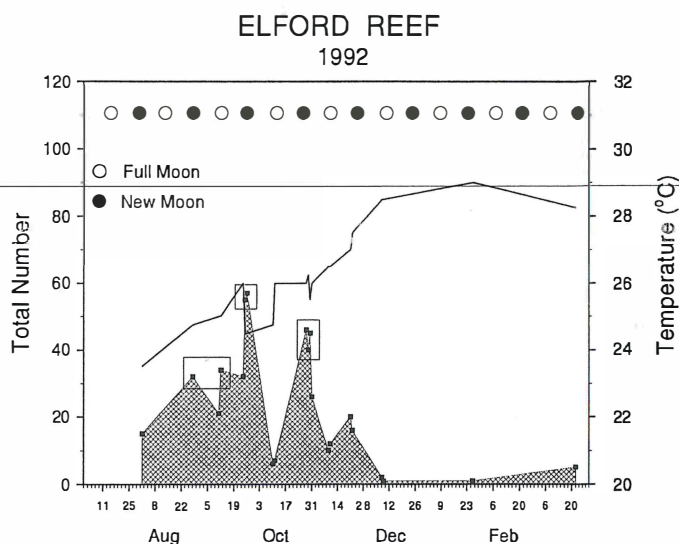


Figure 11 Numbers of coral trout seen at the Elford Reef aggregation site at dusk in 1992.

### 2.3.1.2 Spawning Behaviour

Spawning was observed on our first attempt to monitor trout behaviour until darkness, at Scott Reef in 1990. *P. leopardus* spawned in pairs, by swimming up from the bottom in a classic spawning "rush". This consisted of a fast, often high, ascent, at the peak of which both fish turned abruptly and at this point presumably released gametes. The gamete cloud was not visible but its presence was assumed both by the characteristic behaviour pattern and the frenzied feeding activity of planktivorous fusiliers (*Caesio spp.*) often observed at the peak of the spawning rush. The evenings on which spawning was observed are shown as boxed areas on Figs. 7-11. In most cases spawning corresponded with the occurrence of aggregations which were primarily during the new moon phase. However spawning rushes also occurred when trout numbers were low at new moon (e.g. in September 1991 at Scott Reef), and rushes were not observed on occasions when trout were aggregating, (e.g. during part of September 1991 at Scott and November 1992 at Elford). The latter results are not conclusive, because visibility at dusk was poor.

In 1990 spawning was not observed until 19 October, the first day we remained on site until darkness. Thereafter it became apparent that spawning occurred during a narrow time window (30-40 minutes) around sunset. It is therefore almost certain that earlier censuses in 1990 would have failed to document some spawning rushes. The height of the rushes above the reef bottom varied from approximately 2 m to 12 m, and the proximity of the top

of the rush to the sea surface varied considerably.

Spawning behaviour involves a specific courtship display, in which the male swims towards a female with his body tilted at 45°-90°, quivering along his full length, and making repeated lateral shakes of the head. Continuing in this mode, the male approaches the female and then passes close to her head or body, with either the dorsal or ventral side of his body nearest to the female. He frequently circles and repeats the process.

Spawning rushes were always observed after courtship, although courtship did not always elicit rushes. All male *P. leopardus* seen courting or in spawning rushes exhibited a specific colour pattern of blackened caudal, dorsal and ventral fin edges (Fig. 13). Males could switch this colour pattern on or off instantly. Fish size also provided an indication of sex because of the coral trout's protogynous hermaphroditic development - larger fish tend to be male, smaller fish female.

Courtship displays were seen constantly throughout the aggregation periods, and always when rushes were seen. Courtship displays were also seen at other times when fish were not aggregating, or on the full moon, and during daylight hours. However rushes were never seen during daylight hours.

Some individuals spawned more than once in an evening, with individual males observed to spawn as often as four times, and individual females as often as three times. One pair was seen together spawning three times in the same evening. In these cases, the observer fixed upon the same individual(s). On rare occasions a second male was seen to join a spawning pair. This behaviour, termed "sneaky" spawning, occurs quite frequently in fishes (Turner 1986). On one occasion a sneaky female was seen; this has rarely been recorded in the literature.

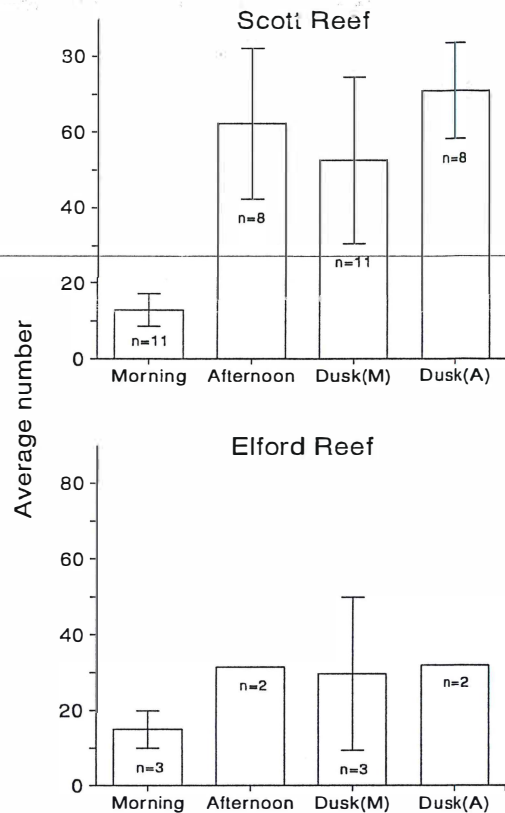


Figure 12 Number of trout on Scott and Elford Reefs aggregation sites in the morning, afternoon and dusk.



Figure 13 Male *Plectropomus leopardus* showing typical courtship markings of darkened fin edges.



A repetitive pattern was observed in the behaviour of trout during peak aggregation periods. The following description refers to Scott Reef aggregation site in 1990, starting 1 - 1.5 hr before sunset; similar behaviour was seen at Elford and in different years. Large fish (around 51-55 cm FL), presumably males, were very active, moving back and forth along the coral wall at the site, and frequently showing aggression towards each other. This behaviour involved chasing, jaw locking and form of less exaggerated courtship display. Smaller fish (around 31-40 cm FL), presumably female, remained on top of the wall on the reef plateau during that time. Periodically males would swim up and court the females, but without eliciting reactions. Some larger females (>40 cm FL, recognised as female from male courting behaviour) remained deeper on the walls among the active males, but again were unresponsive to the males' courting displays. At approximately 30 minutes prior to sunset, some males started exhibiting territorial courtship behaviour. Such males established a temporary territory and exhibited aggressive postures to other males. The territories were of approximately 25 m<sup>2</sup> and were observed primarily on the reef plateau, but also on one wall. Just prior to sunset, a territorial male would start patrolling and courting females within his territory, and would continue until dark. The number of females counted in each territory was between two and five. These figures are probably underestimates, since females were generally inactive, remaining stationary near the reef bottom, and consequently often difficult to detect against the coral background. Responsive females moved off the reef bottom becoming easily discernible above the coral, and swam slowly, until stimulated to participate in a rush. Territorial males participated in at least 75% of the rushes observed between 17 and 26 Oct 1990. By 15 min. after sunset females were no longer visible in the territories, but male courtship continued until dark (approx. 20 min. after sunset), presumably to females hidden in the coral. Once it was dark, searches by torchlight did not reveal any coral trout out in the open.

### 2.3.1.3 Secondary aggregation site identification

Having determined that aggregations are well established by the afternoon, snorkel diving surveys of neighbouring reef areas were carried out in the afternoon (after 1230 hr). At Scott Reef, surveys located one other "major" aggregation site 1 km from the primary aggregation site. Fish collected from this location were used in projects to verify sex and colour pattern, and in fertilization and larval rearing experiments (Rimmer *et al.* 1994) so as to avoid disrupting the primary aggregation site. Another aggregation site was located on Scott Reef, where spawning behaviour was seen, though numbers of trout were not as great as on the primary site. These "secondary" aggregation sites are being monitored in detail as part of a continuing research project. Results so far suggest these aggregations are more variable than at the primary site, and do not always occur when predicted.

At Elford Reef no other major aggregation sites were located within the 2 km<sup>2</sup> area around the primary site. However sites were found at the south western end of the reef which is characterised by a series of channels cutting through the reef edge. Again spawning behaviour was seen, though aggregations were smaller than at the primary site. These secondary aggregation sites are also being monitored in detail as part of the ongoing research project. Subsequent searches (in 1993) have located smaller aggregations on spurs on the seaward edge of the reef near the primary site. As at Scott Reef, the secondary sites on

Elford appear to be more changeable than the primary site, and not always present when anticipated.

Spawning behaviour was seen at other locations, where there was no evidence of an aggregation. Courtship behaviour was observed, but not spawning rushes. The numbers of fish in such situations rarely exceeded one male and between one and four females.

## 2.3.2 Reproductive development

### 2.3.2.1 Gonad anatomy

The gonads of male and female *P. leopardus* consist of two elongated lobes, usually unequal in size, and joined posteriorly into the common duct. The gonad is formed by a germinal epithelium extending from the dorsal and lateral gonad walls into the central lumen. The gonad wall comprises smooth muscle and connective tissue covered by a peritoneal layer. It is attached dorsally to a complex net of mesenteries, ligaments, arteries and veins. The left lobe is connected by these mesenteries to the dorsal body wall and to the right lobe, which is also attached by the same mesenteries to the intestine and other organs in the coelomic cavity. Fat is deposited along the mesenteries in quantities varying from nil to a thick layer covering the entire viscera. Macroscopic sex determination is possible only if gonads are active. Resting gonads are not greatly reduced in length, but are much more slender. Male and female gonads during this stage are difficult to tell apart.

The germinal tissue is of the undelimited or *Epinephelus* type (Smith 1959), with intermingling of ovarian and testicular tissues. All male gonads examined had a remnant ovarian lumen and sperm sinuses located in the dorsal part of the gonad wall. Sperm is carried not in the remnant ovarian lumen, but rather in dorsal sinuses formed by the splitting of muscle layers of the ovarian capsule. Within the testicular lobules, central sinuses are formed by the rupture of crypts of spermatozoa, and join the dorsal sperm sinuses.

### 2.3.2.2 Macroscopic staging

Ovaries were considered to be mature when in stages IV-IX (NFC). These stages included yolk globule vitellogenic or atretic oocyte stages which were indicative of maturity in scombrids (Schaefer 1987, McPherson 1991, McPherson in press) and lutjanids in Great Barrier Reef waters (McPherson *et al.* 1992).

The reliability of macroscopic assessment of maturity in ovaries was estimated with respect to the histological assessment of maturity which was assumed to be free from error. Stage I virgin females were considered easy to identify as their thin strap-like gonads could not be mistaken for resting non-mature ovaries or ovaries developing for the first time.

If a gonad was assessed macroscopically as immature (i.e. macroscopic stages II and III), there was a 12% chance ( $23/(23+163) = 0.12$ ) that the assessment would be incorrect (Table 10). However if an ovary was macroscopically determined to be mature (macroscopic stages

IV to IX), there was a 98% chance ( $653/668 = 0.98$ ) that the assessment would be correct. Therefore mature females could be macroscopically assessed reliably when histological material was not available.

**Table 10** Probability table for macroscopic identification of sexual maturity in *P. leopardus*.

Macroscopic category	Histological assessment	
	Immature	Mature
Stages II and III (immature)	0.88	0.12
Stages IV to IX (mature)	0.02	0.98

### 2.3.2.3 Sex transition - histological evidence

Histological examination at NFC of the gonads of 2,358 *P. leopardus* collected from the Cairns and southern GBR regions provided clear evidence that *P. leopardus* is a protogynous hermaphrodite. Identification of the earliest stages of protogynous sex change relied on a cytological assessment of the status of primary or stem germ cells. The early meiotic stages of oocytes and spermatozoa were identified from figures and descriptions for lampreys (Hardisty 1965) and a protogynous labrid fish (McPherson 1977).

Identification of primary germ cells in mitotic prophase, or in the earliest stages of chromatin arrangement prior to or during the sex-determining meiotic cell division requires well-preserved material. As many specimens were not preserved until several hours after capture, accurate identification of the status of early germinal cells was difficult, and the frequency of early changing fish may therefore have been underestimated.

The most obvious sign of protogynous sex change in *P. leopardus* is the presence of variable numbers of late diplotene stage oocytes present within the connective tissue of the testes. The 'brown bodies' referred to in numerous studies on protogynous species as indicating a recent sex change (on the assumption that they were atretic or degenerative oocytes) were commonly observed in the gonads of *P. leopardus*. As many of these fish were clearly not in sex-changing mode, we do not consider 'brown bodies' to be indicative of sex change in this species.

In only 1% of the 596 testes examined histologically were late diplotene oocytes absent, and in one third of these only a single section was examined. The appearance of the testes in all these instances was consistent with those of secondary male testes; there was no suggestion of a primary male phase in *P. leopardus*.

Analysis of tissue sections established six histological categories of sex change in *P. leopardus* which are summarised in Table 11. These histological categories were grouped as three functional sex categories: female, uncertain, and male, which were appropriate for use during the annual spawning season of the species. A functional female gonad could

include females showing no sign of sex change, or a gonad histologically determined to be changing sex when either mature female tissue predominated, or was in an immediate pre or post-spawning condition despite having spermatogenic tissue including spermatozoa.

**Table 11.** Categories for the histological description of the sex change of *P. leopardus* and corresponding functional sex categories.

Histological category	Histological description	Functional category
FF - Female - no change	No cytological evidence for sex change	Female
IE - Intersex - early	Ovarian tissue with scattered groups of spermatogonia, both primary and secondary, scattered throughout the ovary.	Female
IL - Intersex - late	Predominantly ovarian tissue with spermatogonia, as well as spermatocytes and, or spermatogonia present.	Female
IU - Intersex - uncertain	Difficult to identify whether gonad is predominantly ovarian or testicular. Often gonad primarily connective tissue with scattered crypts of spermatogenic material.	Uncertain
MR - Male - recent	Predominantly spermatogenic material with spermatozoa commonly in body of gonad, as well as in the peripheral collecting ducts. Mature oocytes may be present, late diplotene oocytes common at frequency of > 10 per field of view at 400 magnification.	Male
ME - Male - established	Functional testicular material. Number of diplotene oocytes < 10 per field of view at 400X.	Male

The earliest category of sex change, intersex-early (IE), occurred when spermatogonia were evident within germinal cell areas. The next category in the sex change sequence, intersex-late (IL), demonstrated the presence of all spermatogenic stages, from spermatogonia to spermatozoa.

The intersex-uncertain (IU) stage was represented by a very small number of fish. The sections could not be readily identified as predominantly either female or male and usually featured considerable areas of connective tissue between germinal areas. The paucity of specimens at this stage of development suggests that it may be an artefact or an aberrant form of sex change.

The length distribution of Cairns fish histologically categorised by the above scheme is given in Fig. 14. Fish appear to change sex throughout the entire length distribution of the species as the length distribution of IE and IL females closely resembled that of FF non-changing females. The distribution of MR males which are considered to be the most recently transformed stage, is only slightly skewed to the right of the females and IE and IL females. The distribution of established males ME is clearly skewed to the right of length distributions of all other sex categories. The reliability of the macroscopic techniques used to determine the functional sex of a gonad was estimated (Table 12) with respect to the histological assessment of reproductive status which was assumed to be free from error. When all samples throughout the study were combined, if a gonad was macroscopically determined to be a functional female, there was a 94% chance (i.e.  $1077/(1077+71)$ ) that the assessment would be correct. However if a gonad was macroscopically determined to be a functional male or uncertain intersex, there was a 26% chance ( $133/515$ ) that the assessment would be incorrect. Therefore functional females could be macroscopically assessed more reliably than males.

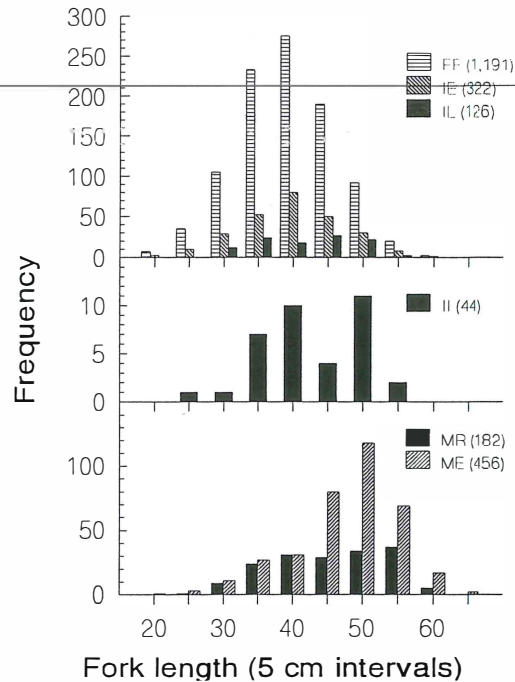


Figure 14 Size distribution of female (top), uncertain sex (centre) and male (bottom) coral trout.

The length at which sex change occurred in *P. leopardus* was examined by considering the length of IE females throughout the year (Fig. 15). ANOVA failed to demonstrate any significant differences between length at sex change and time of year. While IE fish were close to a significant difference ( $P=0.06$ ) in December, the mean size of fish sampled in this month was significantly less ( $P<0.05$ ) than in other months. Therefore the reduced mean size at sex change for the month was more likely to be due to a variation in the length distribution of the monthly sample. The mean length at earliest sex-change was 42.2 cm ( $n=322$ , S.E.=0.3) with a range from 22.5 to 61.5 cm.

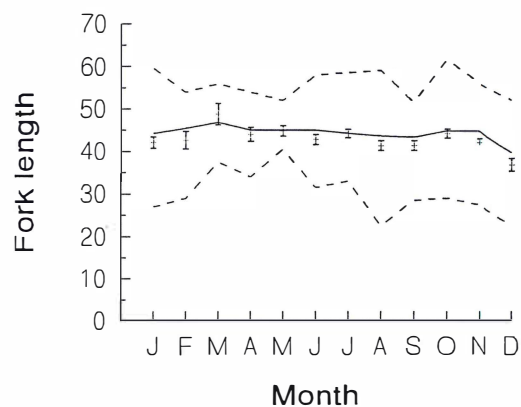


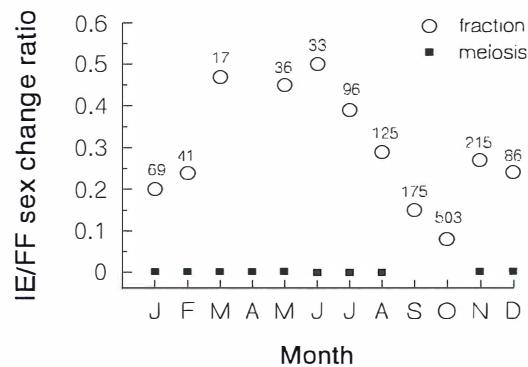
Figure 15 Monthly change in mean length of early sex-change coral trout. Solid line - mean length of all fish; dashed line - length range of IE females.

**Table 12.** Probability table for identifying the sex of *P. leopardus* from macroscopic examination.

Macroscopic category	Histological assessment	
	FF+IE+IL	IU+MR+ME
Female	0.94	0.06
Male and uncertain	0.26	0.74

The occurrence of sex change commencing in the ovaries of individuals in the population is expressed as the ratio of early changing females to non-changing females; i.e. IE/FF females. This proportion varied considerably throughout the year being highest in the autumn and early winter months of March to June (Fig. 16). The months when sex change appeared to be at its lowest level was in September and October. It is during the latter two months that oocyte meiosis figures were not identified in histological sections.

Transitional gonads that resembled immature ovaries were observed during and outside the spawning season (JCU). Individuals observed during the spawning season (n=7) were aged between 2 and 3 years (mean=2.7, s.e.=0.184) and measured between 26.9 and 36.2 cm (mean=33.1, s.e.=1.37), indicating the possibility of prematurational sex-change.



**Figure 16** Ratio of IE/FF female *P. leopardus*, and occurrence of meiotic prophase figures by month.

A few precocious sperm crypts (*sensu* Smith 1965) were observed in the ovaries of some resting females from Townsville and Lizard Is. Transition was clearly indicated only when proliferation of sperm crypts was more advanced and accompanied by fragmentation and reabsorption of previtellogenic oocytes. Transitional gonads typically had a large number of germ cells, presumably spermatogonia. Proliferation of sperm crypts was concentrated in the dorsal part of the gonad, apparently in close association with the stromal tissue. Stromal cells were conspicuous during this phase and seemed to be undergoing proliferation.

During the spawning season, sperm crypts were observed in the ovaries of some mature ripe females in the Townsville region (n=5). These sperm crypts were in all stages of development, from primary spermatocytes to spermatozoa. Vitellogenic oocytes were in the final stages of development, and showed no signs of degeneration, though fragmenting previtellogenic oocytes were observed. No sperm sinuses were formed, indicating that in spite of the presence of spermatozoa, these individuals probably would not spawn

The parameters of the logistic relationship (Saila *et al.* 1988) between fish length and the proportion of mature ovaries from the Cairns area are given for the months from August to December (Table 13). The length at 50% maturity ( $l_m$ ) and asymmetric standard error, and  $R^2$  of the model are given along with the minimum observed length at maturity, and spawning as determined by the presence of stage 7 hydrated ovaries, or postovulatory follicles.

There was a substantial variation in  $l_m$  during the months when mature fish were sampled. During August it was apparent that larger fish matured earlier than smaller fish, the  $l_m$  for this month being substantially larger than samples taken in September. The estimated  $l_m$  for September and October were comparable, and lower than August which corresponded with substantially lower observed lengths at first maturity. Observed lengths at spawning during these months varied between 26 and 30 cm.

While the observed minimum lengths at maturity (and spawning) of individual fish remained comparable in November and December, the  $l_m$  for the monthly samples rose back to the August estimate when spawning did not occur.

There was insufficient data to determine  $l_m$  for southern GBR *P. leopardus*. The observed minimum lengths at maturity and spawning are given in Table 13. Fish were mature and spawning by October, with spawning events occurring into February. The minimum length

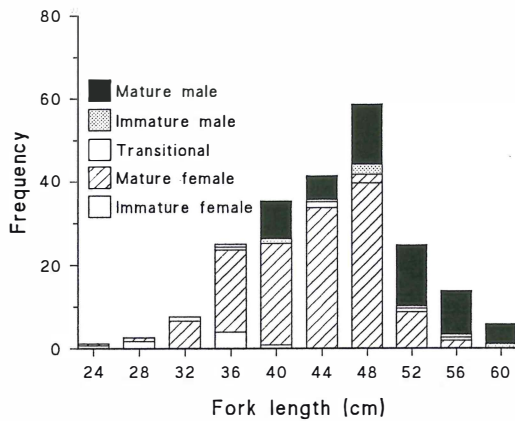
**Table 13.** Lengths at 50% maturity ( $l_m$ ) and minimum observed lengths of maturity and spawning for *P. leopardus* for Cairns and southern GBR areas for months when mature ovaries were sampled.

Month	$l_m$	(se)	$R^2$	Minimum FL		Sample size
				Mature	Spawn	
<b>CAIRNS</b>						
August	39.5	(0.76)	0.92	32.5	---	121
September	27.5	(1.77)	0.79	26.0	30.0	245
October	28.2	(1.34)	0.89	21.0	26.0	749
November	33.4	(1.76)	0.84	25.0	30.5	325
December	41.9	(2.70)	0.77	24.5	29.5	118
<b>STHN GBR</b>						
August				---	---	35
September				---	---	9
October				31.0	36.0	2
November				27.5	27.5	71
December				---	---	0
January				36.0	36.0	16
February				45.0	45.0	5

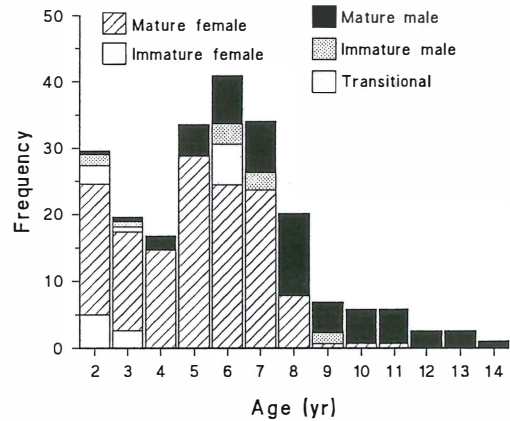
at spawning observed for November of 27.5 cm was directly comparable to the Cairns area of 26.0 cm. The observed estimates of the length at maturity are not considered to be indicative as the southern GBR sample was taken entirely by line.

Analysis of the length-at-age data from the Cairns region (see later section) indicated that *P. leopardus* becomes sexually mature in its second year. A small number of mature one-year-old fish were found, but their otolith structure indicated that they were nearly two years old.

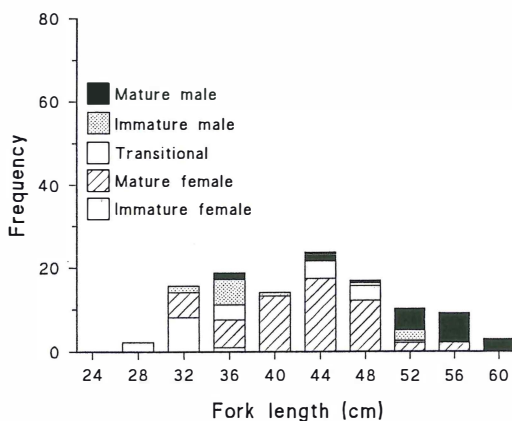
The size class of first reproduction (50% of individuals reproductive) for females was 32 cm FL (30-34 cm) for Lizard Is (Fig. 18) and Townsville (Fig. 20) (JCU). The age of first reproduction for females was 3 years in the Lizard Is sample (Fig. 19) and 2 years in the Townsville sample (Fig. 21).



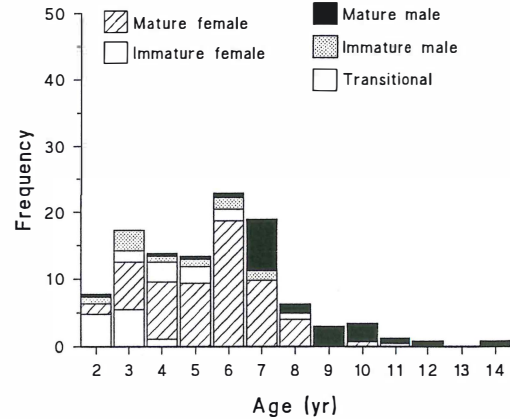
**Figure 18** Proportion of gonad development stages by size (FL) for coral trout at Lizard Is.



**Figure 19** Proportion of gonad developmental stages by age for coral trout from Lizard Is.



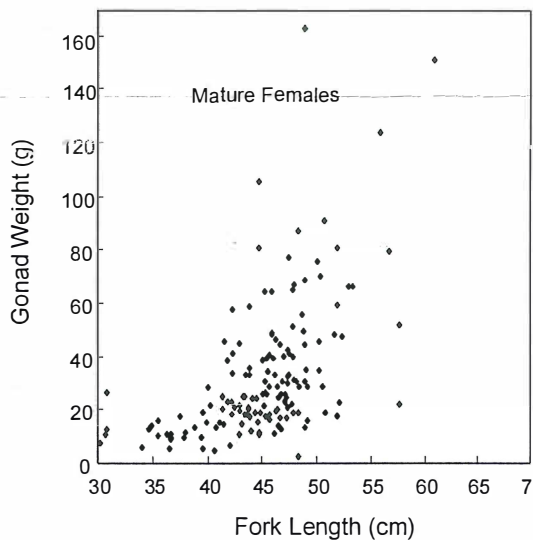
**Figure 20** Proportion of gonad development stages by size (FL) for coral trout in the Townsville area.



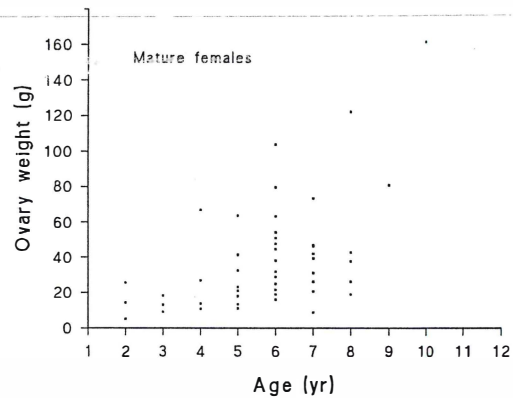
**Figure 21** Proportion of gonad developmental stages by age for coral trout in the Townsville area.



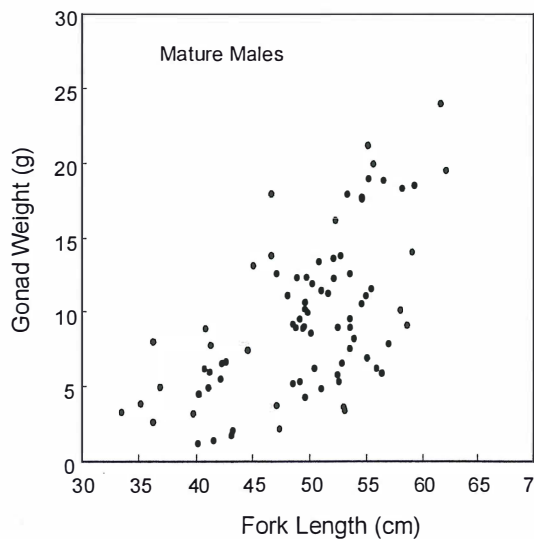
Gonad weight was positively related to age and size for mature males and females ( $p < 0.0001$ ) (Figs 22-25). Some females were mature at 30 cm FL but gonad weight started to increase only after 40 cm FL (Fig. 22).



**Figure 22** Relationship between ovary weight and fork length.



**Figure 23** Relationship between ovary weight and age.



**Figure 24** Relationship between testis weight and fork length.



**Figure 25** Relationship between testis weight and age.

### 2.3.2.5 Spawning fraction

The spawning fraction of fishes is one of the prerequisite parameters for the egg production method of biomass estimation (Hunter and Macewicz 1985). In this study it was used to estimate the period of peak reproductive activity of *P. leopardus*.

### Hydrated oocyte method

For the spawning fraction to be calculated it must be demonstrated that hydrated oocytes are formed during a single time frame in a 24 hour day, followed by ovulation (Hunter and Macewicz 1985). Eleven histological stages of oocyte development were identified in the ovaries of *P. leopardus*, similar to those described by McPherson (1991). These stages fell into three categories: oogenesis and vitellogenesis (pre-maturation categories) and a final maturation category represented by six oocyte stages. The latter were (in chronological sequence) tertiary yolk globule (TYG), migratory nucleus (MN) and the hydration stages H1, H2, H3 and H4. The time of their occurrence as the most advanced oocyte stage within each ovary histologically examined is given in Fig. 26.

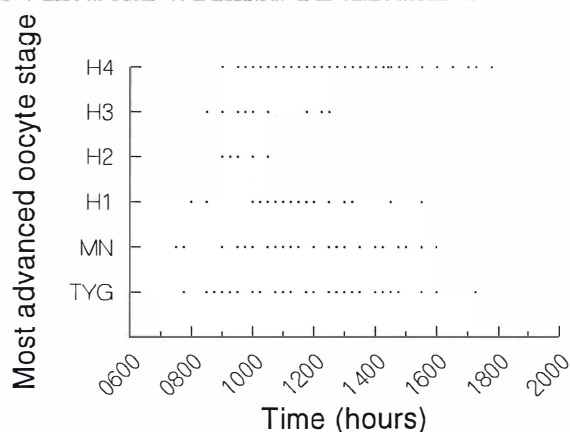


Figure 26 Relationship between the occurrence of the final oocyte maturation stages and sampling time for *P. leopardus*.

The earliest of the final maturation stages were observed between 0730 and 1730 hours, although they appeared more frequently prior to early afternoon (1400 hours). A similar pattern was apparent for MN and H1 stages. Stages H2 and H3 were only rarely recorded as the most advanced final maturation stage. The most advanced final maturation stage (that is, H4) was first observed around 0900 hours and was commonly observed throughout the day until early evening.

Compared to yellowfin, bigeye and narrow barred Spanish mackerel (McPherson 1991; McPherson in press) the final maturation stages were far from synchronised during the day. It appeared that commencement of final oocyte maturation could occur throughout the day, although predominantly during the morning and early afternoon. The final H4 stage was clearly more common in the afternoon.

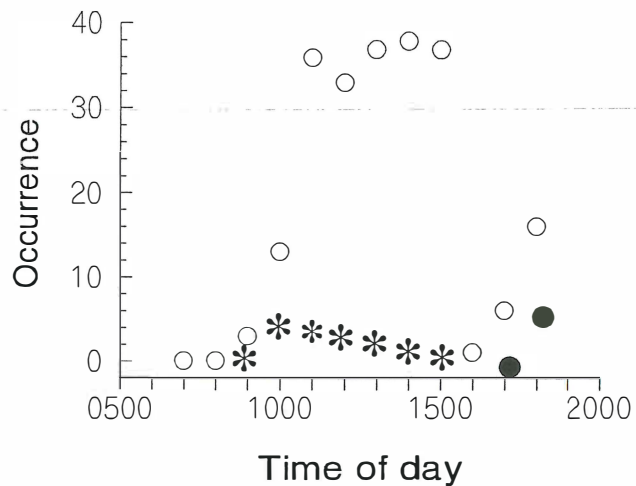
The relative scarcity of H2 and H3 stages and the rarity of clearly identified migratory nucleus figures (Hunter *et al.* 1986; Schaefer 1987) suggest that the final oocyte maturation is far more rapid in *P. leopardus* than other species studied. However there were sufficient data available to confirm that a single batch of oocytes hydrate within a 24 hour period, and that the hydrated oocyte method can be used to estimate spawning fraction and spawning frequency.

### Postovulatory follicle method

Three age groups of postovulatory follicles (POFs) were observed in ovaries of *P. leopardus*. They were classified as early, middle and late according to Hunter *et al.* (1986), Schaefer (1987) and McPherson (1988). The relationship between the occurrence of POF's and time of sampling is given in Fig. 27.

The early POFs were restricted to early evening samples. The mid age POFs were distributed between the morning and early afternoon samples, while the late follicles were in ovaries throughout the day. The dominant peak of late POFs occurring between approximately 1000 and 1500 hours, and the secondary peak after 1600 hours was probably related to sampling effort.

The restricted presence of early POF's to early evening is consistent with early POFs in scombrids (McPherson 1992; in press) and in lutjanids (McPherson *et al.* 1992) indicating that a spawning peak occurred around this time. Mid age POFs were not often encountered, as relatively few samples were taken during early morning hours and none during the hours of darkness. A reduction in their occurrence was apparent by the early afternoon.



**Figure 27** Time of occurrence of three POF-types throughout the day. Closed circles=early POFs; asterisks=mid-age POFs; open circles=late POFs.

The maximum age of identifiable POFs was at least in the order of 24 hours. With spawning confined to a specific period of the day, this technique could be used to determine the spawning fraction of *P. leopardus*.

It was not possible to determine the proportion of POFs resorbed within 24 hours of formation. With sampling conducted between 12 and 24 hours after spawning, (daylight hours on the day after the early evening spawning), resorption of POFs in less than 24 hours would lead to an underestimate of spawning fraction by this method.

#### *Spawning fraction for coral trout in the Cairns region*

The spawning fractions of *P. leopardus* sampled in the Cairns region are calculated by the POF and hydrated oocyte methods for 1989 and are given in Fig. 28. Both methods indicated a peak in spawning fraction in the seven day period leading up to the new moon in October. Both methods also demonstrated a second peak of spawning, although not as high as the first, during the seven day period after the November new moon. Spawning then tailed off over the following 14 or 21 days depending on the method.

The spawning fraction estimated by the POF method occurred at a lower rate between the two new moon periods, with a secondary peak apparent centred about the full moon period. The hydrated oocyte method however did not demonstrate any clear trough in spawning fraction between the two new moon periods.

Spawning fractions were highly variable, but no significant differences existed between the spawning fractions of the sequential moon day periods for either method as the spawning season progressed (chi<sup>2</sup> differences between proportions,  $P > 0.05$  - where sample sizes were sufficient).

The spawning fractions from samples taken in the Cairns region during 1990 estimated by the POF and hydrated oocyte methods also indicated that a significant peak in spawning occurred around the period of the new moon in September. However spawning did occur after the previous full moon, 7 to 14 days before the September new moon period (Fig. 29). As in 1989, spawning occurred between the new moons, and the spawning fraction was higher for one new moon period. The 1990 data differed from the 1989 data in that the peak spawning fraction occurred on the later new moon. Spawning fractions were also highly variable and no significant differences were detected between the spawning fractions of the sequential moon day periods for both methods as the spawning season progressed (chi<sup>2</sup> differences between proportions,  $P > 0.05$  - where sample sizes were adequate).

Charter vessel operators in the Cairns region reported isolated spawning activity of *P. leopardus*, as evidenced by hydrated ovaries, occurring in December and January after the 1989 season and in November after the 1990 season. This spawning activity appeared to be isolated as sampling the same locations on successive days did not provide evidence for spawning activity more than two days.

The largest collection of data was made during the moon days 78-85, 85-91 and 92-98 after the July new moon in 1990, i.e. the 7 day period prior to the October new moon, the 7 day period after, and the 7 to 14 day period after the new moon in October. The spawning fraction estimates of three size classes (that is,  $> 30$  to  $\leq 40$ ,  $> 40$  to  $\leq 50$  and  $> 50$  to  $\leq 60$  cm) from both methods did not differ significantly (chi<sup>2</sup>  $P > 0.05$ ) between these three moon periods. The spawning fraction of the three 10 cm length classes did not differ between these moon day periods (chi<sup>2</sup> differences between proportions:  $P > 0.05$ ). During the peak of the spawning period, at least, smaller *P. leopardus* did not spawn at a significantly different rate than larger fish.

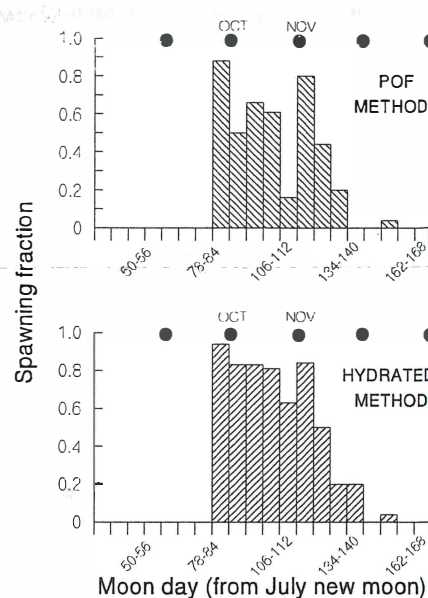


Figure 28 Changes in estimated proportion of female coral trout spawning by lunar week. Cairns; 1989 data.

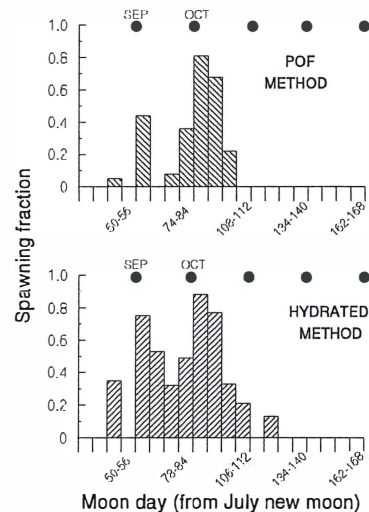


Figure 29 Changes in estimated proportion of female coral trout spawning by lunar week. Cairns; 1990 data.

Despite the estimates of spawning fraction being based on histological analyses of the same samples for both methods, the estimates of spawning fraction differed. The estimates made by the hydrated oocyte method were consistently higher than those by the POF method. The reason for this differential is not known: neither method is considered to be more accurate or precise than the other. Differential feeding behaviour of females, hence catchability, either prior to or after spawning (Hunter and Macewicz 1985; McPherson in press), variable longevity of POFs between individual fish etc are possible reasons.

Monthly and annual mean spawning fractions estimated by the POF and hydrated oocyte methods for the 7 day moon day periods during the 1989 and 1990 seasons (Figs. 28 and 29) are shown in Table 14. The spawning fractions for each season estimated by the hydrated oocyte method were consistently higher than the estimates by the POF method.

**Table 14.** Spawning fraction by 7 day moon day period and mean total for spawning season estimated by the POF and hydrated oocyte methods. Standard errors of mean total are given. Spawning commenced in 1989 and 1990 during the 7 day moon periods 78 to 84 and 43 to 49 days after the new moon in July respectively.

Moon day period	1989		1990	
	POF	HYDRATED	POF	HYDRATED
1	0.88	0.94	0.05	0.35
2	0.50	0.83	0.00	0.00
3	0.60	0.83	0.44	0.75
4	0.61	0.81	0.00	0.53
5	0.16	0.63	0.08	0.56
6	0.80	0.84	0.36	0.51
7	0.44	0.50	0.81	0.94
8	0.20	0.20	0.68	0.85
9	0.00	0.20	0.22	0.44
10			0.00	0.21
n	205	205	386	386
MEAN	0.52	0.76	0.40	0.67
(se)	(0.11)	(0.06)	(0.12)	(0.08)

Individual *P. leopardus* demonstrated the ability to spawn on successive evenings. This was indicated by the proportion of pre-spawning (hydrating) ovaries indicative of imminent spawning, with POFs indicative of recent spawning, compared to the proportion of pre-spawning fish not in a post-spawning condition. Table 15 gives the proportion of pre-spawning ovaries observed to be in a post-spawning condition. The proportion of fish during the 1989 and 1990 spawning seasons that were successive spawners was very high, ranging primarily between 0.83 and 1.0 with a low proportion of fish within a 5 cm length class of 0.66 (with a very small sample size).

**Table 15.** Proportion of successive evening spawning *P. leopardus* ovaries in by length class.

Length range	Number post-spawning	Number not pre-spawning	Proportion
60.5 - 65.0	2	1	0.66
55.5 - 60.0	5	1	0.83
50.5 - 55.0	28	2	0.93
45.5 - 50.0	63	2	0.97
40.5 - 45.0	68	5	0.93
35.0 - 40.0	50	4	0.93
30.5 - 35.0	19	1	0.93
25.5 - 30.0	7	0	1.00

### 2.3.2.6 Location of spawning

*P. leopardus* in spawning condition did not appear to be restricted to specific localities such as reef crests, reef slopes, emergent reefs or inter-reef waters. Fig. 30 shows the mean and maximum depths at which immediate pre- and post-spawning females were captured in each of three distance intervals from the reef crest. These distance intervals or zones were 0.0-0.5 km, 0.5-1.0 km, and >1.0 km. Only fish estimated to be less than 10 hr pre-spawning or 24 hr post-spawning were included in this analysis.

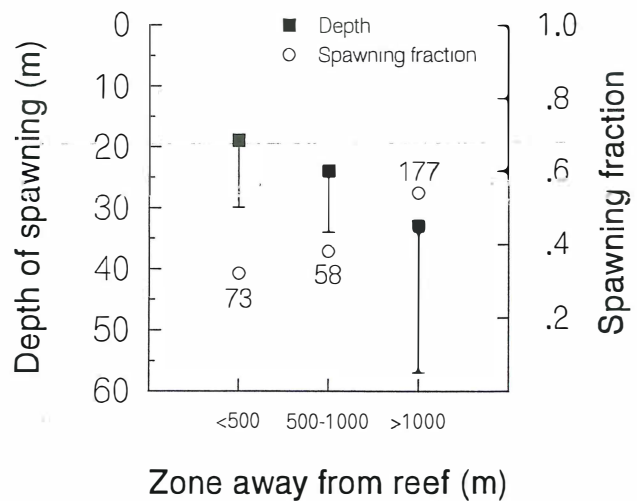


Figure 30 Relationship between spawning fraction, depth and distance from the reef crest.

The proportion of fish in the catch which were in spawning condition increased with increasing distance

from the reef crest. Samples were taken from as far as 10 km from the nearest reef crest, and most line-caught samples from the >1.0 km zone were from more than 2 km from the nearest reef crest. The spawning fraction (hydrated oocyte method) increased away from the reef crest zone and was highest in the >1.0 km zone.

A small spawning aggregation, consistent with that described by Samoily and Squire (1993), was observed using scuba-diving at North Point, Lizard Island, on the 5th of November 1991, approximately half an hour before sunset. Three females and one male were captured at sunset. Two of the females were running ripe, with the ovarian lumen full of eggs, and the other one had hydrated oocytes. Histologically, the male was ripe but only a small amount of milt could be obtained.

### 2.3.2.7 Reproductive chronology

Before the spawning season, ovaries of immature females showed no evidence of prior spawning (JCU). The lamellae were filled with previtellogenic oocytes in early and late perinucleolus stages and abundant oogonium and chromatin nucleus stages. During the spawning season, however, some immature females were observed undergoing vitellogenesis, as indicated by the presence of yolk oocytes in early stages, but no actual spawning was detected and gonads remained small. After the spawning season, it is possible that signs of previous vitellogenesis remained, in the form of scattered yolk globules or brown-bodies, making it difficult to separate these immature gonads from mature resting gonads. Therefore, for the calculation of size and age of first maturity, only immature individuals classified during the spawning season were included.

Analysis of gonad stages and gonosomatic indices indicated that spawning occurs between September and December in both the Lizard Island and Townsville regions. There were no significant differences between GSI values observed for Townsville and Lizard Island Reefs. GSI values of females were significantly higher than those of males, and both varied equally between months in the two locations (Table 16; Figs. 31 and 32). There was a significant increase from August to the peak in October, with values remaining high until November and dropping significantly by December (Tukey-Kramer,  $p < 0.05$ ).

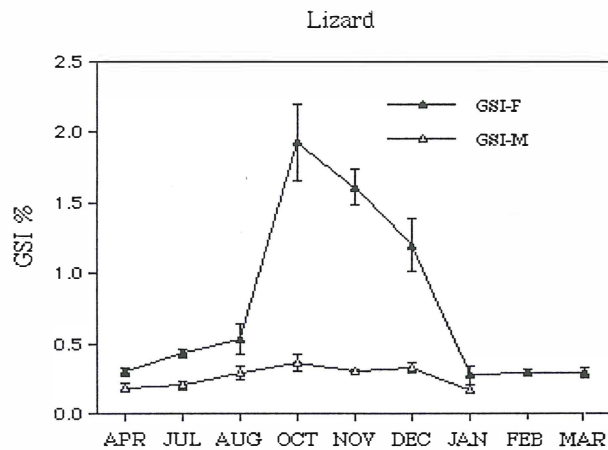


Figure 31 Seasonal variation in GSI of *P. leopardus* at Lizard Is.

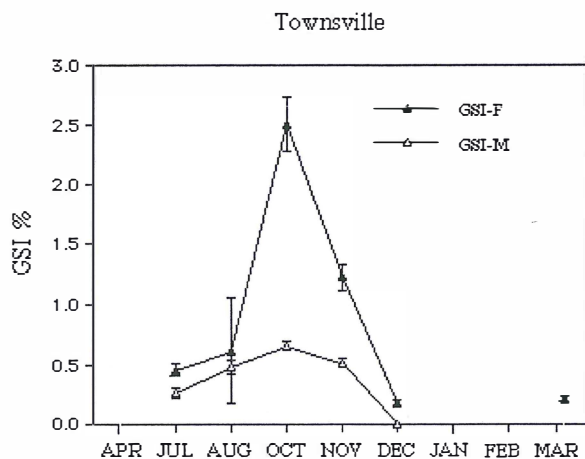


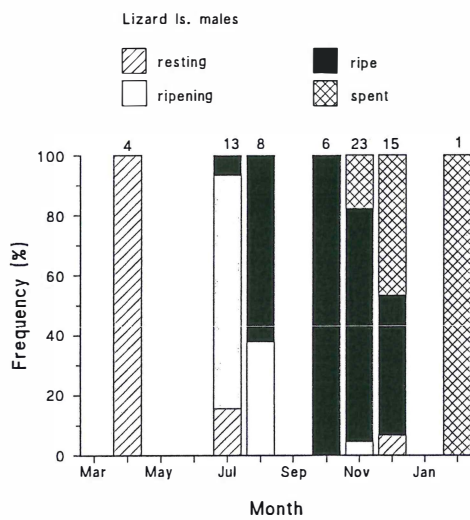
Figure 32 Seasonal change in GSI of *P. leopardus* in the Townsville region. means and S.E. shown.



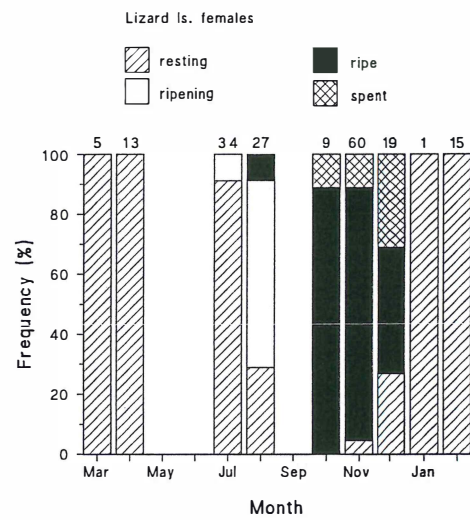
**Table 16:** Three-way analysis of variance examining the effects of location, sex and month on the variation of GSI values of mature males and females.

SOURCE	d.f.	S.S.	M.S.	F	P	Sig.
Location	1	0.324	0.324	0.340	0.5601	
Sex	1	9.332	9.332	9.783	0.0019	***
Date	8	24.415	3.052	3.199	0.0016	***
Location*sex	1	0.052	0.052	0.054	0.8163	
Location*date	3	2.111	0.704	0.738	0.5301	
Sex*date	6	10.785	1.798	1.884	0.0822	
Location*sex*date	3	1.518	0.506	0.531	0.6615	
Residual	402	383.463	0.954			

Ripe males were present from July through December at Lizard Is (Fig. 33) and from July through November at Townsville (no data for December) (Fig. 35). Ripe females were observed from August through December at Lizard Is. (Fig. 34) and from September through November at Townsville (no data for December) (Fig. 36).



**Figure 33** Seasonality in gonad development stages in male coral trout at Lizard Is.



**Figure 34** Seasonality in gonad development stages of female coral trout at Lizard Is.

In testes of ripe males, spermatogenesis and spermiogenesis occurred simultaneously, indicating continuous spawning activity. Ripe females characteristically had lamellae packed with oocytes in the tertiary yolk globule stage, but oocytes in earlier stages of development were always present, indicating multiple spawning throughout the season. Oocytes in final stages of maturation (hydrated oocytes) were present in 40% of the ripe female gonads observed in the period from September through December. In those oocytes the lipid droplets and yolk globules had coalesced and the overall size of the

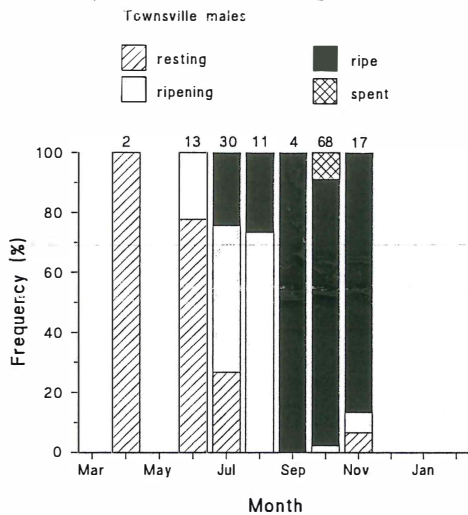


Figure 35 Seasonality in gonad development stage for male coral trout in the Townsville area.

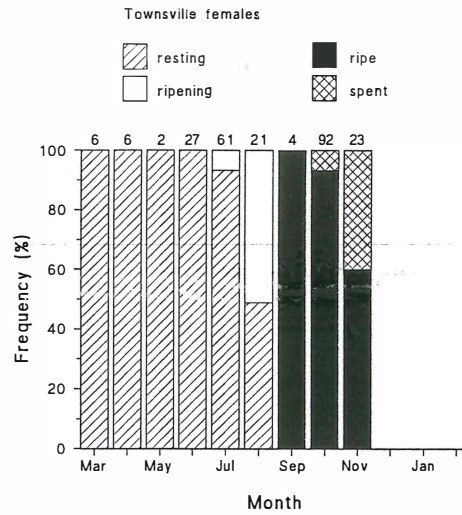


Figure 36 Seasonality in gonad development stages in female coral trout in the Townsville area.

oocyte increased due to hydration. Hydrated oocytes were present in gonads of females caught during all moon phases.

In the gonads of females caught in the morning and early afternoon, they were present in numbers varying from just a few to more than half of the late vitellogenic oocytes in the gonad. Females in which all the hydrated eggs had been emptied into the lumen ("running-ripe"), however, were observed only during late afternoon. The ovaries of these females were flaccid and histologically were characteristically spent gonads, with disorganised lamellae and post ovulatory follicles (POF). Post ovulatory follicles are probably very short-lived as they were only observed in the ovaries of running-ripe females. Vitellogenic oocytes in several stages were also present and no hydrated oocytes were left in the gonad.

The percentage of mature ovaries by month for the Cairns area is given in Fig. 37. Effectively mature ovaries were restricted to the months from August through to December. Histological analysis indicated that the majority of fish sampled in December, although mature, demonstrated high levels of atresia, categories 2 and 3 of Hunter *et al.* (1986) (Table 17).

Gonosomatic indices were calculated (NFC) as the ratio of gonad weight to total body weight for females and males separately, from both Cairns and the southern GBR areas. Where total weight data were not available, weight was estimated from the total weight/fork length relationships given in Section 2.2.9. The GSIs of females and males from the Cairns region increased substantially between August

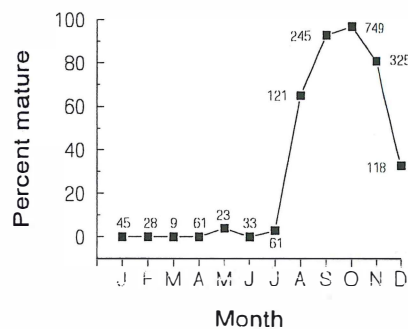


Figure 37 Monthly changes in the proportion of mature ovaries in coral trout from Cairns.

and September, with a peak in October (Fig. 38). Samples from the southern GBR were smaller, but the data for females clearly demonstrated a single mode of elevated GSI in October-Novemeber. The data for both female and male coral trout indicates that the increase in GSI commenced about a month later than in the Cairns area.

**Table 17.** Proportion of *P. leopardus* gonads each month with atretic oocytes.

Month	Percentage in atretic state				n
	0	1	2	3	
August	50.0	41.7	6.3	2.1	48
September	26.2	69.3	4.3	0.0	137
October	44.5	48.9	5.9	0.7	456
November	33.6	48.2	9.4	8.8	137
December	15.0	31.3	38.1	25.0	32

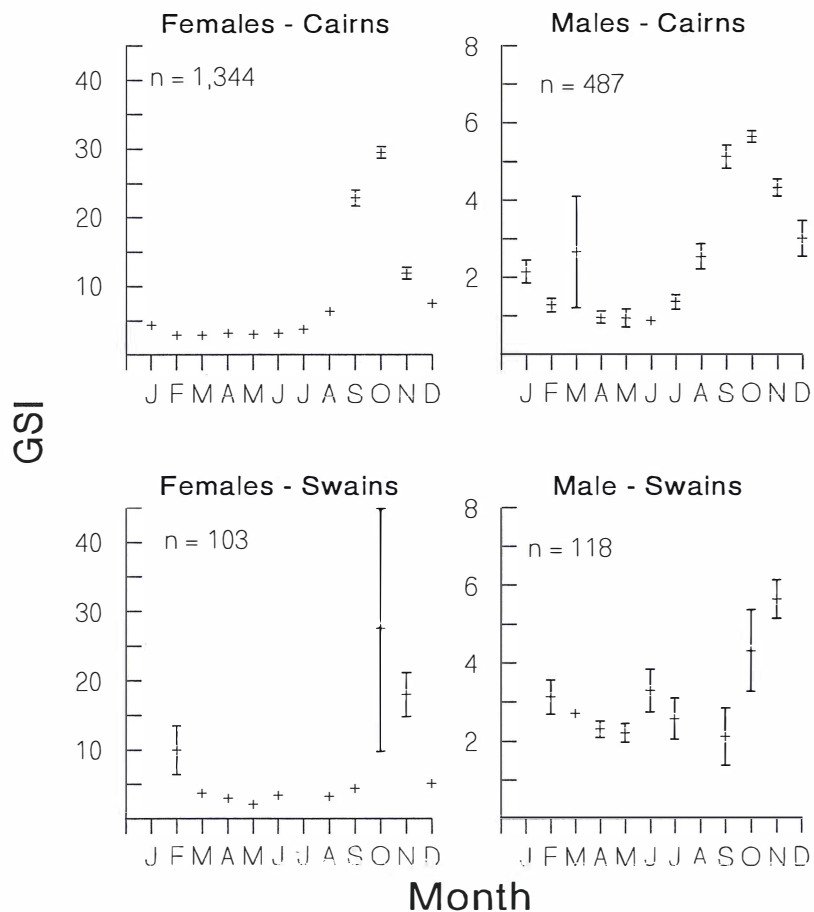


Figure 38 Monthly changes in gonosomatic index (GSI) of male and female coral trout in the Cairns area and the Swains Reefs.

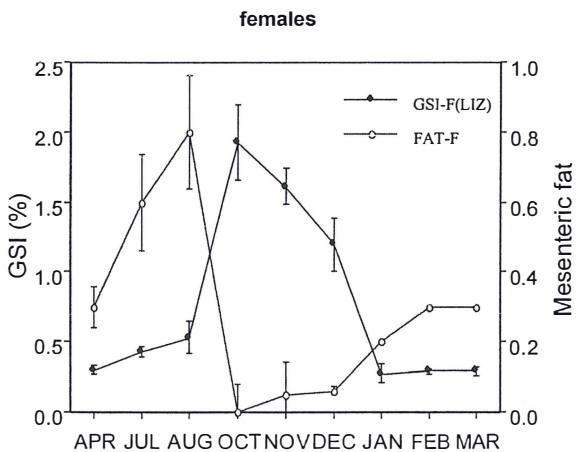
### 2.3.2.8 Mesenteric fat content

The amount of fat deposited in the mesenteries of mature males and females from Lizard Island varied seasonally (Table 18). There was no significant difference between males and females, and both sexes showed a significant variation between months. From April onwards there was a significant increase in the amount of fat until the peak in August (Tukey-Kramer,  $p < 0.05$ ). By October, the amount of mesenteric fat observed had dropped to almost zero in most individuals, and remained low until December, with a

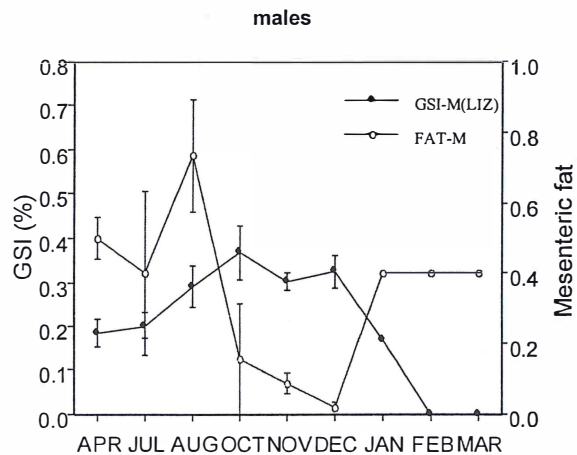
**Table 18:** Two-way analysis of variance examining the effects of sex and month on the amount of fat deposited in the mesenteries of mature males and females from Lizard Island.

SOURCE	d.f.	S.S.	M.S.	F	P
Date	8	25.404	3.175	29.129	0.0001***
Sex	1	0.105	0.105	0.959	0.3281
Date x sex	7	1.160	0.166	1.520	0.1597
Residuals	305	33.250	0.109		

slight increase by February (Figs. 39 and 40). The variation in the amount of mesenteric fat was antiphase with the variation observed in the GSI for males and females, and the amount of fat was inversely correlated with gonad weight for mature females (Spearman rank  $R_s = -0.361$ ,  $p < 0.001$ ).



**Figure 39** Seasonal variation in GSI and mesenteric fat in female trout from Lizard Is.



**Figure 40** Seasonal variation in GSI and mesenteric fat in male coral trout from Lizard Is.

### 2.3.2.9 Population structure and sex ratio

The proportion of each developmental stage for each location is shown in Table 19. Sex-ratio (mature females : mature males) in both samples was biased towards females. The Townsville sample had a smaller proportion of mature males, but a higher proportion of transitional and young male stages. If these individuals were considered as males, the sex-ratio would be: Lizard Is. = 1.74:1; Townsville = 1.33:1.

**Table 19:** Proportion of developmental stages and sex-ratio (mature females:mature males) for the Lizard island and Townsville samples.

SOURCE	Immature female	Mature female	Transitional	Young male	Mature male	sex-ratio F:M
Lizard Is.	8 (3.5%)	141 (61%)	10 (4%)	10 (4%)	61 (26.5%)	2.31:1
Townsville	1.2 (10%)	61 (51%)	12 (10%)	12 (10%)	22 (19%)	2.77:1

Size distributions of mature males and females overlapped over most of the range of sizes observed (Figs 41-44). The mean sizes and ages of the Lizard Is. and Townsville samples were not significantly different (Tables 20 and 21). There were significant differences among ontogenetic stages (immature and mature females, transitional individuals and young and mature males), but no interaction between location and stage, indicating that the mean sizes and ages of each stage were not different for each location.

Sizes and ages of mature females, transitional and young males were not significantly different, but immature females were significantly smaller, and mature males significantly larger respectively than all other stages. Size and age of individuals within the zone where frequency distribution of males overlapped with females were not significantly different between locations (t-test, size:  $p = 0.192$ ; age:  $p = 0.190$ ).

**TABLE 20.** Two-way ANOVA comparing mean sizes of the Lizard Island and Townsville samples.

SOURCE	d.f.	S.S.	M.S.	F	P
Location	1	94.364	94.364	2.620	0.1064
Stage	4	5370.695	1342.670	37.285	0.0001***
Location x stage	4	217.141	54.285	1.507	0.1996
Residual	336	12099.851	36.011		

**TABLE 21.** Two way ANOVA comparing mean log-transformed ages of the Lizard Is. and Townsville samples.

SOURCE	d.f.	S.S.	M.S.	F	P
Location	1	0.006	0.006	0.180	0.6716
Stage	4	3.959	0.990	32.179	0.0001***
Location stage	4	0.181	0.045	1.468	0.2115
Residual	339	10.427	0.031		

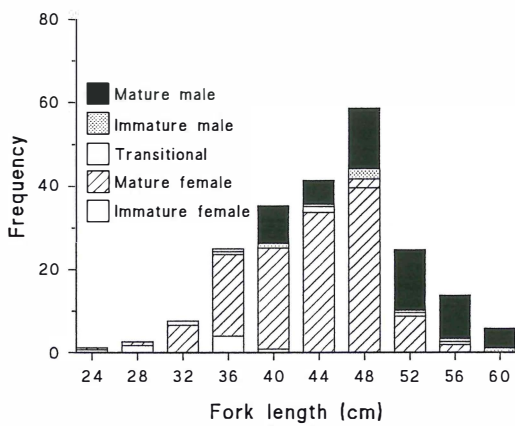


Figure 41 Proportions of development stages by size class at Lizard Is.

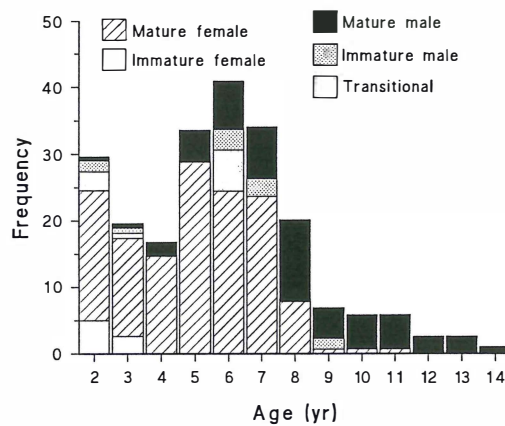


Figure 42 Proportions of development stages in coral trout by age class at Lizard Is.

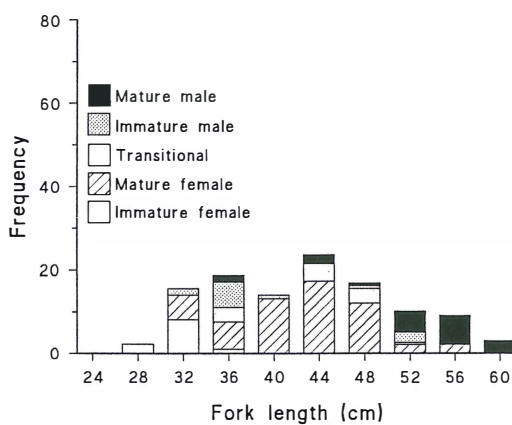


Figure 43 Proportions of development stages by size in coral trout from Townsville.

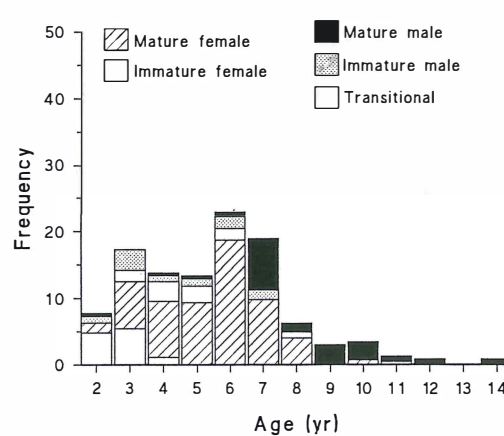


Figure 44 Proportions of development stages by age in coral trout from Townsville.

### 2.3.3 Spawning, Larval Supply and Recruitment

#### *1990/91 Season*

*Larval supply:* A total of 237 pelagic juvenile trout were collected by light-traps and identified as *Plectropomus* from their unique dorsal spine count (Leis 1986). Four juveniles were grown out to confirm the generic identification; three metamorphosed into *Plectropomus leopardus*, one into *P. maculatus*, which is the second most common trout encountered on these reefs.

All 237 pelagic juveniles were caught during a 17 day time window centred on the new moon in November. Within this period, three nights yielded the majority of the catch (11 Nov: 105, 17 Nov: 39, 24 Nov: 32) and this timing was consistent among productive sites. A possible explanation for this daily variation was revealed by the analysis of wind records, which showed that highest catches were correlated with northerly winds even though these represented only one third of the wind records during the November fishing period.

Analysis of spatial patterns was limited by the lack of replication at sites; however, sampling effort was close to orthogonal between depths, reefs, and among sites within reefs. On the basis of this standardized effort, it is clear that catches were not distributed uniformly in space. More trout were caught at Arlington Reef (n=226, CPUE=1.82) than at Green (n=11, CPUE=0.10) and more were caught in shallow water (202, CPUE=1.68) than in deep (n=35, CPUE=0.31). Most trout were collected from the three shallow traps at Arlington (n=191, CPUE=3.08) and catches increased towards the southeast corner of the reef (A1:21, A2:63, A3:107). Catches in shallow and deep traps on the same sites at Arlington were correlated (Pearson's  $r=0.98$ ), albeit at different intensities, indicating a vertical coherence in the patchiness of the pelagic assemblages.

All of the trout collected in light-traps were of similar size and assumed to be competent to settle. Their average size was  $16.8 \text{ mm} \pm 0.19$  (95% CL) with a range from 15 - 18.5 mm. Although not analysed formally, no pattern was evident in the distribution of fish size between depths or among reefs, sites, or days.

*Juveniles:* The otoliths from 36 juveniles collected at the end of summer contained distinct settlement marks. The back-calculated settlement dates for these individuals showed acceptable agreement with the light-trap catches considering the limited resolving power of otolith records (Meekan in press). The back-calculations showed that recruitment peaked on the new moon in November and did not reveal any individuals that settled during other months.

Analysis of the presettlement increments from these individuals revealed an average of  $25.2 \pm 0.9$  (95% CL) presumptive daily increments with a range of 19-31. While this estimates minimum pelagic larval duration, it is almost certainly an underestimate because the first ring is unlikely to have been formed on the day of fertilisation.

Apart from the data on early life history, the juvenile collections also provided a record of postsettlement growth given that a discrete cohort was indicated by both light-traps and

back-calculation. By the end of January, the size distribution of this cohort was skewed with a pronounced tail of smaller fish. When analysed as size at age, however, most of these smaller juveniles were also found to be younger. Between November and January, the average daily growth of this cohort was  $0.81 \pm 0.04$  (95% CL) mm.day<sup>-1</sup> which is significantly faster than estimates of early growth rates from Von Bertalanffy projections fitted to static size-frequency data collected in other parts of this project (Ferreira and Russ in press).

*Spawning:* The single cohort of recruitment observed in this season (primarily on Arlington Reef) was consistent with the pattern observed on the primary aggregation site at Scott Reef, which indicated just one major peak of spawning lasting two weeks about the new moon in October. The analysis of the microstructure of otoliths from speared juveniles collected in January yielded back-calculated birth dates that corresponded reasonably well with the observed spawning pattern.

Samoilys and Squire (in press) also observed isolated spawnings on the new moon in November and inferred spawnings on the new moon in September. Our failure to detect recruitment at Arlington or Green from either of these spawning episodes may simply reflect the low level of activity at such times and the relatively small size of our sample of juveniles.

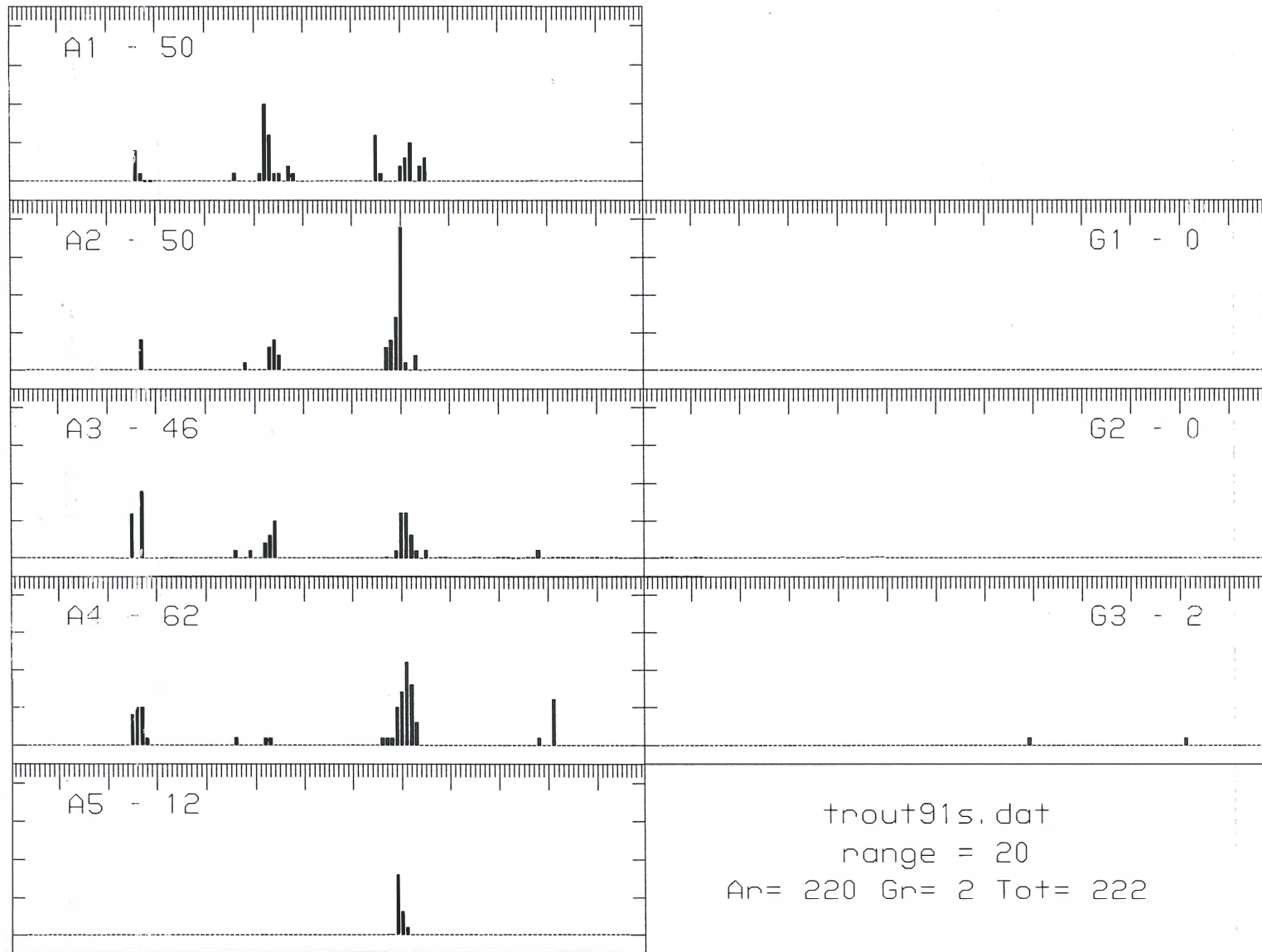
In summary, the data from all three sources (light-traps, back-calculations, spawning) were consistent in suggesting that all replenishment of trout stock on Arlington Reef in this season was derived from a single episode of recruitment occurring on the new moon in November. This simple signal and the synchrony among the three variables suggests that spawning was a major determinant of the timing of recruitment in this year. Because of the southerly direction of the baseline flows over this part of the shelf, it is not likely that Scott reef was the source of the recruitment monitored at Arlington, which implies that spawning in this stock may be synchronised on at least a regional scale.

### ***1991/92 Season***

*Larval supply:* In most ways, the second season was a successful repeat of the first. Total catch was similar to the previous year (229 pelagic juveniles although this must be discounted by slightly greater sampling effort at Arlington); however, the temporal pattern of larval supply was quite different from the previous season with the catch spread across at least three monthly episodes (October, November, December). As before, CPUE was greater at Arlington and greater from shallow traps; indicating consistent patterns in larval supply (Fig. 45).

*Juveniles:* The loss of Dr Tony Fowler from AIMS to a new position in Canada stopped the otolith studies at this point. As his position had not been funded either by AIMS appropriations or this project, he could not be replaced and no expertise was available to continue this work. Nonetheless, the otoliths from the juveniles collected at the end of this season have been archived and will be processed when possible. Preliminary analyses were attempted by a postgraduate student using one otolith from each fish but apart from showing a much greater spread of ages among this juvenile cohort, the results were not





**Figure 45.** Catches of *Plectropomus* from shallow light-traps on Arlington ( $A_n$ ) and Green ( $G_n$ ) Reefs during the 1991/92 season. Only 7 were caught from deep traps at the same locations.

convincingly accurate. The remaining otoliths have been preserved until the necessary expertise becomes available.

*Spawning:* As in the previous year, a correlation was observed between the number of presumptive spawners on the aggregation sites monitored by QDPI and the larval supply patterns monitored by the light-traps. Both data sets suggested that replenishment in this season was sourced from consecutive spawnings in at least three months.

*Growout:* As in the previous year, we took advantage of the supply of live pelagic juveniles to transfer substantial numbers of fish to the Northern Fisheries Centre for experimental growout. Although not a formal aim of the project, there was a substantial opportunistic gain in experience of culturing this species. Several problems were encountered following the first two transfers but eventually a third cohort of more than 30 trout was established in aquaria. Some of these fish survived >12 months but dietary problems caused many to develop spinal deformities.

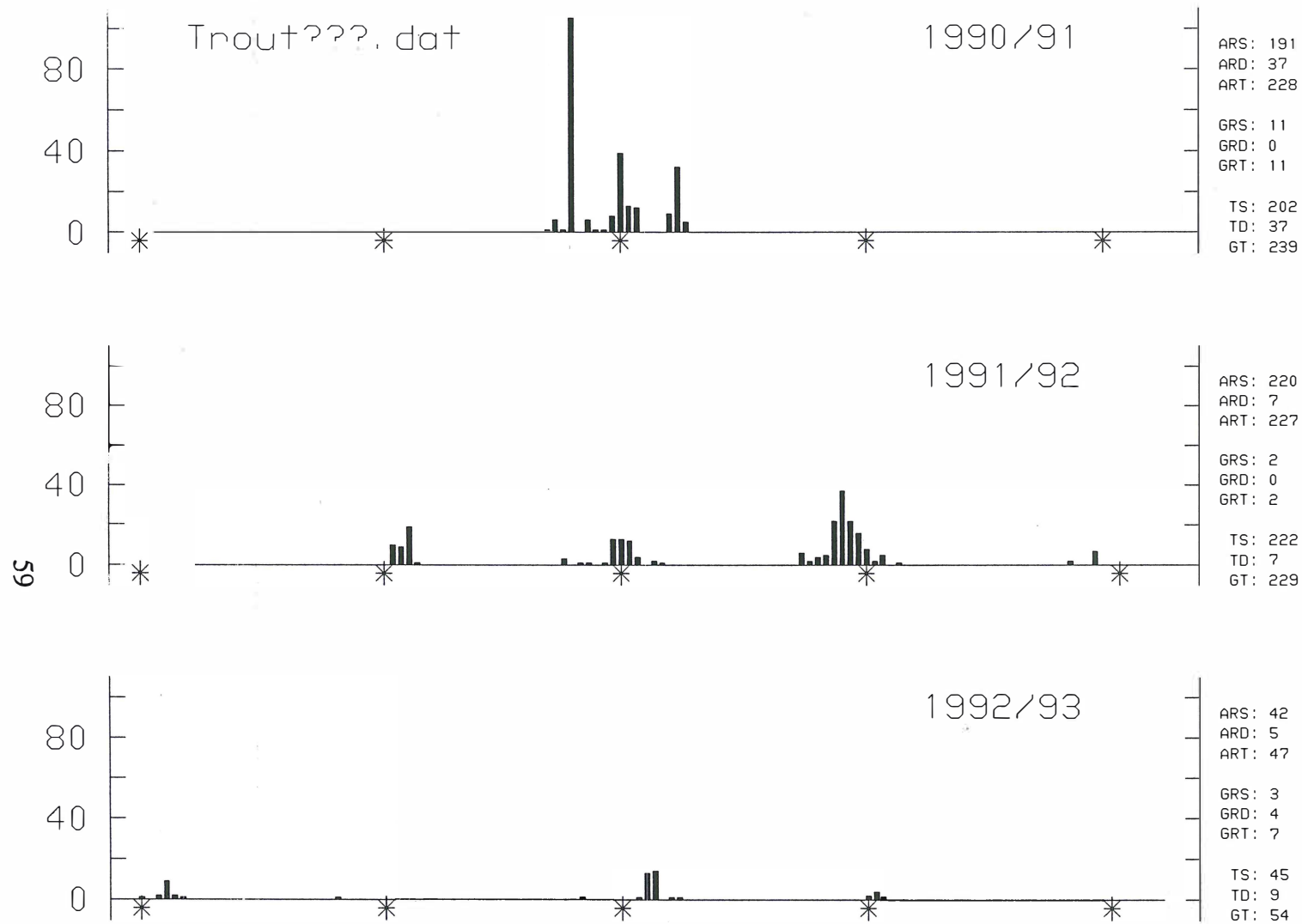
### *1992/93 season*

*Larval supply:* The third and final season began like the others but ended with different outcomes. Because the aggregation monitored at Scott Reef showed spawning activity during August, the light-traps were put into the water a month ahead of the previous years and 15 pelagic juveniles were collected on the new moon in September. Catches in subsequent months, however, were very low and finally resulted in a total catch of just 54 trout, despite the same sampling effort as in the previous year. Although the total catch was much lower, it was distributed spatially as on the previous occasions with the majority caught in shallow traps behind Arlington Reef (Fig. 46).

One unresolved question from this season concerns the identity of another 105 serranids that were collected in this season. In each previous year, almost all of the serranids were identified as *Plectropomus* by their distinctive dorsal fin count. In the final year, the largest group of serranids remains unidentified even at generic level. The main evidence that they were not coral trout is that 80% of them were collected in the deep (20 m) traps. These individuals will be examined carefully to make sure that they are not simply younger trout with incomplete fin development, but this seems unlikely given that they were not smaller than previous catches.

*Juveniles:* Despite intensive effort, the diving team found it difficult to locate many juveniles on the reef slope at the end of summer and ended up collecting just 35 individuals from the youngest cohort. While confirming that the low catches in the traps did measure reduced larval supply, such a small collection of juveniles will have limited power to resolve the temporal sequence of settlement which was spread from September to December. As with the juveniles from the previous years, the otoliths from these fish have been archived until a person with appropriate skills can be recruited to interpret them (see below for progress in this area).

*Spawning:* Unlike the previous two years, there was no correlation between the spawning pattern and the recruitment data. The monitoring of the aggregation sites suggested levels



**Figure 46.** Summary of the total catches of *Plectropomus* in light-traps over the three sampling seasons. The three time series have been aligned to lunar phase; asterisks identify consecutive new moons from September to January. Marginal totals on the right provide subtotals within years for shallow traps at Arlington (ARS), deep traps at Arlington (ARD), all traps at Arlington (ART), and so on.

of activity at least comparable with previous years, while the observations from Scott Reef included one month with record reproductive activity (see spawning section).

The UVC surveys of juvenile coral trout at Arlington Reef are summarised in Figure 47. Results are expressed as "effort" data: number of juveniles observed hour<sup>-1</sup> observer<sup>-1</sup> (no.hr<sup>-1</sup>obs<sup>-1</sup>). Surveys from the deeper sites (>6m) gave a total of 2 fish only, and are therefore not presented. Densities were very low, and variance levels high, therefore no further analysis of the data was performed. Average densities in 1991 (Arlington) ranged from maximums of 5.0-9.0 hr<sup>-1</sup>obs<sup>-1</sup> on the leeward side of the reef, to 0.0-3.6 hr<sup>-1</sup>obs<sup>-1</sup> at other locations. There was a trend towards greater densities on the leeward face in 1991 (Fig. 47).

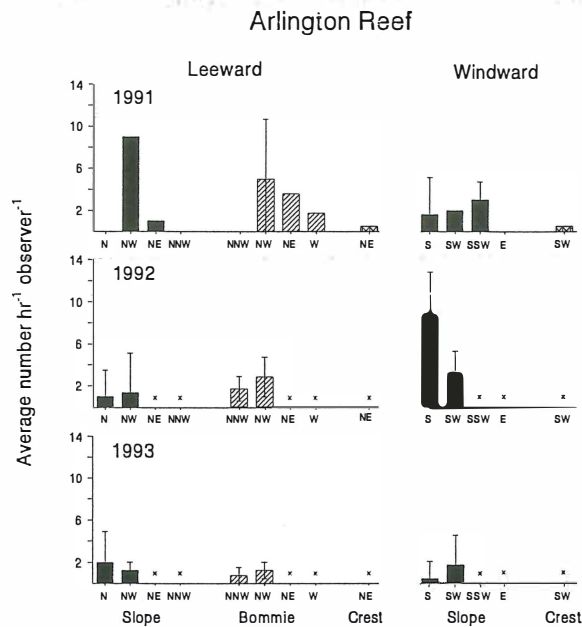


Figure 47 Juveniles in three habitat types at Arlington Reef, 1991-1993. NW, NE etc refer to study sites illustrated in Fig.1. \* = no census conducted.

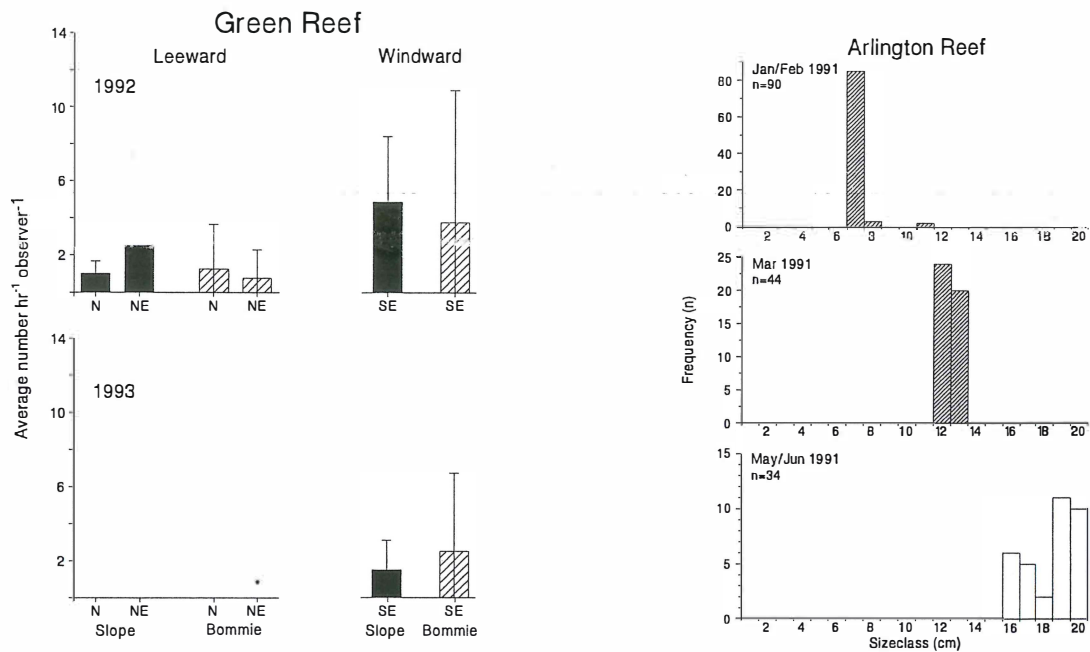
In 1992 densities were greater on the windward side of Arlington Reef, in the southern reef slope sites in the vicinity of the light traps. Densities were similar to 1991 with a maximum density of 8.9 hr<sup>-1</sup>obs<sup>-1</sup> recorded in the S site, and densities at other sites ranging from 1.0-3.3 hr<sup>-1</sup>obs<sup>-1</sup>. Juvenile densities at Green Reef in 1992 were slightly lower ranging from 0.8-4.9 hr<sup>-1</sup>obs<sup>-1</sup> (Fig. 48). In both years densities were higher in the windward sites at Green Reef.

In 1993 densities of juveniles were noticeably lower at all sites, with mean values ranging from 0.5-2.0 hr<sup>-1</sup>obs<sup>-1</sup> at Arlington Reef, and 0.0-2.5 hr<sup>-1</sup> obs<sup>-1</sup> at Green Reef (Fig. 48).

*Size structure:*

All years, habitats and sites were pooled to plot the size frequency distributions from the visual surveys at Arlington and Green Reefs (Figs. 49-51). In 1991 (Arlington Reef only) the average size of juvenile trout was 7 cm FL in January, 12-13 cm in March, and between 16 cm and 20 cm FL in May-June (Fig. 49). The 7 cm FL estimate was approximate, as these were the first surveys, and probably refer to a range of 5-8 cm.

In 1992, the size range at both reefs was broader in Jan/Feb, ranging from 5-16 cm, with



**Figure 48** Juvenile density in two habitats at Green Reef, 1992-93. N, NE etc refer to study sites shown in Fig.1. \* = no census conducted.

**Figure 49** Size frequency of juvenile coral trout estimated visually at Arlington Reef, 1991. Open bars: sizes >15 cm FL, not included in 1993 census.

modes at 7 cm and 12 cm (Fig. 50), suggesting two cohorts of juveniles. Similarly, in 1993 a broad size range was apparent in February, with juvenile sizes ranging from 6 cm to 16 cm (Fig. 51). The sample size was very small in 1993 due to low densities and therefore difficult to detect any modes. The Apr/May surveys in 1992 (Fig. 50) show that there were no small juveniles present, with all estimates being  $\geq 9$  cm. Modes at 12 cm and 15 cm were apparent.

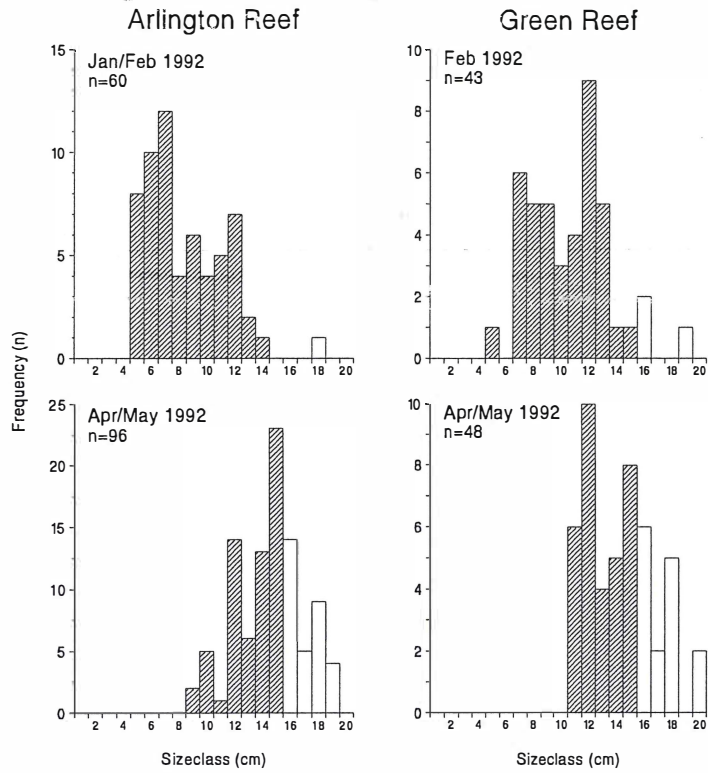


Figure 50 Juvenile coral trout size frequencies from Arlington and Green Reefs, 1992.

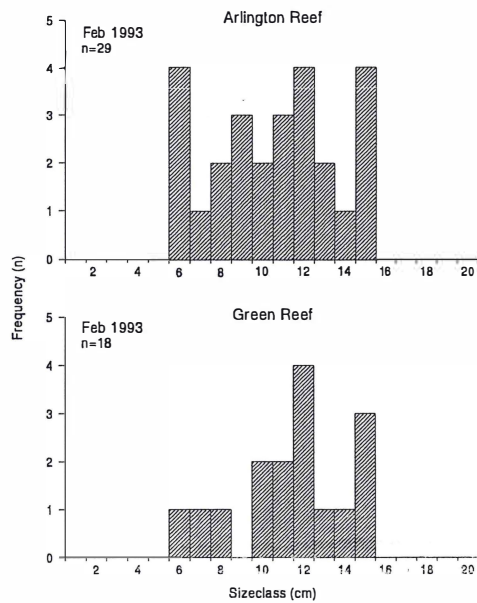
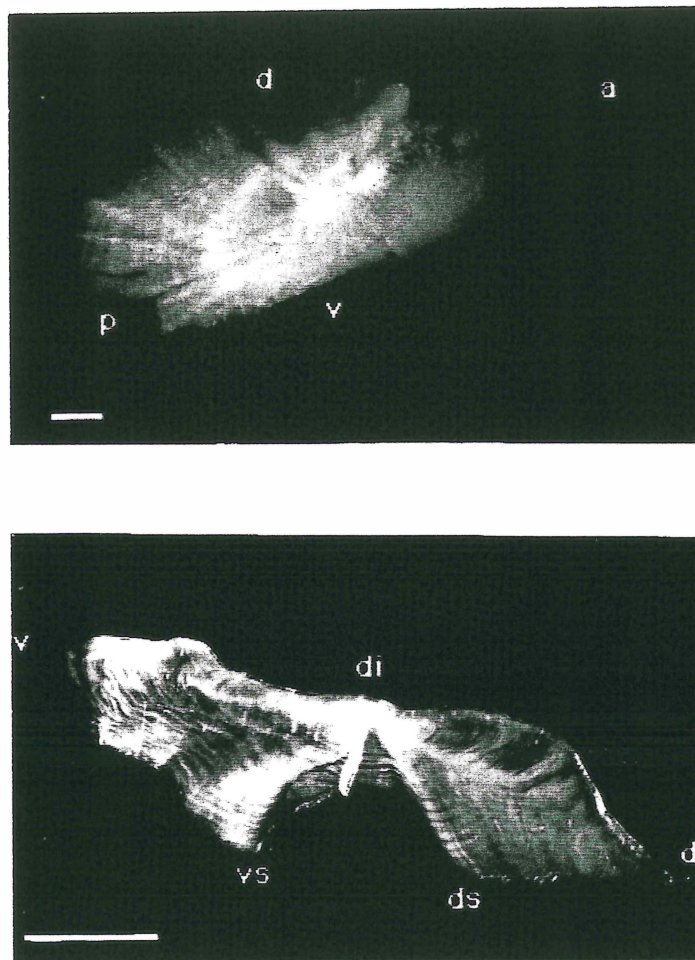


Figure 51 Juvenile coral trout size frequencies at Arlington and Green Reefs, 1993.

## 2.3.4 Age estimation and validation

### 2.3.4.1 Otolith readability

The sagittae are the largest of the coral trout's three pairs of otoliths. They are oval structures, laterally compressed, with a concave distal surface and a pointed rostrum. A curved *sulcus* or groove crosses their proximal surface longitudinally. The otolith nucleus is usually opaque and followed by alternating translucent and opaque zones (annuli).



**Figure 52** Whole otolith (top) and section (bottom) from an 11-year-old coral trout (*P. leopardus*), showing translucent and opaque bands.

The annuli in the coral trout otoliths are wide, and there is no sharp contrast between zones. Individual annuli are difficult to discern under transmitted light but clearly distinguishable under reflected light with a black background. Under reflected light the opaque zones had

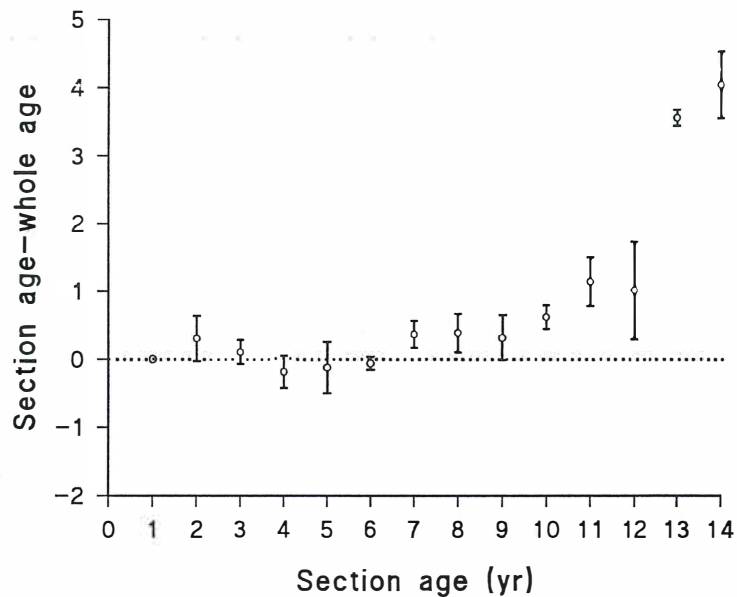
a milky appearance and the translucent zones were dark (Fig. 52). The first two annuli were notably wider, and less well defined than the subsequent ones in sectioned otoliths.

In whole otoliths, annuli were clearly distinguishable and easy to count along the dorsal side of the otolith, where up to 12 rings were counted in some otoliths. However, readings from whole otoliths tended to be lower than readings from sectioned otoliths when more than 6 rings were present and this tendency increased with the mean number of rings, particularly after 10 rings (Fig. 53).

Whole sagittae were useful to confirm the presence of these first two annuli. In sectioned otoliths, the region from the nucleus to the proximal surface of the sagitta along the ventral margin of the *sulcus acousticus* was used for countings, as the annuli in this region were more distinct and had more consistent growth patterns.

Preliminary investigations at NFC also indicated that the the use of whole untreated otoliths could result in underestimation of age. Heat treatment improved the resolution of the banding structure and frequently resulted in a greater number of growth bands being identified (Table 22). Heat treatment produced increased age estimates in 11 of 13 age groups examined, and became the standard otolith reading procedure at both NFC and JCU laboratories for any otoliths that were difficult to interpret.

Preliminary examination of the thin sections of 30 otoliths (NFC) indicated that sections could be used to age *P. leopardus*. The ease of interpretation of the sections was often improved when the otolith was heated prior to sectioning. Approximately 10% of the total number of whole otoliths have been sectioned but have yet to be read. NFC staff suggest that the sectioning technique may not significantly alter the age estimates of *P. leopardus* as it could overestimate age in some otoliths, and the treated whole otolith ageing technique has been validated for age groups 1 to 9.



**Figure 53** Difference between age estimates from whole and sectioned otoliths vs section age. Means and S.E. shown.



**Table 22.** Deviations from untreated whole otolith age readings after heat treatment.

Age	-2	-1	0	+1	+2	+3	+4
14			1	1			
13	1	1	2	1	1	1	1
12		1	3	2	1	1	
11		1	3	1	1	1	
10			4	4	2	1	
9			11	2	1		
8			10	4	2		
7			4	7	2		
6			8	6	1		
5			12	2			
4			7	6			
3			3				
2							

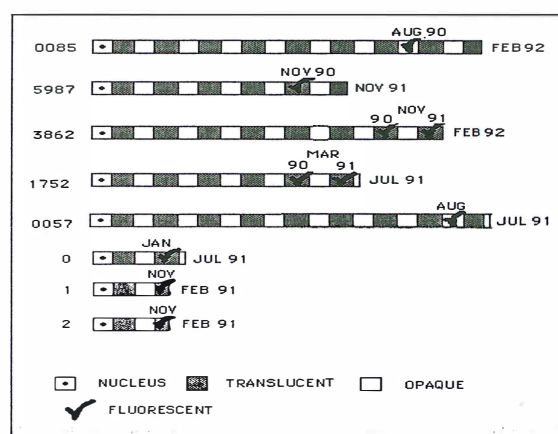
#### 2.3.4.2 Precision of estimates

The Beamish and Fournier (1981) Index of Average Percent Error (IAPE) for 2,950 otoliths read whole, but heat treated when necessary, was 3.99% (NFC).

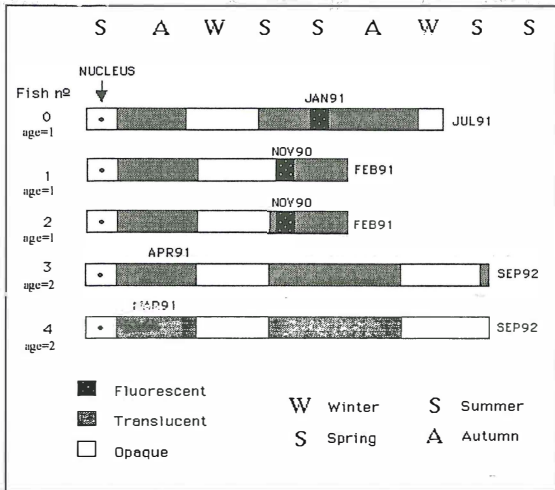
A comparison between results of counts performed on whole and sectioned otoliths at JCU showed that, in the sub-sample analysed, the IAPE was lower for counts performed on whole (6.7%) than for counts performed on sectioned otoliths (12.1%). For the total sample, where readings from whole and sectioned otoliths were combined, the IAPE was reduced to 5.1%.

#### 2.3.4.3 Validation of age estimates

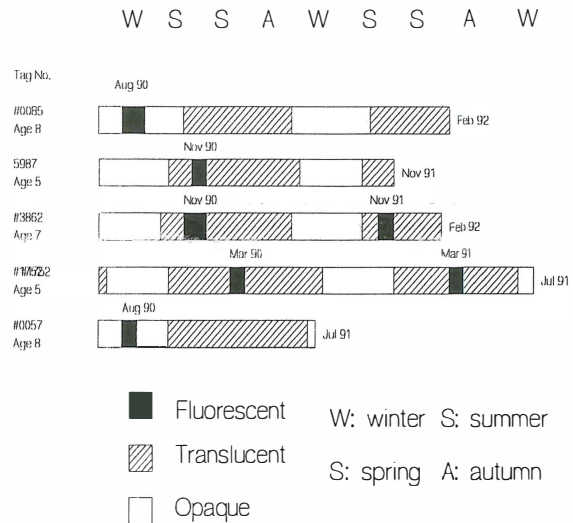
All fish treated with tetracycline displayed clear fluorescent marks in their otoliths. The results obtained for fish recaptured from the Lizard Is area and for a subset retained in captivity (ranging from 1 to 8 years old) indicated that the annuli are formed once per year (Fig. 54). The first annulus is formed in the otoliths of the juvenile coral trout during their first year of life (Fig. 55). The relative positions of the fluorescent bands in relation to the otolith margin and the translucent and opaque zones (annuli) indicated that the formation of the annulus occurred mainly during winter and early spring (Figs. 55 and 56).



**Figure 54** Representation of the otoliths of marked-recaptured-released coral trout treated with OTC. See text for explanation.



**Figure 55** Representation of the otoliths of OTC-labeled young-of-the-year coral trout kept in captivity.



**Figure 56** Representation of the otolith of marked-released-recaptured coral trout labelled with OTC.

Tetracycline-labelled otoliths validated the periodicity of annuli in sectioned otoliths, indicating that whole otolith readings tend to underestimate age of fish >10 years old. Additional validation by OTC around Orpheus Island (Townsville region) confirmed that the checks in otoliths described previously were annuli.

Twenty four fish which had been tagged, injected with tetracycline, and released on reefs in the Cairns region (NFC) were recaptured after a year at liberty. Tags were recaptured up to 26 mo after release. Fish were tagged during October and early November at a time when (according to marginal increment analysis) growth checks were formed. Fluorescent marks occurred on the otoliths of 6 fish at liberty for one year at a position that corresponded to the previous check on the otolith. One fish at liberty for two years demonstrated a fluorescent mark two checks in from the otolith margin.

Marginal increment analysis demonstrated that otolith margins slowly increased in width from a minimum in October until about May and June. After this time margins increased substantially so that the increments measured from June to September were significantly different ( $P < 0.05$ ) to previous months and highly significant ( $P < 0.01$ ) from October, November and December.

#### 2.3.4.4 Otolith weight/age and otolith weight/fish length relationships

Otolith weights in coral trout from Lizard Is. were related exponentially to fork length (Fig. 57). Within most age classes otolith weight was positively correlated to fork length, indicating that there is a tendency for larger fish to have larger otoliths than smaller fish of the same age.

A linear approximation of the relationship between otolith weight and age of coral trout from Lizard Island is given by the expression

$$W_o = 12 + 5.1 * A$$

where  $W_o$  is otolith weight in mg and  $A$  is age in years ( $R^2 = 0.873$ ). However the data in Fig. 58 suggest that a decaying exponential function of the type found for redthroat emperor (Section 3.4.2.4) may be more appropriate.

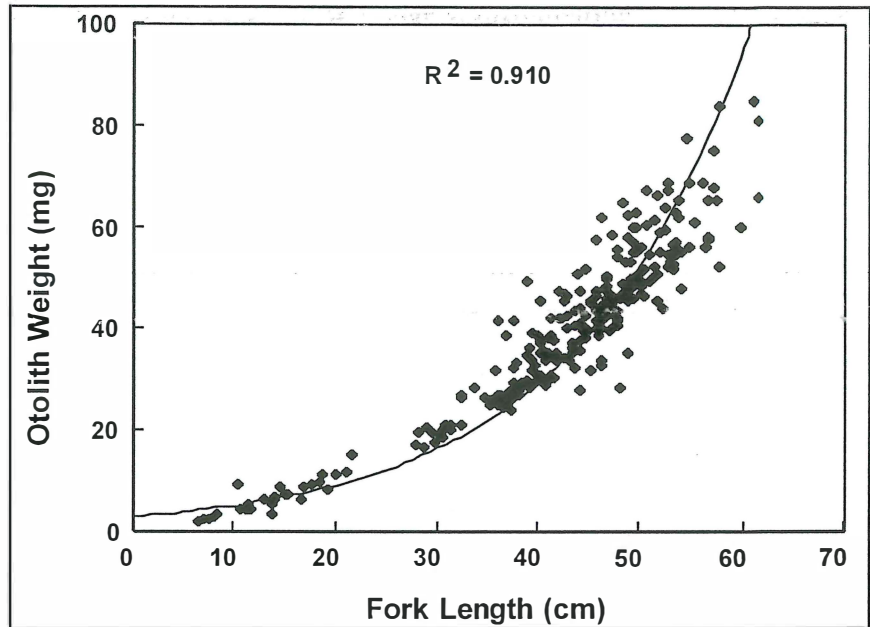


Figure 57 Relationship between otolith weight and fork length in *P. leopardus*.

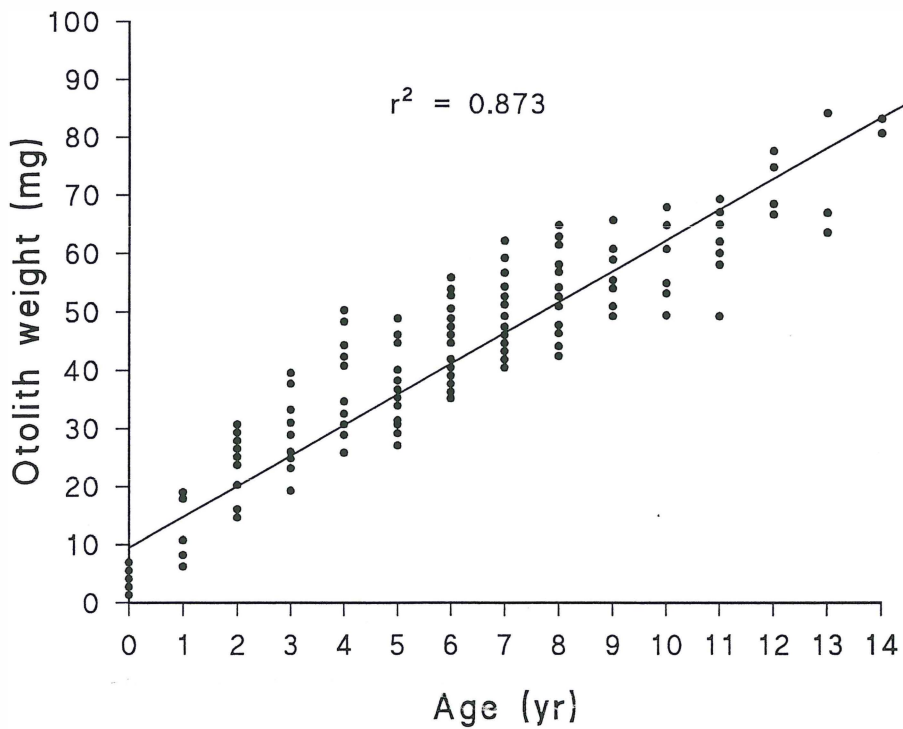


Figure 58 Relationship between otolith weight and age in coral trout.

## 2.3.5 Growth Parameter Estimation and Regional Comparisons

### 2.3.5.1 Growth estimates from tagging

Tag recapture data for 14 *P. leopardus* at liberty in the Cairns region for between 0.9 and 2.15 years were fitted to the Fabens tag recapture growth model by the LMM minimisation routine. While the minimum FL at recapture was 27.5 cm, the mean FL at recapture was substantially larger (41.6 cm). The mean recapture length was 49.4 cm and 51.3 cm for females and males respectively. The least squares estimates of the parameters are given in Table 23. The  $L_{\infty}$  and K parameters of the von Bertalanffy curve were larger than those estimated from otoliths. While the tag data was able to confirm the relatively slow annual growth of *P. leopardus*, the data set was not sufficient to verify the growth parameters estimated from otoliths.

**Table 23.** Estimates and approximate standard errors for the parameters of the von Bertalanffy growth curve fitted to tag recapture data for Cairns *P. leopardus*.

Parameter	Cairns
$L_{\infty}$ (s.e.)	64.86 (0.47)
K (s.e.)	0.25 (0.07)

### 2.3.5.2 Growth estimates from otolith ages

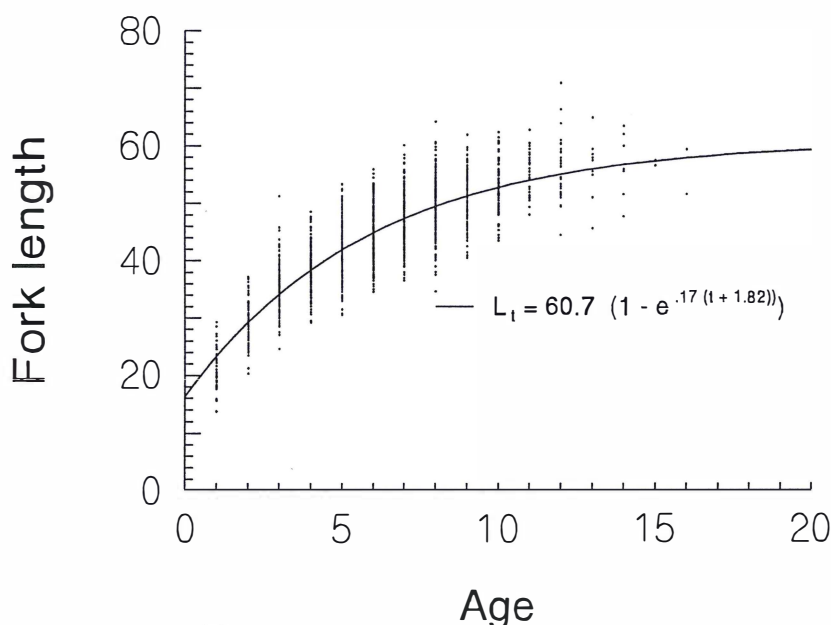
Lengths-at-age for *P. leopardus* from Cairns and southern GBR were determined by the proportional back-calculation method recommended by Gutreuter (1987) and Francis (1991). Lengths-at-age were backcalculated to the last check formed to reduce the effects of size selective mortality (Gutreuter 1987) and unequal sample sizes from a highly seasonal fishery (Davis and Kirkwood 1984; McPherson 1992b).

Von Bertalanffy growth curves were fitted to back-calculated lengths for coral trout from Cairns (Fig 59) and the southern GBR (Fig. 60). The least squares estimates of the parameters of the curves are given in Table 24.

Length-at-age differences between the Cairns and southern GBR samples of *P. leopardus* were tested using the LSMLMW (Harvey 1960) ANOVA program. Because of insufficient numbers, fish aged > 12 yr were excluded from the analysis. The main effects of location and age were significant ( $p < 0.04$  and  $p < 0.01$  respectively) but the interaction effect was not significant at the 95% level.

**Table 24.** Estimates, standard errors and 95% confidence intervals for the parameters of the von Bertalanffy growth curve fitted to back-calculated length-at-age data for Cairns and southern GBR *P. leopardus*.

Parameter	Cairns	Southern GBR
$L_{\infty}$ (s.e.)	60.67 (0.09)	73.9 (7.28)
(95% CI)	(59.0, 62.4)	(59.6, 88.1)
K (s.e.)	0.172 (0.006)	0.087 (0.021)
(95% CI)	(0.156, 0.189)	(0.046, 0.127)
$t_0$ (s.e.)	-1.82 (0.015)	-4.00 (0.080)
(95% CI)	(-2.11, -1.53)	(-5.59, -2.45)
$R^2$	0.75	0.64
n	(2,372)	(527)



**Figure 59** von Bertalanffy growth curve for common coral trout from the Cairns area.

Von Bertalanffy curves were fitted to the mean length-at-age data using LMM. Comparisons of the parameters in the curve determined that there was no difference ( $P > 0.05$ ) in estimates of  $K$ ,  $t_0$  and  $L_{\infty}$  between the two regions, indicating that a common curve may be used to describe the growth pattern of coral trout in the vicinity of Cairns and in the southern GBR. This appeared to contradict the slight significance ( $p < 0.04$ ) of the location effect, probably because LSMLMW used fish-to-fish variation while LMM analysis used age by location interaction means (David Reid, QDPI, pers. comm). As the lengths-at-age for southern GBR fish were greater for ages in the very young (2 and 3 yr) and moderately old (11 and 12 yr) age groups, the curves were not greatly different. There was a slightly higher mean length

for Cairns fish over that for the southern GBR, due primarily to the large number of fish within the 4 to 10 year age groups (43.6 compared to 42.2 cm respectively) however the curves were essentially the same (Fig 61).

The southern GBR sample used in the above analyses (ages 1 to 12 only) comprised 525 fish taken from the Swains Reefs and the Capricorn-Bunker Group,

widely separated areas of the southern GBR. At this stage, the growth curves of *P. leopardus* from the Cairns area and the southern GBR region appear comparable.

Samples obtained in vicinity of Lizard Is. by line-fishing and spear-fishing were selective towards individuals larger than 25 cm FL. Consequently, the 0+ age class was not represented in this sample and the 1 year class was represented only by 4 individuals (Fig. 62). Fence-nets were used to collect individuals from the smaller size classes. The fence-net sample consisted entirely of 0+ and 1+ year classes (Fig. 62). Table 25 lists the results obtained when fitting the growth model to the data including all age classes and to the data including only ages  $\geq 2+$ .

When fitting Schnute's model to both sets of data, the value of the parameter  $b$  obtained was very close to 1. In the boundary where  $b = 1$  the curve is reduced to a three parameter model that corresponds to

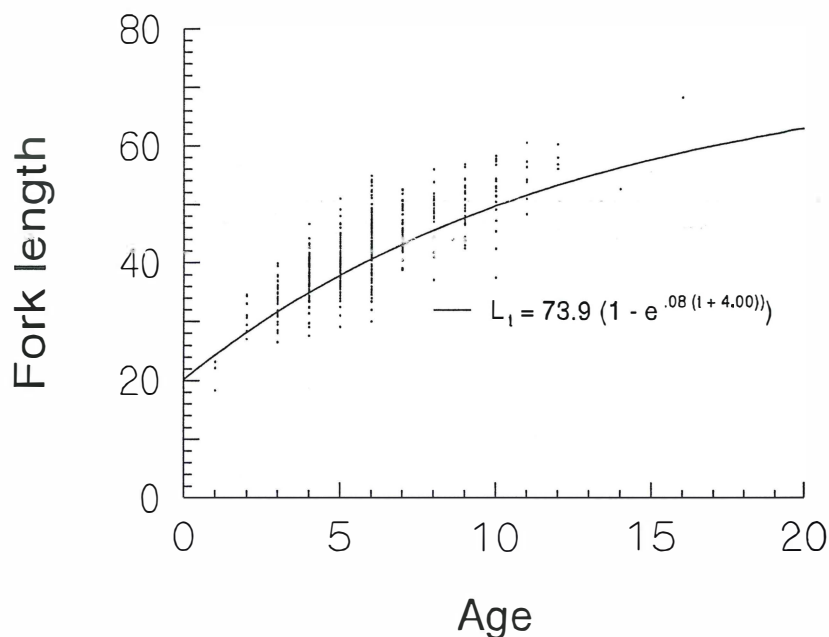


Figure 60 von Bertalanffy growth curve for common coral trout from the southern GBR.

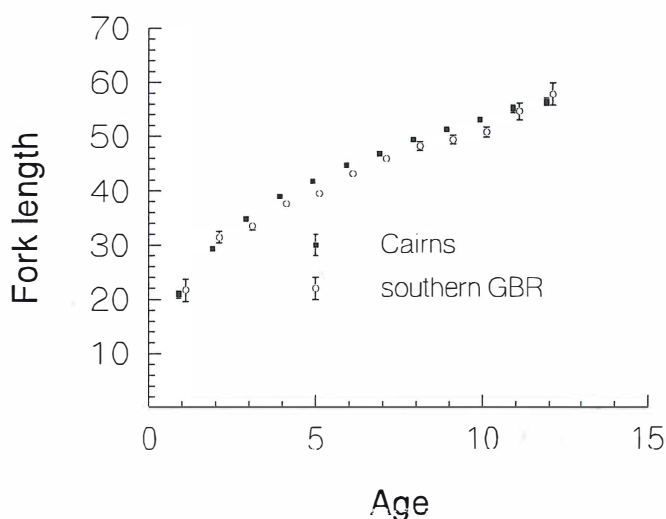


Figure 61 Comparison of predicted (from LSMLMW) lengths-at-age for coral trout from the Cairns and southern GBR areas.

the von Bertalanffy curve for length (Schnute, 1981). The resulting growth model for all age classes, in the form of a von Bertalanffy model (Fig. 63) was

$$L_t = 52.2(1 - e^{-0.354(t+0.766)})$$

with  $r^2=0.895$ . The results obtained when fitting the growth curve to all data and to the data for fish  $\geq 2+$  year-old only were quite different (Table 25). From age 2 onwards, the growth rate is much slower than the one estimated using all age classes, as indicated by the growth coefficient K. Consequently the estimated  $L_\infty$  is larger, and  $t_0$  is a large negative value. The resulting growth expression was:

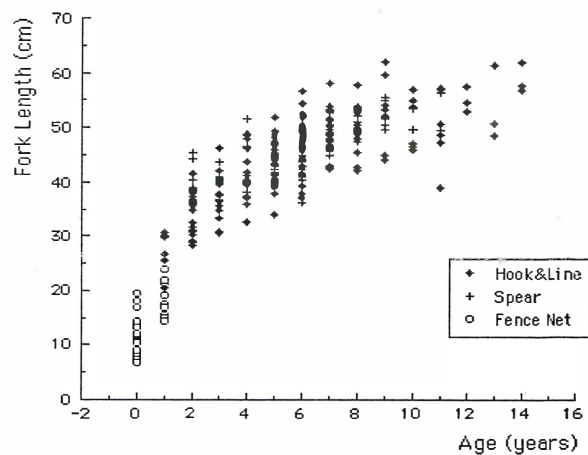
$$L_t = 61.29(1 - e^{-0.132(t+4.66)}), \text{ with } r^2 = 0.622$$

**Table 25.** Von Bertalanffy growth parameters and standard errors (se), correlation coefficients ( $r^2$ ) and degrees of freedom (df) for the growth curves for Lizard Is. coral trout fitted to all data and to the data for fish  $\geq 2$  year old only.

MODEL	$L_\infty$ (se)	K (se)	$t_0$ (se)	$r^2$	d.f.
All ages	52.20 (0.768)	0.354 (0.024)	-0.766 (0.097)	0.895	310
Age $\geq 2+$	61.29 (3.483)	0.132 (0.030)	-4.660 (1.024)	0.622	272

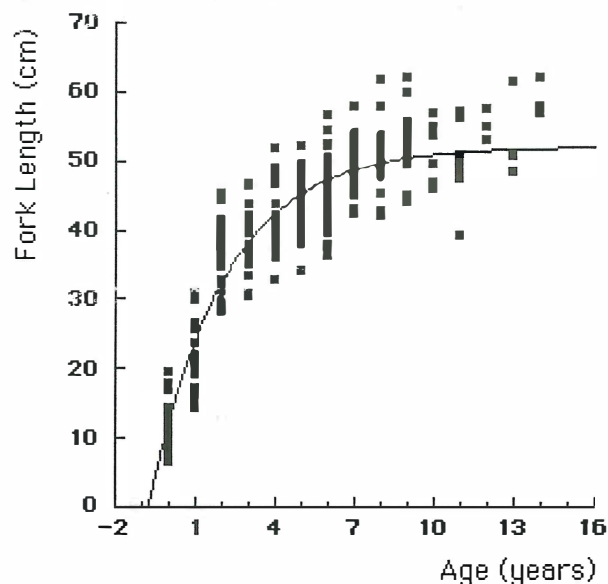
No systematic trend in the residuals was observed (normality test  $p > 0.1$ ). Growth parameters for coral trout from the Townsville area were calculated from the pooled data set ( $n = 479$ ) and are summarized in Table 26. The growth curve based on the data in Table 26 is shown in Figure 64.

There was a substantial difference in size distribution between the Lizard Is and Townsville samples because age classes younger than 2 years tend not to be vulnerable to line-fishing, and therefore were not well represented in the Townsville sample. At Lizard Island younger fish were captured with the use of fence-nets. The first years of life represent the period of fastest growth, after which the growth pattern changes considerably. Significant differences in the estimates of the von Bertalanffy growth parameters were obtained when different age



**Figure 62** Length-at-age distributions of samples of coral trout taken by hook and line, spear, and fence nets at Lizard Is.

ranges were used. Because of this the first 2 age classes were excluded from analyses comparing the growth parameter estimates between the Lizard Is. (Fig. 64) and Townsville (Fig. 65) samples. There were no significant inter-regional differences between the growth parameters when age 0+ and 1+ fish were excluded (Table 27)



**Figure 63** von Bertalanffy growth curve for coral trout at Lizard Is. (all age-classes included).

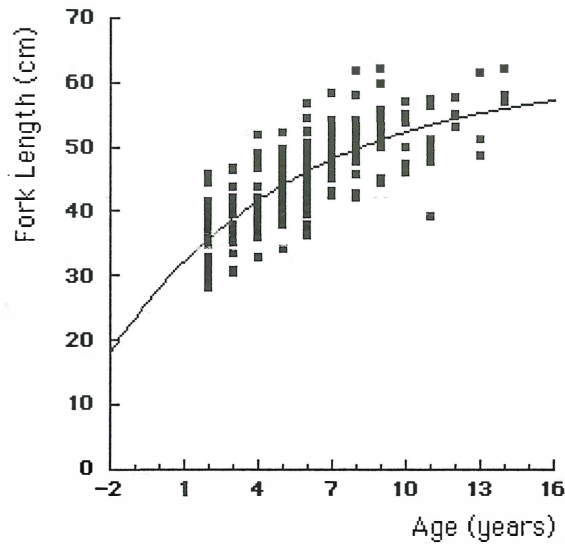
**Table 26.** Growth parameter estimates with associated standard error and confidence intervals for *P. leopardus* in the Townsville area.

Parameter	Estimate	S.E.	95 % C.I.
$L_{\infty}$	68.274	7.017	54.464 - 82.085
K	0.106	0.031	0.046 - 0.166
$t_0$	-4.131	1.070	-6.238 to -2.025

**Table 27.** Comparison of von Bertalanffy growth parameters for *P. leopardus* at Lizard Island and Townsville. Only fish of age  $\geq 2 +$  years were included in curve fits.

LOCALITY	$L_{\infty}$ (95% C.I.)	K (95% C.I.)	$t_0$ (95% C.I.)
Lizard Is.	61.29 (6.827)	0.132 (0.059)	-4.660 (2.007)
Townsville	68.274 (13.810)	0.106 (0.608)	-4.131 (2.106)



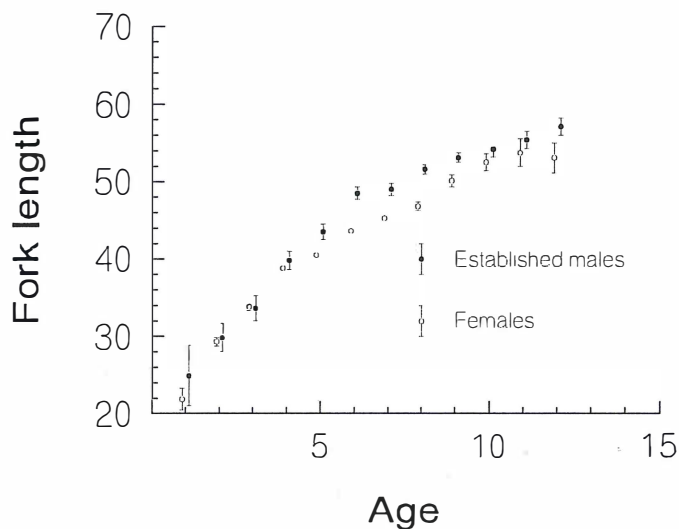


**Figure 64** von Bertalanffy growth curve for coral trout from reefs in the vicinity of Townsville.

### 2.3.5.3 Differential growth between the sexes

Differential growth between the female and male phases of *P. leopardus* in the Cairns area was examined by comparing the backcalculated lengths-at-age between fish in the histological sex change categories of FF (females) and ME (males). Mean lengths-at-age and associated S.E.s for the two sex categories are shown in Fig. 65.

The main effects of sex and age (ages 13 and 14 were excluded due to insufficient numbers) and the interaction of sex and age were examined using the ANOVA program LSMLMW (Harvey 1960). The main effects of sex



**Figure 65** Von Bertalanffy growth curves for female and male reproductive phases of common coral trout from the Cairns region.

and age were highly significant ( $P < 0.001$ ) and there was some evidence of an interaction effect ( $P = 0.073$ ). The least squares estimates of the mean (and standard error) lengths-at-age from the ANOVA for both sex categories are shown in Table 28. There were distinct differences in length at age between the sexes, males being larger than females.

Von Bertalanffy curves were fitted to the least squares mean length-at-age data of FF females and ME males (Table 28) using the LMM program. There was no difference ( $P > 0.10$ ) between  $K$  and  $t_0$  estimates between the sexes, but the estimates of  $L_\infty$  were significantly different ( $P < 0.01$ ).  $L_\infty$  for FF females was 58.87 (s.e. = 1.30) and for ME males was 62.50 (s.e. = 1.38).  $W_\infty$  for FF females and ME males was 2.93 and 3.49 kg respectively.

While  $K$  and  $t_0$  were the same, male *P. leopardus* grew toward a larger population  $L_\infty$ . This change in growth pattern following sex change is referred to by Bannerot *et al.* (1987) as the 'transitional growth spurt'.

**Table 28.** Least squares estimates of the mean (and standard error) lengths-at-age for FF females (females-no change) and ME (males-established) from the LSMLMW analysis of variance.

Age	FF females			ME males		
	Mean	(se)	n	Mean	(se)	n
1	21.9	(1.4)	8	24.9	(3.9)	1
2	29.3	(0.5)	53	29.8	(1.8)	5
3	33.8	(0.4)	80	33.6	(1.6)	6
4	38.8	(0.4)	115	39.8	(1.2)	11
5	40.5	(0.4)	99	43.5	(1.0)	17
6	43.6	(0.4)	106	48.5	(0.8)	22
7	45.3	(0.4)	90	49.0	(0.8)	24
8	46.8	(0.5)	54	51.6	(0.6)	41
9	50.1	(0.8)	24	53.1	(0.6)	39
10	52.5	(1.1)	13	54.2	(1.0)	16
11	53.7	(1.8)	5	55.4	(1.1)	13
12	53.1	(2.0)	4	57.1	(1.1)	14

### 2.3.6 Total Mortality Rate Estimation

The annual total mortality rate ( $Z$ ) for 7,399 coral trout collected from recreational and research operations in the Cairns area was estimated by the program "Catcurv" to be 0.68. The fishing mortality ( $F$ ) component of this is probably seasonally variable, peaking during the spawning season. "Catcurv" estimated that coral trout are not fully recruited to the recreational line fishery in the Cairns area until they are 9 years of age. Size composition data from the commercial catches, together with the current high demand for "plate size" fish not much greater than the minimum legal size, would suggest that coral trout are fully recruited to the commercial sector at the minimum legal size.

Preliminary estimates of annual rates of total mortality for *P. leopardus* at Lizard Island and the four Townsville reefs are given in Table 29. These estimates are based on age structured catch curves with the exception of the two reefs off Townsville closed to fishing (Glow, Yankee). At these reefs age structure was dominated by one strong age class, precluding any reasonable estimate of total mortality based purely on age structure. In the case of these two reefs, a "length-converted" catch curve was used to estimate  $Z$ , using length frequency data pooled over three (Glow) or two (Yankee) years and using growth parameters from size at age data to calculate "relative age". In addition, two estimates of rate of natural mortality ( $M$ ) based on Pauly's (1980) equation relating  $L_{\infty}$ ,  $K$  and mean environmental temperature are provided for comparison. These are very similar to the estimate (0.36) derived from the Ralston (1987) method.

Estimates of the rate of total mortality ( $Z$ ) for open reefs off Townsville based on aged-based catch curves ranged from 0.27 to 0.36. These estimates were noticeably higher than those for Lizard (0.12-0.25) which may reflect actual differences in fishing mortality between the two areas. They were only about 50% of the estimated value for Cairns fish (see above), but no meaningful comparisons of mortality rates could be made between closed and open reefs off Townsville because the age structures of the closed reefs were dominated by a single age class, creating considerable bias in the estimate of  $Z$  based on an age-based catch curve. The "length converted" catch curve was included to provide a "ball park" estimate of  $Z$ . Not too much should be read into the suggestion that mortality rates may be higher on the closed reefs because of the limitation of the data sets and the method of analysis for the closed reefs. The estimates of  $Z$  for *P. maculatus* in the Townsville area are included for comparison (Ferreira and Russ 1992). The evidence suggests that rates of total mortality of *P. maculatus* (the inshore coral trout) are higher than those of *P. leopardus* on midshelf reefs.

**Table 29.** Estimates of mortality rates for *P.leopardus* in the Townsville and Lizard Island areas. All estimates of total mortality (Z) are calculated from age-based catch curves except for Glow and Yankee reefs which are calculated from "length converted" catch curves (LCCCs). Estimates of natural mortality (M) are based on Pauly's (1980) formula relating  $L_{\infty}$ , K and mean environmental temperature and should be considered as very preliminary. Estimates of Z for the congeneric *P. maculatus* are provided for comparison.

Area	Reef	Reef Status	Age Span of Catch Curve (yr)	Z	95 % CI	M
<i>Plectropomus leopardus</i>						
T'sville	Hopkinson 1990	Open	4-9	0.36	.09-.81	
T'sville	Hopkinson 1990	Open	3-9	0.28	.13-.69	
T'sville	Grub 1990	Open	3-9	0.30	.05-.55	
T'sville	Grub 1991	Open	3-9	0.27	.11-.44	
T'sville	Glow	Closed	LCCC*	0.38	.17-.59	
T'sville	Yankee	Closed	LCCC†	0.41	.22-.59	
T'sville	Midshelf Reefs	--	--	--	--	.31††
Lizard	Lizard	Open	2-14	0.25	.17-.33	
Lizard	Lizard	Open	3-9	0.12	.11-.34	
Lizard	Lizard	Open	2-10	0.14	.05-.28	
Lizard	Lizard	Open	--	--	--	.37††
<i>Plectropomus maculatus</i>						
T'sville	Inshore Reefs	Open	2-8	0.57	--	
T'sville	Inshore Reefs	Open	2-12	0.39	--	

\* Based on length frequency sample of n=258 fish collected in 1990, 1991 and 1992 and using growth parameters calculated from size at age data.

† Based on length frequency sample of n=124 fish collected in 1990 and 1991 and using growth parameters calculated from size at age data.

†† Based on the empirical formula of Pauly (1980).

### 2.3.7 Yield-per-recruit analysis

The present minimum legal size for *P. leopardus* in Queensland waters is 38 cm TL. Prior to the 1993, the legal size was 35 cm. Yield-per-recruit simulations were performed on four minimum legal sizes: 32, 35, 38 and 40 cm TL (Table 30). Growth and age at maturity parameters were those estimated for the Cairns region and presented in Table 24 (Section 2.3.5.2). An approximation of M (0.36) was derived using Ralston's (1987) formula for snappers and groper:

$$M = -0.0666 + 2.52 K$$

where K was estimated previously from the length-at-age data. Fishing mortality ( $F = 0.32$ ) was derived by subtracting M from the total mortality ( $Z = 0.68$ ), estimated from the age-based catch curve. The mortality rate for small (<36 cm TL) *P. leopardus* released by the line fishery is not known, but is probably high for small fish taken by hook and line from deep water (>20 m). In the following YPR analysis we assume that fish between 22 and 35 cm returned to the water after being caught are subject to a 10% mortality rate.

The yield-per-recruit at  $F = 0.32$  estimated for the Cairns fishery predicted a maximum yield at 35 cm TL. This assumes a gonochorist reproductive strategy, where different sexes are maintained throughout the life cycle of the fish. This assumption does not hold for *P. leopardus*, and is the major problem in utilising the traditional yield-per-recruit model of Beverton and Holt (1957) instead of more flexible integrated models which can incorporate the effects of different reproductive strategies.

**Table 30.** Yield-per-recruit parameters of a range of minimum legal sizes for Cairns *P. leopardus*.

LEGAL SIZE (cm)		AGE (years)	YIELD at F=0.32	SSB/R at F=0.32	% VIRGIN SSB at F=0.32	F <sub>0.1</sub>
FL	TL					
30.0	32	2.65	144	827	51%	0.33
32.9	35	3.29	157	888	53%	0.42
35.7	38	3.97	136	1029	62%	0.47
37.6	40	4.48	112	1153	71%	0.54

Spawning stock biomass/recruit (SSB/R) increased with progressively increasing minimum legal size. The predictions for the percentage (or relative) virgin spawning stock biomass indicated that approximately 52% would exist for legal sizes of 32 or 35 cm, however there was a substantial increase in spawning stock biomass to 62% if legal size was increased to 38 cm. There was an equally substantial increase in % virgin SSB at  $F = 0.32$ , to 71%, for a legal size of 40 cm.

For a legal size of 32 cm, the model indicated that the stock would be fished at its optimum as the predicted  $F_{0.1}$  (F considered to produce a high sustainable yield; Mace 1988) was 0.33. Minimum legal sizes of 35 cm TL and above had predicted  $F_{0.1}$  levels above the present F calculated for the Cairns area. The calculation of  $F_{0.1}$  however takes no account of its effect on the spawning stock or subsequent recruitment (Clark 1991).

## 2.3.8 Morphometric relationships

### 2.3.8.1 Length: total, standard and fork

The relationships between length measurements for *P. leopardus* ~~*L. miniatus*~~ from the southern part of the GBR (Swains and Capricorn-Bunker Groups) were estimated using each variate in each pair as the independent variable separately, to allow for an approximate conversion formula in either direction. The parameters of the linear regression models are shown in Table 31.

**Table 31.** Parameters ( $a$  and  $b$ ) of the linear regression  $Y_1 = b*Y_2 + a$  between several basic length measurements (standard, fork and total length) in ~~redthroat emperor~~ coral trout from the southern GBR. Standard errors (in brackets),  $R^2$  values and the probability levels associated with the regression  $F$ s are also shown. In all comparisons  $n > 1300$ .

$Y_1$	$Y_2$	$a$ (S.E.)	$b$ (S.E.)	$R^2$	$p$
FL	SL	1.241 (0.450)	1.152 (0.012)	0.954	<0.001
SL	FL	0.714 (0.383)	0.828 (0.008)	0.954	<0.001
SL	TL	0.938 (0.369)	0.775 (0.008)	0.957	<0.001
TL	SL	0.907 (0.467)	1.234 (0.012)	0.957	<0.001
LF	LT	0.668 (0.248)	0.931 (0.005)	0.975	<0.001
LT	LF	0.485 (0.264)	1.048 (0.006)	0.975	<0.001

The relationship between the fork length and total length of coral trout was determined (NFC; using linear regression) from the Cairns region as:

$$TL = -0.27 + 1.07 \times FL \quad (R^2 = 0.99)$$

The relationship between fork length and standard length for coral trout from Lizard Is (JCU) was

$$SL = -0.308 + 0.852 \times FL \quad (R^2 = 0.994)$$

### 2.3.8.2 Length-weight relationship

There was a significant difference ( $P < 0.05$ ) between the FL and total weight (TWT) relationship between *P. leopardus* from the Cairns and southern GBR areas. The intercept and slope of the southern GBR natural log FL-TWT relationship were greater than those for Cairns. The regression coefficients are given in Table 32.

Plotting the actual weights against the predicted weights from the Cairns FL-TWT relationship indicated that there was variability in the relationship throughout the year. Actual weights were consistently higher than predicted weights during August, September and October but this tendency was reversed in November.

**Table 32.** Fork length (cm) and total weight (kg) relationships in the form  $\log_e TWT = a + b \cdot \log_e FL$  for *P. leopardus* from the Cairns and southern GBR areas.

Area	Parameters	
	a (se)	b (se)
Cairns (all data)	-11.03 (0.023)	2.97 (0.006)
Cairns (Aug-Oct)	-11.26 (0.085)	3.04 (0.022)
Cairns (Nov-July)	-10.98 (0.025)	2.95 (0.007)
Swains	-11.63 (0.136)	3.14 (0.037)

From the pooled Swains/Capricorn Bunker Group sample of coral trout we (SFC) estimated the total weight (g)-fork length (cm) relationship as:

$$\ln(W) = -4.655 + 3.12 * \ln(L), \text{ with } R^2 = 0.97 \text{ and } n = 399.$$

The relationships between fork length (cm) and total weight (g) of coral trout from Lizard Is. and Townsville were estimated as follows:

Lizard Is:  $\ln(W) = -4.831 + 3.17 * \ln(L), \text{ with } R^2 = 0.98 \text{ and } n = 273$

Townsville:  $\ln(W) = -5.142 + 3.23 * \ln(L), \text{ with } R^2 = 0.92 \text{ and } n = 378.$

### 2.3.8.3 Fillet recovery rate

The proportion of the total body weight recovered as fillets from the common coral trout *P. leopardus* was estimated using the total weight - fork length relationship shown above in Section 2.3.8.3 for southern GBR fish, and frame weight from samples supplied by commercial fishermen. Firstly the total weight of fish supplied as frames was computed from the frame FL, then the frame weight subtracted to produce an estimated fillet weight. The frames were supplied with viscera intact (to enable sampling of reproductive organs), and were filleted by competent fishermen, so we believe the estimates are reliable. The only factor not taken into consideration is the weight of the skin and scales (which would be normally be removed from the fillets before freezing), but this is not likely to represent a significant fraction of the fillet weight and has been ignored.

A scatter plot of the relationship between estimated fillet weight and estimated total weight was examined by eye for non-linearity (i.e. in case the proportional meat return varied with fish size). However the relationship appeared to be rectilinear, and linear regression parameters were therefore estimated ( $R^2 = 0.910, n = 399$ ). The resulting formula relating fillet weight to total body weight (both measured in grammes) is

$$W_{\text{fillet}} = 0.53 * W_{\text{whole}} - 59.09$$

indicating that the recovery rate for coral trout fillets is very close to 50% by weight.

## 2.4 DISCUSSION

### 2.4.1 Timing of aggregations and spawning

Regular monitoring over a period of four months each year for three years at Scott Reef, and two years at Elford Reef has shown that spawning aggregations of *P. leopardus* occurred primarily around the new moon from September to November. Specifically, by year, peak spawning time occurred in October in 1990, in October, November and December in 1991, and in September, October and November in 1992. A general pattern of three aggregations per site per year, of varying magnitude, was apparent. In 1990 the variation was extreme, with only minor first and third aggregations.

The lunar and monthly timing of major spawning events is corroborated by the timing of larval recruitment and juvenile settlement at neighbouring reefs Arlington and Green (section (c) recruitment). The seasonal timing is further verified by records of peak spawning times occurring in September and October in 1989-1991, determined from gonadosomatic indices, and histological analyses of mature ovaries (section (a)).

The occurrence of spawning around the new moon is also partly supported by the calculations of spawning fraction from histological readings of mature ovaries collected in 1989 and 1990, in which peak spawning fractions coincided with the new moon period, though spawning was not limited to this period (section (a)). In 1990 the highest spawning fraction coincided with the October new moon which is reflected in the aggregation site surveys at Scott Reef (Fig. 4). Peak numbers of trout on the site occurred from 10 days prior to the new moon to at least 7 days after the new moon, with no aggregation present by 12 days after the new moon. This corresponds fairly closely with the comparison of spawning fractions between 7 day moon periods around the October 1990 new moon which revealed no significant differences. Goeden's (1978) study on the southern GBR using gonadosomatic indices also suggested *P. leopardus* spawned around the new moon.

Actual spawning was only observed during a discrete period of 30-40 min. spanning sunset. This early evening spawning is corroborated by histological analysis based on the occurrence of early stage postovulatory follicles. A similar narrow time frame on sunset is reported for *Epinephelus striatus* (Colin 1992).

Prior to this study, coral trout spawning aggregations on the GBR have not been recorded in the scientific literature. Samoilys (1987) reports of "pre-spawning aggregations" of *P. leopardus* at Heron Island Reef, southern GBR, in October 1985, but spawning was not observed. The only other reports of aggregations of *Plectropomus* species are for *P. areolatus* in Palau (Johannes, 1981) and in the Solomon Islands (Johannes 1988). Actual spawning in groupers has rarely been observed (Shapiro 1987), presumably because it commonly occurs in the late afternoon - early evening.

Pronounced lunar periodicity has been observed in the spawning of other groupers (Johannes 1978, Thresher 1984, Colin *et al.* 1987, Colin 1992), with spawning occurring around new or full moon. Johannes (1978) suggested that this pattern allows gametes to be released during strong tidal flows, frequently on ebbing tides, which should facilitate the offshore transport of eggs, thereby reducing potential predation. At Scott and Elford Reefs, spawning episodes spanned both ebbing and flooding tides, but the tidal flow usually ran parallel to the reef edge. The combination of strong tidal currents on the new



moon and the steep seaward aspect of the sites lend support to Johannes's theory that spawning timing and site selection favour egg survival. Other studies on groupers report similar site conditions (Shapiro *et al.* [in press], Donaldson 1989). Low light conditions on the dark moon may also assist in reducing predation on the eggs. However, the hypothesis that spawning timing and location enhance egg survival remains conjectural, because survivorship of eggs released has not been measured (Shapiro *et al.* 1988).

Colin and co-workers (Colin *et al.* 1987, Colin and Clavijo 1988) maintain that the specific timing of spawning serves to synchronise adult activities. Thus, moon phase is used merely as a cue to coordinate individuals' behaviour, and the tidal currents at this time are of secondary importance (see also Robertson *et al.* 1990). The two hypotheses are not mutually exclusive. Whatever the causes for maximal spawning around the new moon, it is not an exclusive strategy in *P. leopardus* since spawning behaviour was also observed on the full moon, and this is confirmed by the histological analyses.

The spawning rush observed in *P. leopardus* is typical of many species of reef fish (Thresher 1984), and has been assumed to be an adaptation to place the gametes beyond the ambit of most planktivorous fishes (Johannes 1978). The emission of eggs and sperm could not be seen, partly due to poor light and visibility, but also because the total volume released per individual was probably small (Rimmer *et al.* 1994). On several rushes, we observed a tight mass of fusiliers (*Caesio spp.*) form rapidly around the spawning pair at the peak of the ascent, and remain there after the trout had returned to the reef. The fusiliers were undoubtedly feeding, presumably on the coral trout eggs. Subsequent to this study (1993), eggs have been captured from a spawning pair and reared in the laboratory at NFC. The resulting larvae survived to four days and were identical to *P. leopardus* larvae reared from experimental source spawning in 1989 and 1990 at NFC (Rimmer *et al.* 1994).

Based on a review of the literature, Thresher (1984) suggested that tropical serranids tend to spawn at water temperatures below the annual maximum, compared with more temperate serranids which spawn at maximum temperatures. Our results are consistent with this observation as the major spawning episode occurred as temperatures rose above 24°C, with annual maximums peaking at 28-30°C (P. Hewitt, AIMS, pers. comm.). Interestingly, Colin (1992) reports that *Epinephelus striatus* spawns consistently in the range of 25-26°C.

#### 2.4.2 Spawning behaviour

The behavioural observations are still preliminary because of the exploratory nature of the study, and in particular the difficulty in recognising individuals without tagging. In addition, a thorough monitoring of behaviour through the day was beyond the financial and time constraints of this study. Hence the emphasis on dusk observations, giving less information on trout on the site during the day. It is especially important to understand that we cannot claim that particular behaviours only occurred at the time of observation.

Despite these limitations the study provides the first witness of coral trout spawning, revealing a reproductive strategy that is particularly relevant to management of the fishery, and which generated some interesting new questions. For example, what fraction of the male population form territories?, are females loyal to particular territories?, the

frequency of spawning in aggregations? etc. These questions require more detailed study involving tagging.

The pattern recorded so far suggests that males aggregate and establish temporary territories, to which females are attracted. This resembles a dominance polygyny (Huntingford 1984) or lek-like mating system (Clavijo 1983, Thresher 1984), where high status males attract females in a specific arena (Bradbury 1981, Bradbury and Gibson 1983, Turner 1986). The performance of distinctive courtship displays with a specific colour pattern by males (previously described by Goeden (1978), Thresher (1984) and Samoily (1987)), further supports the theory of a lek-like system. Coral trout are not classical lek species (Bradbury 1981) because the spawning area does contain significant resources such as food and shelter, and may also be significant for optimising gamete release (see above). Clavijo (1983) also found that the lekking location for terminal male *Scarus vetula* may function to enhance gamete release away from the reef. A number of scarid species adopt more than one mating strategy, such as the lek-like and harem systems of *S. vetula* (Clavijo 1983). We have no evidence that coral trout employ other mating strategies such as harem systems.

It was not always easy to observe actual spawning rushes because they were restricted to such a narrow window of time, and they were not seen that frequently. We assumed that the occurrence of male courting was an acceptable indication that spawning was occurring or would occur in that area on the basis that no spawning rushes were seen which were not preceded by courting. Spawning rushes were not always restricted to large aggregations e.g. at Scott Reef in September 1991 spawning rushes were observed with only 11 fish on the site at dusk. This has been seen again in 1993. Similarly, courting behaviour has been observed in locations where there was no aggregation of trout. The picture emerging is that *P. leopardus* spawning is complex and their mating strategies not a simple predictive pattern.

Shapiro *et al.* (in press) suggest that aggregations play an important role in mate selection. Possibly coral trout aggregations play a role in facilitating male selection by females, since several (dominant) males are congregated in the one area. For example during the major aggregation in October 1990, 20% of the fish recorded in visual counts were large trout (> 50 cm FL), probably males. Eighty-five percent of these large trout were confirmed as male by their courting colour pattern. Such high densities of large males congregated within the one area are not seen in the dispersed social structure of non-breeding coral trout (Samoily 1987). There is some evidence that larger *P. leopardus* move from deeper to shallow waters during spawning time (McPherson *et al.* 1988). The high density of trout in an aggregation would increase the frequency of social interactions and hence spawning opportunities. Intraspecific interactions are infrequent in non-reproductive trout (Samoily 1987). Sex change cues may well be behavioural (Shapiro 1987) because sex change occurs over a broad range of sizes. If so, aggregations may enable females to assess their future reproductive value from the sex-ratio of the population represented by the aggregation, from the number of interactions with males (Shapiro *et al.* [in press]).

### 2.4.3 Management implications of aggregative behaviour

This study is the first to demonstrate that *P. leopardus* forms spawning aggregations on the GBR. Understanding the potential for overexploitation from targeted fishing of aggregations, demands further assessment of the significance of aggregations to the overall stock. At this stage we cannot conclude how universal spawning aggregations are, or whether all individuals use such aggregations to spawn. This is particularly difficult to assess given the depth limitations of SCUBA based surveys, and that trout in spawning condition were captured to depths of 60 m, and up to 10 km away from emergent reef edges. The most dense aggregation (at Scott Reef) represented a 19 fold increase in local density, but this is still only a fraction of the likely stock on Scott Reef. The turn-over of individuals on the aggregation sites is not known, but preliminary results from the tagging at Elford Reef indicate that certain individuals aggregate on the site throughout the season. They are present during the new moon periods and absent on the full moon, returning for subsequent new moons. If this is the common strategy there must be several aggregations to support the population, or a significant proportion do not use aggregations. The latter leads one to ask "why aggregate at all?".

The picture emerging, at least in the depth range of 0-30 m on emergent reef edges, is that *P. leopardus* aggregates at varying densities at multiple sites, with possibly two or three major sites. This strategy contrasts with that of the congeneric *P. areolatus* in Palau and the Solomon Islands (Johannes 1981, 1988). This species aggregates in much larger groups (at least 350 in the Solomons), and consequently may use far fewer sites per reef. Fishermen in the Cairns region report large aggregations and few sites for another congener - *P. laevis*. *Plectropomus leopardus* may be less vulnerable to potential overfishing on aggregations because of its more dispersed pattern. This is supported by anecdotal observations from fishermen that *P. laevis* spawning aggregations no longer exist on reefs close to Cairns (L.C. Squire, pers. comm.), whereas *P. leopardus* spawning aggregations can still be found on these reefs. Nevertheless, aggregations are easy for anglers to target, and off Cairns aggregations have now become the focus of the commercial *P. leopardus* fishery which is likely to increase the CPUE significantly. The large difference in density between Scott and Elford Reef aggregations is possibly caused by targeted fishing at Elford, since this site is easy to locate, and we have received several reports of commercial boats fishing at this site.

Aggregations provide an opportunity to monitor reproduction closely, and an opportunity for stock assessment (Johannes 1980). Correct interpretation of stock assessment models for the coral trout fishery requires an understanding of protogynous hermaphroditism, including a knowledge of their mating strategies (Goeden 1978, Bannerot *et al.* 1987). If aggregations are stable associations and reflect fish density in the catchment area, then aggregation sites may also represent effective places to monitor population change. This is particularly relevant since current stock surveys have limited power to detect change because of the patchy low densities typical of non-spawning populations (Samoilys 1992).

Based on the results of this study, the following definition of spawning aggregations of *P. leopardus* was formulated, to provide a guideline for future monitoring of aggregations. The key feature to look for is a several-orders-of-magnitude change in density within a particular location over a short period of time. For example this study measured at least a 7-fold increase in numbers and up to a 19-fold increase in numbers over periods of 5-15 days. Clearly the aggregation site needs to be located, and then monitored over time, and

the relative change in numbers of trout recorded. To locate sites initially, in the Cairns region, the new moon phase of September, October and November are the times to look, and surveys should be conducted after mid-day. Surveys should look for groups of trout, and the characteristic male colouration and courting behaviour. The closer to sunset the searches are conducted, the more likely spawning behaviour will be seen.

Monitoring of coral trout stocks, and environmental impact assessment studies (e.g. by agencies such as the Great Barrier Reef Marine Park Authority), have often involve visual census surveys of coral trout to quantify population densities in specific reef areas. Clearly the results of this study demonstrate that the timing of such surveys is critical. If surveys are conducted during periods in which trout are aggregating the results could be seriously compromised, both through underestimation or overestimation depending on whether aggregations are located in surveys. It is therefore important that the periodic clumping of coral trout be considered prior to conducting population monitoring surveys.

Both the distinct clumping of coral trout at certain times of the year, and the targeted fishing of these aggregations are also relevant to stock assessments based on production models. Such models assume a random distribution of the population and a random distribution of fishing effort.

#### 2.4.4 Spawning Season

The spawning period observed for *P. leopardus* (early spring and summer) in the Central and Northern regions of the Great Barrier Reef (JCU) coincides with those observed by Goeden (1978) in the Southern region and Samoilys and Squire (1993) in the Cairns region. Spawning season during this period has also been observed for the congeneric species *P. maculatus* from the Townsville region (Ferreira 1993). The sampling design employed here did not allow for effective comparisons between locations regarding the exact time of spawning, and it is possible that latitudinal differences exist for coral trout populations of the Great Barrier Reef in terms of the time of the beginning and end of the spawning season. Nevertheless, it seems reasonable to infer that the spawning season for the coral trout on the Great Barrier Reef occurs generally in the same period, i.e. from early spring to early summer.

Multiple-spawning occurs during this period as was indicated by asynchronous oocyte development in females and continuous spermiogenesis in males. Males mature earlier in the season and remain active for longer and have lower GSI values than females. As males in protogynous species tend to spawn more than females (Shapiro 1984) it is likely that the strategy employed by coral trout males is a limited but continuous production of sperm throughout the season.

In fishes, oocytes in the tertiary yolk globule stage are maintained within the ovary for a variable period of time, following completion of vitellogenesis, until a series of endocrine events stimulates their final maturation and ovulation (Liley and Stacey, 1983). Hydration of oocytes is known to occur just a few hours before ovulation for some species (Clarke, 1987), however final oocyte maturation and ovulation are not always associated (Nagahama 1983). Failure to observe hydrated oocytes in mature female gonads during the spawning season lead Smith (1965) and Moe (1969) to conclude that ovulation quickly

followed maturation for *Cephalopholis fulva* and *Epinephelus morio* respectively. Goeden (1978) did not find any hydrated oocytes within the ovarian lumen of female *P. leopardus* and similarly concluded that those were rapidly ovulated. In contrast, hydrated oocytes were present in 40% of the gonads of ripe female *P. leopardus* observed during the spawning season in the Townsville and Lizard Is. regions. The absence of hydrated stages within the ovarian lamellae of *P. leopardus* reported by Goeden (1978) is probably related to the small sample size, as only 34 ripe females were examined.

Samoilys and Squire (1993) monitored spawning aggregations of coral trout on the northern Great Barrier Reef and observed that spawning rushes were restricted to a 22-minute period around sunset. In the present study, although hydrated oocytes were observed in females caught during the morning and early afternoon, running-ripe females were only caught in the late afternoon, suggesting that hydration can occur as early as 7 to 8 hours before ovulation.

Samoilys and Squire (1993) also described that fish density in the spawning aggregations peaked during the new moon. This lunar periodicity has been associated with increased egg survival, through quick dispersion by strong tidal flows (Johannes 1978), or with the necessity to synchronise spawning activity (Colin et al. 1987). Females with hydrated oocytes within the lamellae were observed during all moon phases. Hence, it seems that although spawning activity may peak at a certain moon phase (Samoilys and Squire, 1993), spawning also occurs throughout most of the spawning season.

An inverse relationship between fat and gonad weight was observed for the coral trout, indicating that these deposits of mesenteric fat are probably being used in the processing of gonad products. A similar pattern has been observed for the Baltic Herring (Rajasilta, 1992). Male GSIs were much lower than female GSIs, but no differences were observed in the amounts of fat stored. It is possible that males and females have similar energy requirements, as males remain reproductively active for longer periods in the season and probably become involved in more spawning episodes than females.

#### **2.4.5 Reproductive strategy - protogyny**

As reviewed by Sadovy and Shapiro (1987) a series of characteristics that have been used as indicative of protogynous hermaphroditism require careful assessment before concluding on the mode of reproduction of a species. The presence of a vestigial lumen and dorsal sperm sinuses in male gonads is not necessarily an indicator of functional hermaphroditism, as their presence, as well as remnant ovarian tissue, can result from juvenile hermaphroditism or bisexuality (Sadovy and Shapiro 1987, Ebisawa 1990). Therefore, only the occurrence of developing sperm crypts in the presence of degenerating mature, ripe female tissue is conclusive evidence of functional protogynous hermaphroditism. Such evidence was found for coral trout, where crypts of spermatocytes, spermatids and spermatozoa were observed in spent female gonads.

Classification of transitional individuals is also dependent on the basic structure of the gonad. In the *Epinephelus* type gonad (*sensu* Smith, 1965), where the female and male tissues are intermingled, the development of precocious sperm crypts in immature and mature female ovaries seems to be a widespread phenomenon (Smith, 1965; Moe, 1969). Developing sperm crypts were observed in the ovaries of some female coral trout, but

their development did not seem to interfere with the spawning process, as no degeneration of the vitellogenic oocytes was observed. Smith (1965) also observed sperm crypts in ovaries of ripe females of *Cephalopholis fulva* and *Petrometopon cruentatus* and concluded that they did not interfere with spawning.

It is not clear if the development of sperm tissue in gonads of ripe females will proceed into sex-change following the spawning season. However, for several species of Serranidae, it has been suggested that sex transition is initiated immediately after spawning (Smith 1965, Moe 1969, Shapiro 1984, Sadovy and Shapiro 1987). In fact, sex transition was observed occurring in spent gonads of female coral trout. As the coral trout is a multiple spawner, it is possible that development of sperm tissue is initiated in a ripe female after an early spawning event, and continues while the ovary is preparing for the next. The presence of fragmenting previtellogenic oocytes in the ovaries of these ripe females seems to substantiate this hypothesis. Actual sex transition, with degeneration and reabsorption of vitellogenic oocytes, would take place when the female entered the spent stage.

The process of sex-transition can apparently be completed within the same spawning season, as indicated by the presence of degenerating yolk oocytes in the gonads of young males. However, transitional individuals with gonads largely ovarian and no sperm sinuses were observed outside the spawning season. Thus, the sex-transition process in the coral trout can either take a variable length of time to be completed, or it can be initiated year-round. The reasons for this variability may be related to the factors influencing sex-change.

#### **2.4.6 Population structure and mechanisms determining sex-change**

Hermaphroditism has been defined as a process of sex differentiation rather than sex determination. The control of sex is known to be primarily genetic, however mechanisms of sex determination in fishes are primitive and labile (Chan and Yeung 1983). The precise genetic basis for sexuality in hermaphroditic fishes is not well understood (Price, 1984). Sex phenotype is probably a consequence of the interaction between genetic constitution of the organism and the environment, although the extent of environmental influences probably varies from one species to another (Chan and Yeung 1983). In theory, sex-reversal may be induced by developmental or environmental (physical or social) causes (Sadovy and Shapiro 1987). Social induction of sex-change is known or claimed for many species of fish, but behaviourally induced sex-change has not yet been convincingly demonstrated in groupers (Shapiro 1987).

Size and age of mature females were significantly lower than those for males in samples from both geographic regions. This expected consequence of protogynous hermaphroditism has been interpreted as an indication that sex change is a developmental process, initiated endogenously when females attain a certain size and age (Smith 1965, Moe 1969). Alternatively, Shapiro and Lubbock (1980) formulated a model suggesting that this characteristic population structure could equally be explained if sex change was controlled mainly by social processes, where a decline in the level of male-female interactions would cause female to male sex change.

The sex-ratio indicated a slightly higher proportion of females in the Townsville sample than in the Lizard Is. sample. However, there were proportionally more transitional and young male stages in the Townsville sample. Development of sperm crypts in the ovaries of ripe females was observed only in the Townsville sample. It is possible that the reefs off Townsville are subject to a greater fishing pressure than the reefs around Lizard Island, due to proximity to populated areas (Craig *et al.* 1989). If so, it is possible that the selective removal of larger individuals (presumably mostly males), is triggering sex-change as a form of compensatory mechanism.

The coral trout, like other species of groupers (Shapiro 1987), is known to aggregate at specific sites during their spawning season (Johannes 1978, Samoilys and Squire 1993), and it has been suggested that social interactions occurring during these aggregations would be important for the determination of the distribution of sexes in such populations (Shapiro 1987, Gilmore and Jones 1992, Samoilys and Squire 1993).

Chan and Yeung (1983) referred to a hypothetical scheme combining developmental and environmental factors. Under this model, sex change would be determined by an inherited responsiveness of the germ cells to hormonal stimulation, the gonadal endocrine interactions, and the function of the hypothalamic-hypophysial-gonadal axis. Chan and Yeung (1983) suggested that under external stimuli, the central nervous system may act through the pituitary in sex control and maturation of the germinal elements in the gonad. The pituitary is involved in germ cell maturation and formation of associated endocrine tissues, and a possible route by which it may affect sex-change is through somatic elements of the gonad (Chan and Yeung 1983). Development of sperm crypts in transitional coral trout usually occurs in the dorsal part of the gonad, in apparent association with stromal tissue. Brown-bodies, formed after the spawning season, have been described as steroidogenic tissues (Nagahama, 1983) and that would indicate a possible role in sex change and also explain their resilient presence in mature male gonads.

Distribution of size and age of male and female coral trout overlapped over a wide range of sizes and ages. Several factors could be contributing to the occurrence of such extensive overlap. Among these are the occurrence of prematurational sex-change, presence of "primary females" (Warner and Robertson 1978) that never change sex, and variation in the size at sex change among sub-populations that have been pooled. All alternatives are likely to apply in the case of the coral trout. Occurrence of prematurational sex change was indicated not only by the presence of young and small transitional, young and mature males but also by histological observation of gonads of some individuals which did not seem to have spawned as a female before. The occurrence of females that never change sex is possible, as large and old females were observed in the samples analysed. However, this species seems to be able to attain older ages, as observed by Loubens (1980) in New Caledonia. Collection of individuals in the upper limits of ages would be necessary to test this hypothesis. Finally, both Townsville and Lizard Island samples are likely to contain elements from different sub populations within the two locations. In this case, if sex-change is behaviourally induced and different mechanisms are operating in each sub population, great variability in size and age at sex change would be expected in the pooled sample.

While at the present point it is not clear how sex change is determined for the coral trout, the variability observed in the size and age at which sex change occurs and in the process

of transition itself, suggests that behavioural processes could be involved. If so, factors such as recruitment variability and fishing mortality are likely to influence the social structure of the spawning population, and therefore the distribution of sexes in coral trout populations.

Such a strategy would allow the development of social structures that would optimise egg production and the spread of successful genes (Gilmore and Jones 1992). A major question arises regarding the effect of fishing in relation to such social structures. Even if sex change is stimulated by social conditions assessed during spawning how fast and effectively can the population adjust if its structure is being changed continuously?

Gilmore and Jones (1992) pointed out that an undisturbed population of groupers would contain large numbers of older, sexually active and highly fecund females. Dominant males would fertilise an extraordinary number of ova passing their genotypes to entire generations of offspring. Removal of dominant males would be compensated for by female sex change, but would this replacement be effective under constant fishing pressure?

Considering the difficulties in answering these questions, Gilmore and Jones (1992) proposed closure to fishing during the spawning season to protect grouper populations in Florida. The P.D.T. (1990) argued for fisheries reserves, totally protected areas that would have the important advantage of protecting the genetic variability of the populations.

In conclusion, the coral trout *Plectropomus leopardus* is a protogynous hermaphrodite species in which sex change is probably governed by both developmental and behavioural processes. Population sex structure is a result of the interaction between factors such as recruitment variability and social structure of the spawning population. More information on behavioural aspects of coral trout reproduction is still necessary to understand the precise mechanisms operating in these populations. At the present point, management decisions should include measures to preserve populations in their natural state.

The characteristics of coral trout reproduction and growth (including seasonality of sex change), have been estimated for widely separated geographical areas of the GBR. Despite the fact that some of the data sets were relatively small, it appears that growth parameters of coral trout in the Cairns and southern GBR areas are substantially the same. Significant differences in the length-weight relationships between areas and between seasons were however detected. There is no justification at this stage of analysis of available data that the differences that do occur require separate management consideration. Initial yield-per-recruit estimates have been based on length-weight relationships pooled over areas and months.

Maturity and GSI data suggest that in southern waters coral trout spawn slightly later than is the case in northern waters. Any consideration of closure of fishing operations during spawning periods would have to consider a potential variation in spawning period in northern waters of a month, as well as a possible lag of another two months for southern waters. The appropriateness of variable seasonal closures along the length of the GBR should therefore take into consideration the negative effects of 'pulse' fishing by commercial fishing operations.



The spawning fraction, and therefore spawning frequency, of *P. leopardus* in the Cairns area indicated that the species spawns over a wide region of the reef. Spawning activity was not found to be restricted to the vicinity of reef crest areas. Fish in spawning condition were taken by line up to 10 km from reef crest and as deep as 60 m. The overall spawning contribution of fish distant from the reef crest is uncertain. However as the spawning fraction of fish in the inter-reef waters was substantially higher than for those fish taken in shallow waters around reefs, GBR reef zoning plans that assume the spawning of *P. leopardus* is restricted to a proximity to emergent reef habitat could well underestimate reproductive potential of the species.

The present yield-per-recruit determinations for *P. leopardus* (assuming a gonochorist reproductive cycle) differed a little from the determinations made using the data of McPherson *et al.* (1985) and McPherson (unpubl. data) which formed the basis of management recommendations to the Queensland Fish Management Authority. These determinations based on von Bertalanffy parameters including  $L_{\infty}$  of 64 cm, recommended an alteration to the minimum legal size of 35 cm TL. There is no evidence from the present data that the minimum legal size of 38 cm TL should be reduced to the previous minimum legal length of 35 cm TL. The present analyses confirm that 38 cm TL is an appropriate minimum legal size as it offers a small margin of safety by allowing for a small increase in  $F$  to occur, at least for the Cairns simulations .

Bannerot *et al.* (1987) examined the appropriateness of standard yield-per-recruit models to simulated populations of protogynous hermaphrodites with serranid type life history parameters. This study determined that there were population parametric regions, notably  $F$ , within which protogynous species were more resilient to exploitation than gonochorist populations. The present yield-per-recruit results for *P. leopardus* suggest that present levels of  $F$  in the Cairns area are within "safe" bounds according to the review of Bannerot *et al.* (1987).

Bannerot *et al.* (1987) also predicted that if protogynous species displayed a spurt of growth after the sex change then equilibrium yield predictions would be substantially in error. The yield at various levels of  $F$  was inversely related to the magnitude of the growth spurt, primarily due to the increase in  $L_{\infty}$  for the fewer older fish rather than the entire population. The simulation of Bannerot *et al.* (1987) for a known population of serranid indicated that fish at age 14 years would differ in weight by only 14% more after a growth spurt, yet the predicted equilibrium yield for the population was 33% less than that predicted for a non-growth spurt population. This coincided with the  $F_{Y_{max}}$  of the same simulated growth spurt population being approximately 60% less than for the non-growth spurt population, that is,  $F_{Y_{max}}$  of 0.35 and 0.87 respectively.

The present study has identified a significant growth spurt for *P. leopardus*. The  $W_{\infty}$  (or weight at  $L_{\infty}$ ) for females and males was 2.93 and 3.49 kg respectively, an increase in weight of 19%. Based on the simulations of Bannerot *et al.* (1987) for a protogynous serranid, the equilibrium yield-per-recruit model could well overestimate equilibrium yield by more than 33%. and overestimate the  $F$  to maximise yield by 60%.  $F_{Y_{max}}$  was not determined for *P. leopardus*.

This study is the first to demonstrate a significant growth spurt after sex change in a protogynous serranid. The review of Bannerot *et al.* (1987) found there was no published empirical data that clearly and significantly demonstrated an increase in growth following

sexual transition. Sadovy *et al.* (1992) did not detect any marked differences in growth between the sexes of a Caribbean serranid.

The simulations of Bannerot *et al.* (1987) indicated that management of serranid populations should be conservative. They demonstrated that fish of this family would show less resilience to exploitation when sperm became limiting (i.e. when the number of males in the population declined).

Clearly, the present results of yield-per-recruit analyses of *P. leopardus* are tentative. Equilibrium yields have yet to be calculated that incorporate a growth spurt after sex transition. However it is apparent that a conservative approach to fishing mortality is required for the immediate present to manage GBR *P. leopardus* stocks until the magnitude of the growth spurt on equilibrium yield is determined. Given the cautions of Bannerot *et al.* (1987), then even fishing mortality at the  $F_{0.1}$  level could be above an optimum for a protogynous species. Maintaining a conservative value of  $F$  does not appear to be occurring in many areas of the GBR, as commercial fishing operations are appearing to radically change as more operators target coral trout for a developing live transport market. The concept of a live fish transport operation adding value to a product is an appropriate method of utilising reef fish resources. However the potential for overfishing to occur on specific reefs and in the vicinity of large population centres such as Cairns and Townsville is of great concern.

The advent of the live fish transport has introduced another potentially serious problem. There are approximately 70 aquarium fish collectors licenced to take live fish. While they are required to observe minimum legal size regulations, there are no restrictions on the number of fish that may be taken on a daily. This could add another 70 to the number of commercial operators taking live coral trout, and has the potential for increasing fishing mortality in localities where recreational sector access has been restricted further.

The peak fishing period for *P. leopardus* in parts of the GBR (particularly in the north) occurs during the spawning period. Fishing effort, whether commercial or recreational, is directed toward aggregations of the species that are engaged in spawning behaviour over a 6-8 week period, depending on location. The present study has determined that the average  $F$  throughout the year is currently less than the  $F_{0.1}$  estimated for the present minimum legal size. However as tentative estimates suggest that fishing mortality in peak spawning season fishing mortality is twice the average  $F$ , then fishing operations during the spawning season could well reach or exceed optimal levels.

Bohnsack (1989), Shapiro (1987) and Sadovy *et al.* (1992) identified problems with target fishing of serranid spawning aggregations. Johannes (CSIRO Fisheries, pers. comm.) has reported severe reductions in serranid populations in four Pacific Island countries, in two of these countries target fishing of spawning aggregations were specifically responsible for the declines. Within 3 years of a Hong Kong based live fish export operation beginning in Palau, a spawning aggregation of serranid fish that had been fished for generations has now been exterminated.

It may be advisable to adapt equilibrium yield-per-recruit models developed for gonochorist fish populations to protogynous sex change fish populations. Quinn (unpubl. data) has developed an integrated yield-per-recruit model for *P. leopardus* that incorporates seasonality into the protogynous sex change, and permits variable mortality

schedules throughout the year to include the spawning season when the species aggregates to spawn. The growth spurt identified after sex change in *P. leopardus* will be integrated into this model. The reproductive output of the spawning stock biomass will be included by considering females and males either separately or in combination. The contribution of spawning females will be considered by incorporation of spawning frequency determined from this study, and spawning batch fecundity.

Goodyear (1989) suggested that the spawning stock biomass of a fished population should not be less than a critical minimum of 20% of the unfished state. Clark (1991) revised this minimum critical spawning biomass upward to approximately 35% for demersal species with a range of mortality schedules and spawner-recruit relationships, and determined that the optimum fishing mortality was similar to  $F_{0.1}$ , which ensured that spawning biomass was maintained above this level.

The current estimates of relative spawning stock biomass per recruit for *P. leopardus* in the Cairns area are on the positive side of this minimum estimate. This however would not necessarily hold for the spawning season fishing mortality schedules and the substantial changes to yield-per-recruit estimates that will occur with the integration of growth spurt data into the model. A conservative fishing policy is therefore advisable until the integrated yield-per-recruit model is developed.

#### 2.4.7 Growth

While some comparisons between readings of whole and sectioned otoliths have indicated good agreement (Boehlert 1985, Maceina and Betsill 1987) others have suggested that whole otoliths give underestimates of true age and that this problem becomes worse with fish age (Boehlert 1985, Hoyer et al. 1985). This is mainly due to the fact that in many species growth of sagittae is asymmetrical (Irie 1960). Growth appears to be linear only up to a certain age or size, after which additions to the structure mainly occur on the interior proximal surface, along the sulcus region (Boehlert 1985, Brothers 1987, Beamish and McFarlane 1987). That seemed to be the case for the coral trout, as comparison of results of whole and sectioned otoliths indicated that lateral views did not reveal many of the outer annual growth zones in older individuals. However, whole otoliths require much less time for analysis than sectioned ones, and seem to provide more precise readings. Therefore, it is useful to determine the limit of reliability of whole readings and thus incorporate the two techniques, as in this study.

Like the inshore coral trout *Plectropomus maculatus* (Ferreira and Russ 1992) the common coral trout *P. leopardus* is a relatively long-lived, slow-growing species. The results obtained here differ somewhat from those of previous studies. Goeden (1978), using the Ptersen method, identified assumed age cohorts up to age 5+ for *P. leopardus*. However, the limitations of the use of length-frequency data to estimate age of long-lived fish are well known (Manooch 1987, Ferreira and Vooren 1991). McPherson *et al.* (1988), using counts of annuli in whole otoliths, were able to age fish up to 7 years old. The longevity was probably underestimated in their study as countings were performed only on whole otoliths. More recently, Brown *et al.* (1992) analysed whole and sectioned otoliths of coral trout from the same area as McPherson *et al.* (1988) and were able to count up to 14 rings. Loubens (1980) counted annuli from burnt and broken otoliths and

estimated a maximum longevity for *P. leopardus* of 19 years in New Caledonia. These higher estimates of longevity suggest that coral trout at both Lizard Island and Townsville could also attain older ages. In this case, the absence of older fishes in the present samples could be related to fishing pressure.

The growth of the otolith was continuous with age but was related also to somatic growth. A similar pattern has been observed for other species of fish (Beckman *et al.* 1991).

Optically different zones in calcified structures are the result of changes in the relative amounts of both organic and inorganic material in the calcified tissue (Casselman 1974). Translucent zones in otoliths contain relatively more calcium while opaque zones contain more protein (Irie 1960, Mugyia 1984, Casselman 1974). Though the physiological basis for the formation of optically different zones in calcified structures has not been directly established, their presence has been commonly associated with varying growth rates, influenced by temperature, photoperiod, feeding rate or reproductive cycle (see Casselman 1983 and Longhurst and Pauly 1987 for review). Mosegaard *et al.* (1988) examined the effect of temperature, fish size and somatic growth rate on otolith growth rate, and suggested that metabolic activity, not necessarily somatic growth rate, governs otolith growth.

In the otoliths of *P. leopardus*, the opaque zone (annulus) was formed during the winter and spring months while the translucent zone was formed during summer and autumn. The formation of the opaque zone has been associated with slower somatic growth for some species (Irie 1960, Mugyia 1984) and to faster somatic growth for others (Pannella 1973, Victor and Brothers 1982). On a daily basis, it has been demonstrated that the translucent zone, or accretion zone, is formed during the phase of more active otolith growth, and the opaque or discontinuous zone is formed during growth stagnation (Watabe *et al.* 1982, Mugyia *et al.* 1981). Thus, if the formation of the opaque zone in the coral trout otoliths is associated with a period of reduced metabolic activity, an external determining factor could be temperature, as the lowest values for water temperature at both Lizard Island and Townsville are observed during winter and early spring. Annulus formation occurred in otoliths of juveniles and adults of coral trout during the same period, suggesting that reproduction is not a determining factor. The presence of annuli in otoliths of juvenile fish seems to be common in many species of fishes (Beckman *et al.* 1991, Ferreira and Russ 1992).

Since the otolith is an acellular structure, its growth might be under different physiological controls than somatic growth (Casselman 1990). This would explain the formation in otoliths of an opaque, protein dominant region during slower growth, while the opposite, i.e., a calcium-dominant region, is formed during slower growth in other calcified structures of fish, like the cleithrum and vertebrae (Casselman 1973, 1990; Ferreira and Vooren 1991).

The main criteria for choosing a growth curve are quality of fit and convenience, differing according to whether the need is for a mathematical description of a detailed physiological growth process or for fishery management (Moreau 1987). The results obtained here indicated clearly that the von Bertalanffy model adequately described the growth of the coral trout. Schnute's model was useful due to its flexibility and the stability of its parameters.

As most fishing gears are selective towards a certain size (Ricker 1969), and smaller sizes are not usually available in samples, it is common that growth curves are fitted to truncated data representing only part of the population. For the coral trout, because of gear selectivity and legal size-restrictions (legal minimum = 35 cm TL pre July 1993), only fish of 2+ years were captured commonly by line and spearfishing. However, these first three years of life represent the period of fastest growth, after which the growth pattern changes considerably. As a result, a dramatic change in the estimates of the growth parameters was obtained at Lizard Island when the growth curve was fitted only to the age classes recruited to the fishery. The VB parameters  $K$  and  $L_{\infty}$  have an inverse relationship over a given longevity (Knight 1968), so a reduction of the growth rate  $K$  generated an increased value of  $L_{\infty}$ . This was accompanied by a direct relationship between  $K$  and the third parameter  $t_0$ , which took a negative and large value. This effect, resulting from a lack of observations at small sizes, greatly compromises comparisons of growth rates between populations (Mulligan and Leaman 1992).

Furthermore, one effect of size-dependent mortality is the selective removal of fast-growing individuals (Ricker 1969, Miranda *et al.* 1987). Thus, it is likely that the average size of the youngest age-groups recruited to the fishery will be biased towards the largest, fast-growing individuals. If this is the case for age class 2+ and 3+, for example, the underestimation of  $K$  would be enhanced further, as well as overestimation of  $L_{\infty}$  (Mulligan and Leaman 1992).

Recent research has suggested the possibility of different growth processes within a population with associated selective fishing mortality (Parma and Deriso 1990) and natural mortality (Leaman and Mulligan 1992). The large variability in size at a given age observed for the coral trout suggests the occurrence of individual variability in growth. The reliability of methods of growth estimation like length-frequency analysis and growth increments from marking-recapture techniques, is greatly affected by this kind of variation (Sainsbury 1980), further enhancing the importance of obtaining validated length-at-age estimates for exploited fishes. The results of selective mortality are a direct effect of growth variability on the dynamics of abundance, and failure to consider the effects of different growth potentials can result in gross overestimation of optimal fishing levels (Parma and Deriso 1990).

The absence of marked seasonal changes in low latitudes lead to the general belief that tropical fishes do not form annual rings in their calcified structures (Panella 1973). Consequently, most of the studies of age determination of tropical fishes have concentrated on counts of daily rings. This technique, however, is time consuming and limited to younger ages (see Longhurst and Pauly 1987 and Beamish and McFarlane, 1987 for review). However, the presence of annual marks in otoliths has been validated for an increasing number of species of tropical fishes (Samuel *et al.* 1987, Fowler 1990, Ferreira and Russ 1992, Lou 1992) showing the potential of this technique to be used routinely in tropical fishery management.

Although estimation of rates of mortality was not a primary objective of this project, the preliminary results suggest an annual rate of total mortality for *P. leopardus* off Townsville in the range of 0.2-0.4, with perhaps a slightly lower rate in the Lizard Island area. These estimates must be considered as very preliminary and better estimates will come from studies specifically addressing mortality rates in this species. Total mortality rates in trout populations in the vicinity of Cairns were very much larger ( $Z=0.68$ ) than

those of the Townsville populations. This may be a result of substantially higher levels of fishing mortality, or to the somewhat different fishing operations used to collect the samples. The Cairns material was largely obtained from charterboats which do not use dories and therefore tend to restrict their operations to the deeper off-reef areas. There is some reason to suspect that the age and size-structure of coral trout populations inhabiting inter-reef waters may not be the same as that of shallow reef habitats.

#### 2.4.8 Larval supply and recruitment

Although some analyses remain unfinished (primarily the otoliths from two seasonal collections of juveniles), the following conclusions can be drawn.

a. Light-traps do collect presettlement coral trout in appreciable numbers, sufficient to resolve temporal patterns in larval supply at whole reef scales, even with relatively few traps.

b. Except in the last year, when larval supply was very low, the temporal patterns in trap catches were validated by comparison with the time series of recruitment generated by an independent method (otolith records). The second year, although not yet analysed completely, did reveal extended recruitment over multiple months matching the trap records.

The relative abundance of trap catches among years was also consistent with the underwater visual surveys of juveniles done by QDPI on both reefs at the end of summer (see appropriate section). Although the high variance in the UVC data means that these tests have low statistical power, there is convincing evidence that the juvenile densities in 1991/92 were less than either of the previous year-classes, matching the light-trap catches.

c. While the otolith records could provide an equally adequate representation of temporal input to the population, the light-traps provided additional information about the spatial distribution of the pelagic juveniles. Two patterns were consistent across all years.

First, pelagic juveniles were more abundant in shallow traps at all productive locations, indicating a nocturnal depth preference for the upper water column. This stands in contrast to results reported by Leis and Goldman (1987) who found greater abundance of larval *Plectropomus* in the middle water column during the day. Because their results referred to the younger larval stages sampled by towed plankton nets, the differences may imply an ontogenetic change in depth distributions. This should be incorporated in future simulations of larval transport.

Second, during all periods of significant catch, trout were taken more often in traps located behind Arlington than any located around Green despite the two reefs being separated by just a few kilometres of similar water. This pattern was not restricted to coral trout; similar differentials were detected across a wide range of taxa. Consequently, the higher abundance of trout may simply represent a rarefaction phenomenon with the key factor being the greater total larval supply evident at Arlington.

It is possible that the larger reef casts a hydrodynamic shadow over its smaller neighbour and depletes its larval supply. Given that the relatively dense reef matrix of the GBR allows for much potential shadowing of downstream reefs, this result suggests that larval supply could be expected to vary on local scales. In practical terms, if reefs of similar size in the same region do not receive the same levels of replenishment, they will vary in their resilience to exploitation.

An alternative explanation for the higher catches at Arlington is that larger reefs provide more effective larval sinks. This has been suggested on theoretical grounds by Dight (1992) and is supported empirically by our observation that rare taxa like coral trout are most often trapped behind large reefs compared with small reefs sampled at the same time in the same region (Doherty and Carleton unpubl. data). Even if this is the appropriate explanation, i.e. that light-trapping is more effective in some locations than others, it implies that large reefs such as Arlington provide the best location at which to monitor larval supply of valuable fishes which are inevitably rare compared with the small species of no commercial significance.

After factoring out consistent variations as described above, larval supply of coral trout at fixed sites showed the same interannual variability as detected in other marine fish populations. This suggests that replenishment is not consistent and that recruitment patterns have the potential to drive abundance in benthic populations. Such effects have been demonstrated in comparisons of the age structures of trout populations on reefs off Townsville that have been open and closed to fishing (see JCU contribution) where Russ observed dominant cohorts passing through two unfished populations. This observation is not easily reconciled with the claim of compensatory cannibalism by Ayling et al. (1992) and suggests that their claim should receive closer scrutiny.

The cause for the observed interannual variability is less clear but it did not reflect a general collapse in larval supply. In fact, catches during the final season were more than double that of the previous year, despite no increase in the level of sampling effort; however, it was less evenly distributed. Meanwhile, the relative importance of *Plectropomus* declined as the taxonomic composition of the catches changed; its ranking at the family level changed from 16, 15 to 27 across the three seasons, respectively.

Most of the increased catch in the third year was the result of a huge multispecific pulse of pomacentrids caught during the full moon in November that was matched in other groups like the siganids. The catch of clupeids, sprats and herrings, among years was inversely correlated with the changes in these other groups. Because these taxa are strongly associated with near reef waters, their patterns of abundance provide some evidence of a change in water quality at the trap sites among the years.

During the first season, daily catch rates of trout were found to fluctuate with wind direction (Doherty et al. in press) showing the extent to which larval supply can be affected by even short-term changes in hydrodynamic flows. At longer time scales, it is possible that the interannual changes in catch composition may reflect changes in the cross-shelf distribution of coastal/oceanic boundaries forced by prevailing weather or low-frequency currents. AIMS has maintained a current meter and tide gauge in the nearby Grafton Passage for many years and these records will be examined for evidence of physical variability.

Given the poleward baseflow of water through the region, it is unlikely that there is much connectivity between Arlington and Scott Reefs. Consequently, the correlation observed between spawning and larval supply in the first two years suggests the possibility of stock-recruitment relationships at regional scales. The main significance of such linkages is that it may be possible to monitor interannual variability at regional scales by monitoring just a few strategic locations.

The decoupling of spawning and recruitment observed in the third and final year shows the potential for environmental influences to affect recruitment. What is not clear from this study is whether there was a breakdown in the stock-recruitment relationship as a result of poorer larval survival or whether the oceanographic climate in the third year resulted in a different displacement of larval assemblages across the continental shelf. Given that reefs occupy fixed positions in a fluid dynamic environment, it makes no difference. A collapse in larval supply to a particular reef will have exactly the same effect on future abundance on that reef no matter whether it is due to altered dispersal pathways or a regional change in larval survival. At a larger scale, however, the former may be less destructive than the latter if the altered dispersal patterns result in the same number of propagules being carried to other reefs (Williams et al. 1984). For this reason, it may be important to monitor larval supply at cross-shelf scales.

Major benefits of this study have been (1) to show that it is possible to monitor the replenishment of valuable coral trout stocks, albeit not without considerable effort, and (2) to show that coral trout populations like other marine fishes experience variations in their natural recruitment. Serendipitously, it appears that Arlington Reef off Cairns is an excellent place at which to monitor this variability and this task has been continued with new funding from the CRC for Ecologically Sustainable Development of the GBR. This extension of the project provides some realistic hope of processing the otoliths outstanding from the 1991/92 and 1992/93 seasons. The main purpose, however, of extending the project is to generate a six year record of consecutive recruitments that can then be matched against the age structures of the benthic populations. This comparison will provide a convincing empirical demonstration of the extent to which abundance in trout populations can be driven by natural variability in the levels of replenishment as has been demonstrated for other coral reef fish (Doherty and Fowler in press a,b).

#### **2.4.9 Juvenile densities**

The densities of juvenile *P. leopardus* on Arlington and Green Reefs were very low, with maximum values of 9 hr<sup>-1</sup>obs<sup>-1</sup>, though densities were usually in the order of 1-3 hr<sup>-1</sup>obs<sup>-1</sup>. This is much lower than would be expected of this species based on adult population densities on these reefs (Ayling and Ayling unpublished data), suggesting the visual surveys are not effective in detecting juvenile trout. The juveniles were noticeably cryptic, particularly in their behaviour, tending to be found close to the reef substrate, frequently under cover, and easily frightened into the coral. They appeared to favour rubble areas; however, this was not quantified. It is recommended that future studies try alternative methods for measuring juvenile densities. Thorough searches of smaller census areas could be effective. It would be advisable to examine distribution patterns in relation to habitat (e.g. rubble versus live coral areas), to enable the stratification of surveys and hence improve their efficiency. However, if a detailed temporal and spatial assessment of



recruitment is desired visual surveys are limited; in which case otolith reconstruction procedures are probably the better option (Doherty 1991). A more experimental approach deploying uniform settlement habitats (Preston and Doherty 1990), in areas where juveniles are known to occur, may be a useful method for studying juvenile populations, but may be logistically difficult for larger less abundant species such as coral trout.

Despite these limitations in the present study, some general patterns were apparent in the data. Interannual comparisons indicate juvenile densities were much lower in 1993, and this is supported by the light trap catches of larvae. The density of juveniles on Arlington and Green Reefs was similar, with slightly lower densities at Green Reef in 1992. This does not correspond with the larval catches where catches at Green Reef were significantly lower. The data did not warrant detailed analyses due to insufficient numbers of juveniles. Thus habitat, reef orientation, and other strata comparisons were not possible. In relation to the light traps, the highest densities of juveniles in the S and SW sites where the light traps were deployed, were measured in 1992.

#### **2.4.10 Size structure**

In 1991 there was a clear monthly progression of one size class, suggesting a single main spawning episode in the season. This interpretation is supported by the spawning behaviour and larval recruitment data, which identified one main episode for the season. However the size frequency plots for 1992 indicated two cohorts of juveniles since there are two modes, and these shifted from 7 cm and 12 cm in February to 12 cm and 15 cm in April-May. Observations of spawning aggregations in 1992 suggest that three cohorts of juveniles recruited.

In terms of timing of juvenile surveys the results demonstrate that the earliest surveys in Jan/Feb detected the smallest size classes of 5-8 cm, which are probably the smallest sizes that can be detected through large scale visual surveys as done here. The 1991 results indicate that by May/June all juveniles were 16 cm FL and greater, and therefore could not be distinguished from 1+ fish. Consequently, surveys in 1992 were terminated in April/May. However the size frequency distribution from this period still indicated that 0+ and 1+ fish cannot be easily distinguished. The plot does suggest that juveniles at this time were primarily in the 12-15 cm size range. Surveys in 1993 were restricted to February to try and avoid conflict with 1+ fish. Observations were limited to  $\leq 15$  cm FL fish on the assumption that juveniles at this time would not be greater than 15 cm in length, based on previous years. Numbers were very low in 1993 so it is difficult to interpret the data. However the size frequency plots suggest that juveniles were larger earlier in the year compared with previous years. This is consistent with the recording of an earlier spawning season in 1992.

### 3 RED-THROAT EMPEROR

#### 3.1 SPECIFIC OBJECTIVES

The aims of this component of the study were as follows:

- . To develop a reliable age-determination protocol for *L. miniatus*.
- . To estimate the growth parameters for populations of *L. miniatus* in various parts of the Great Barrier Reef, from Cairns to the Capricorn-Bunker Group.
- . To determine whether otolith weight could be used as a means of validating age estimates.
- . To determine whether *L. miniatus* has a protogynous hermaphroditic reproductive strategy, and if so to determine size and age at sex change.
- . To define the spawning season for redthroat emperor and assess the extent of geographical differences.
- . To estimate size and age at first maturity.
- . To estimate total mortality rates and to assess geographical differences.
- . To estimate fillet recovery rate and various morphometric conversion functions.
- . To evaluate the effect of an increase in minimum legal size from 30 cm to 35 cm TL.

#### 3.2 MATERIALS AND METHODS

##### 3.2.1 Collection and basic processing of materials

Samples of redthroat emperor *L. miniatus* were obtained from research cruises and from recreational and commercial fishing activities in three major sub-areas of the Great Barrier Reef: Townsville, the Swains Reefs, and the Capricorn-Bunker Group. Unfortunately the particular locations sampled in the Cairns area were evidently not populated by significant numbers of *L. miniatus*, and as a result it was not possible to collect sufficient specimens for meaningful analysis. However some comparative growth data were possible as a result of material (otoliths) previously collected by NFC staff who kindly made them available to this Project for analysis.

A total of 619 *L. miniatus* were collected from a variety of reefs in the Townsville area in 1990 and 1991. These samples were obtained from commercial and recreational fishermen but the majority (540) came from a systematic line sampling of 4 reefs in June-July and September-October of 1990 and 1991 by a team of recreational fishermen using standard

fishing methods. These reefs were Grub and Hopkinson (General Use reefs open to fishing) and Glow and Yankee (Marine Park B reefs closed to fishing since 1987) and were all mid-shelf reefs. Table 33 summarizes the number of *L. miniatus* collected in the Townsville area by year and month.

In the southern (Mackay-Capricorn) Section of the Great Barrier Reef Marine Park samples of redthroat emperor were collected during the period August 1989 to February 1991. Three sub-areas - Mackay, the Swains Reefs (21°30' - 22°20'S) and the Capricorn-Bunker group (23°10' - 24°0'S) were represented, although the first of these was visited on few occasions and sample sizes were quite small.

The fork length (FL) of each fish was measured ( $\pm 0.5$  cm) and on occasions the standard length (SL) and total length (TL) were also noted.

**Table 33.** Number of *L. miniatus* collected per month from the Townsville area. The number of fish examined histologically for gonad status are shown in brackets.

MONTH	1990	1991
Jan	-	-
Feb	-	-
Mar	-	19 (19)
Apr	-	51 (51)
May	-	3 (3)
June	-	-
July	133 (58)	159 (82)
Aug	-	4 (4)
Sept	-	-
Oct	109 (54)	139 (57)
Nov	2 (2)	-
Dec	-	-

### 3.2.2 Reproductive development and chronology

Gonad preservation and histological methods are the same as described previously for *Plectropomus leopardus* at JCU. Gonads from 334 *L. miniatus* were examined histologically and staged as described previously for *P. leopardus* (see Section 2.2.3).

Samples from the Swains were predominantly in the form of frozen frames purchased from commercial fishers. Gonads were removed from these fish in the laboratory (SFC) and fixed in 10% neutral buffered formalin. Fish from the Capricorn-Bunker Group were collected by members of the research team during regular sampling trips to the area. Gonads from these fish were generally removed from the fish within 4 hours of death and fixed in the same manner as the Swains samples. Where possible whole wet weights of fish were recorded to the nearest gram and gonads weighed ( $\pm 0.1$  g). Gonosomatic indices were calculated as the

percentage gonad weight to the gonad-free wet body weight. Where the whole body weight was not available it was estimated from the relationship between fork length and total wet weight.

Gonads from 1977 fish from the Mackay-Capricorn Section (primarily the Swains Reefs and the Capricorn-Bunker Group) were examined microscopically after sectioning the middle portion of one lobe at a thickness of 500 microns and staining with haematoxylin-eosin. Classification of gonads of both males and females followed the scheme of Moe (1969) as did the classification of female oocytes. The presence or absence of brown bodies, sperm sinuses, and a remnant lumen were also noted in male gonads (Sadovy and Shapiro, 1987).

### **3.2.3 Age estimation and validation**

#### **3.2.3.1 Otolith preparation**

Material supplied by commercial and recreational handline fishers was in the form of frozen frames (head and skeleton left after filleting). Individual fish (or frames) were measured (fork length, in mm) prior to otolith extraction. A horizontal cut was made with a stainless hacksaw or stout knife, depending on the size of the fish, through the cranium starting just above the eye. This exposed the brain-case and allowed easy removal of the two sagittal otoliths, which were cleaned, dried and stored in labeled plastic vials. Left and right otoliths were weighed separately to the nearest mg provided they appeared not to have been chipped or otherwise damaged during the process of removal. Each otolith was immersed in clove, aniseed, or domestic cooking oil in a small petri dish with a black background generally as described by Loubens (1978), and examined under a low-power dissecting microscope with incident light provided by a twin fibre-optic source.

#### **3.2.3.2 Otolith reading and interpretation**

Each pair of whole otoliths was read independently on two separate occasions by one reader. Subsequently one of every pair (the left, unless it was missing or damaged) was embedded in a polyester resin block in a flexible silicone rubber mould with a plasticised paper identification label. The block was then mounted in the chuck of a Beuhler Isomet low-speed precision diamond wafering saw and sawn through slightly to one side of the nucleus. A second cut was made producing a thin section (300  $\mu$ ) incorporating the nucleus. The sections were mounted permanently on microscope slides, either in hot Canada balsam or polyester resin, under cover-slips. The mounting medium filled surface irregularities caused by the diamond impregnated saw blade, obviating the need for polishing.

The sections were examined twice (independently) by one reader, and once more by a second reader. At each reading a subjective readability rank was recorded, ranging from zero (no interpretable structure present) to five (exceptionally clear ring structure). As several readers with differing levels of experience were involved in age estimation over the period of the

study, some overall lack of precision inevitably resulted from differences in interpretation of the otolith internal structure. Where two of the three estimates were identical and the third varied from the others by only one year, the "common" estimate was accepted as the final age. In all other circumstances a final assessment was done by one reader (IWB) with reference, where necessary, to auxiliary data on otolith weight-age derived from an unambiguous subset of the data.

Sectioned otoliths of 225 specimens from the Townsville area were read in accordance with the protocol established by JCU for Lizard Island and Townsville *Plectropomus leopardus*. All methods of sectioning and reading are as described previously for *P. leopardus* (Sections 2.2.5.1. and 2.2.5.2).

### 3.2.3.3 Validation procedures

Attempts were made to validate the age estimates of *L. miniatus* directly, by marking the otoliths of tagged and released fish with oxytetracycline. Fluorescent labelling and tagging programmes were conducted in the vicinity of Orpheus Is. (near Townsville) by project staff based at JCU, and also around a protected reef (Llewellyn) in the Capricorn-Bunker group, by QDPI staff based at SFC. Although several tagged redthroat emperor were recaptured, and otolith sections showed very distinct fluorescent bands under violet or UV light, none had been at liberty for more than 12 months, and their utility for validation was therefore limited.

### 3.2.4 Growth parameter estimation and regional comparison

Growth parameters were estimated (SFC) for the southern GBR and historical Cairns length-at-age data using a non-linear curve fitting algorithm in the microcomputer graphics package Fig-P. (BioSoft [Cambridge]). Similarly the von Bertalanffy growth function was fitted to the Townsville data (JCU) with a standard non-linear fitting procedure.

### 3.2.5 Mortality rate estimation

The instantaneous rate of total mortality ( $Z$ ) was estimated for southern GBR populations of *L. miniatus* (primarily the Swains Reefs and the Capricorn-Bunker Group) from the regression of  $\ln(N_a)$  on  $a$ , where  $a$  are fully recruited age-classes. As there was some "tailing-off" in the very old age-classes (up to about age 25 yr), some pooling of the numbers of older fish was necessary. Likewise, preliminary estimates of  $Z$  were obtained from age-based catch curves for *L. miniatus* from the Townsville area.

### 3.2.6 Length-weight relationship and length-conversion formulae

The parameters of the simple linear regressions of each length measure (standard, fork and total) on each other were calculated to allow a convenient means of conversion. This was particularly useful for comparing our data with other sets expressed in different units. The length-weight relationship was estimated, again using the simple linear regression formula, but with log-transformed data. Finally, the fillet recovery rate was estimated by subtracting the weight of the frames of fish filleted by professional fishermen from the estimated total weight of the fish (obtained from the length-weight relationship described above). The fillet weight estimates were plotted against total weights to test for non-linearity, or disproportionate change in the flesh-skeleton ratio with increasing size.

## 3.3 RESULTS

### 3.3.1 Reproductive development and chronology

Some information on the reproduction of *Lethrinus miniatus* is available. Walker (1975) examined gonosomatic indices and concluded that the breeding season for the species occurred around July-August in the Townsville area. Walker (1975) did not do any histology and provided very limited information on potential sex change and the size and age of first reproduction. Young and Martin (1982) provided some preliminary information on the reproduction of *L. miniatus* based on histology of gonads from a small sample of fish. Church (1989) studied reproduction in the species at Norfolk Island.

#### 3.3.1.1 Spawning season

Gonosomatic indices calculated (SFC) for males aged 3 years or greater (Fig. 66) suggested that most reproductive activity was taking place in spring, although there was evidence of earlier development of male gonads in the Swains during 1992. Unfortunately, the lack of samples in some months made statistical comparisons between the two regions difficult, but there were no obvious differences. Female gonosomatic indices (Fig. 67) likewise showed most reproductive activity occurring during September-November,

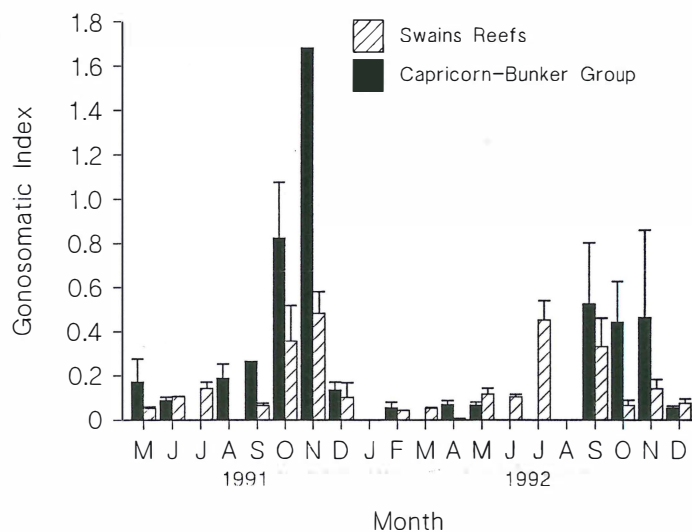


Figure 66 Seasonal changes in gonosomatic index of male *L. miniatus* > 2 yr old. Bars represent 1 S.E. either side of the mean.

and there was an indication of some gonad development taking place in fish from the Swains Reefs during the winter of 1992. When the gonads were staged histologically (SFC), the evidence for earlier spawning in the Swains population was even stronger. Mature fish were caught during June/July 1991 at the Swains when they were absent in samples collected in the Capricorn-Bunker Group. There was evidence of spawning activity at both areas in all months apart from February-May 1992 and December 1992.

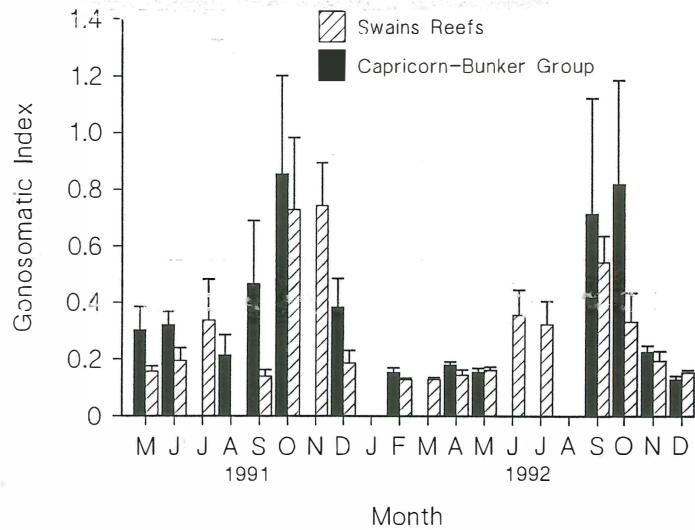


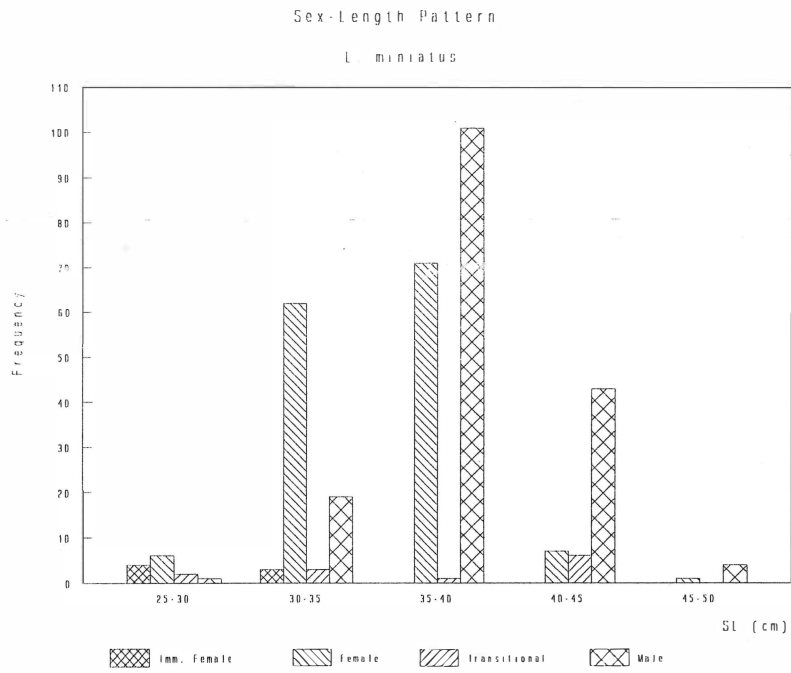
Figure 67 Seasonal changes in GSI of female *L. miniatus* > 2 yr old. Bars represent 1 S.E. either side of the mean.

### 3.3.1.2 Histological development - evidence of protogyny

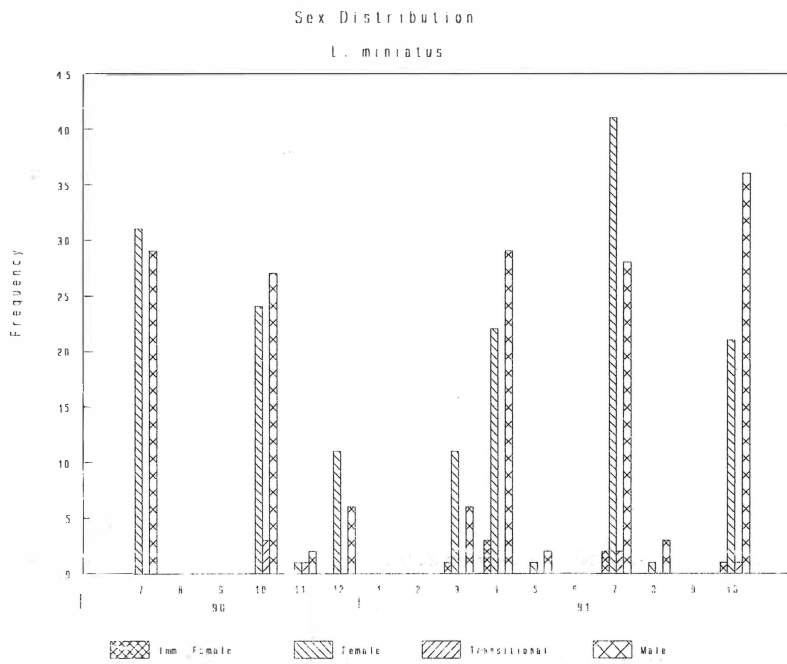
The sex composition of 5 length classes of *L. miniatus* from Townsville is shown in Figure 68. Females were the dominant component of the 25-30 and 30-35 cm (SL) size classes. Males and females were almost equally abundant in the 35-40 cm (SL) size class with males dominant in the 40-45 and 45-50 cm (SL) size classes. Although some fish in the 25-30 cm (SL) size range were reproductively active, most fish were reproductively active in the 30-35 cm (SL) size range (2-3 years old).

In the Townsville region, males and females were approximately equally abundant at most sampling times throughout 1990 and 1991 (Fig. 69). *L. miniatus* appears to spawn in July-August, with spawning fish still abundant as late as October (Figs. 70 and 71). Gonads of most fish were resting during March and April. The limited range of months for which samples were available precludes any further generalization about the spawning pattern of *L. miniatus* in the Townsville area. Table 34 provides a summary of the sex composition of the 334 *L. miniatus* examined in detail (JCU).

The monthly samples of *L. miniatus* from both southern locations sampled (SFC) were generally dominated by females (Figure 72) and overall a total of 1612 females and 362 males were sampled. Statistically there were significantly more females in samples from both the Capricorn-Bunker reefs ( $t = 7.81$ ,  $df = 16$ ,  $P < 0.001$ ) and the Swains Reefs ( $t = 4.39$ ,  $df = 18$ ,  $P < 0.001$ ). All fish less than 30 cm (FL) were females and there were some females captured throughout the entire size range although males often dominated the larger size classes (Figure 73). It was not until fish reached around 45 cm (TL) that males comprised 50% of the samples (Fig. 74).

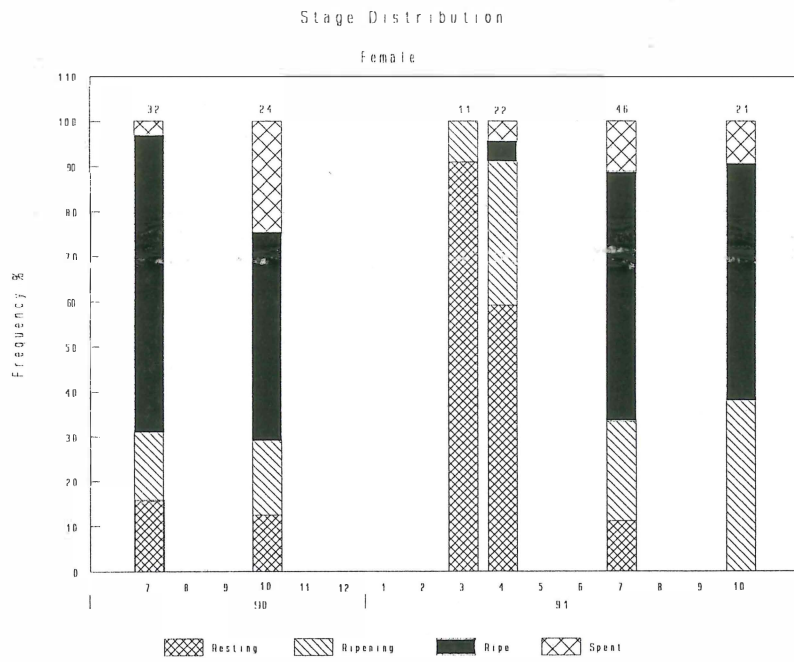


**Figure 68** Sex vs SL for *L. miniatus* in the Townsville area.

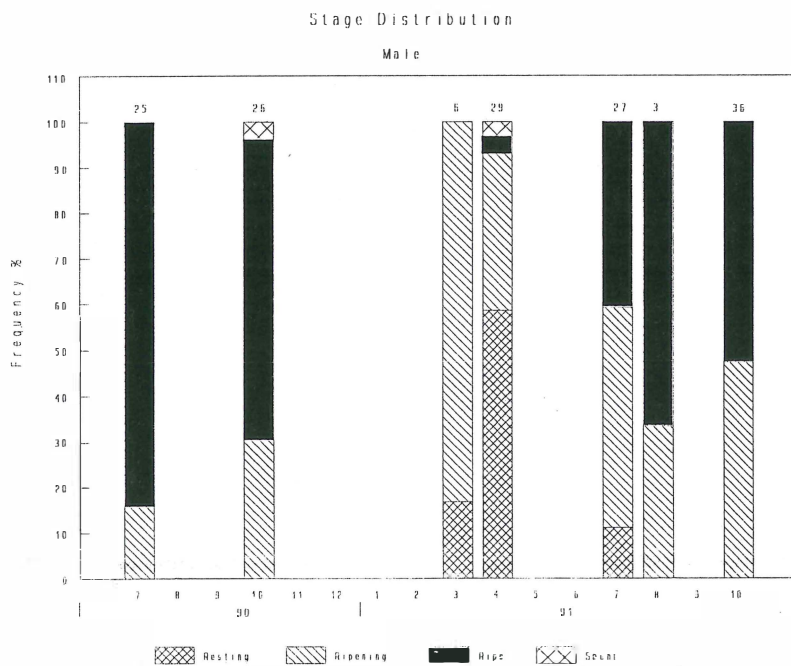


**Figure 69** Sex composition of the samples of *L. miniatus* collected in each sampling month in the Townsville area.





**Figure 70** Relative abundance of gonad stages of mature female *L. miniatus* from the Townsville area. Sample sizes are shown.

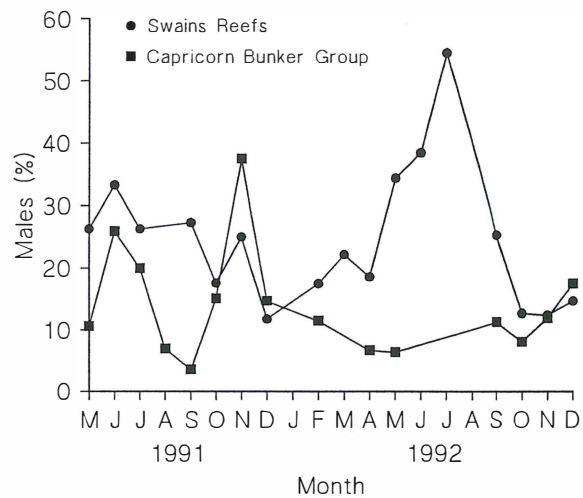


**Figure 71** Relative abundance of gonad stages in male *L. miniatus* from the Townsville area. Sample sizes are shown.

**Table 34.** Sex composition of *Lethrinus miniatus* collected in the Townsville area in 1990 and 1991.

SEX	STAGE NUMBER	
Female	Immature	7
	Mature	147
Transitional		12
Male	Mature	168
Total		334

Similarly males did not appear in samples until about age 3 (Figure 75) but there were four 2 year old fish classified as males. These fish ranged in length between 31 and 33.5 cm (FL) and were all captured in the period July-October. Fish aged at six years were equally represented by males and females, but females became progressively outnumbered by males at increasingly greater ages. However, the oldest fish sampled (25 yr) was in fact a female. Over 95% of all males (including all 2 year old males) which were examined histologically had sperm sinuses, brown bodies and a remnant lumen. In the majority of the other 5% of male sections these features were probably not visible because of inadequate sample preparation and sectioning. There was only one fish whose gonad contained both ovarian and testicular tissue. That fish was a 41 cm (FL), 5 year old fish captured during September.

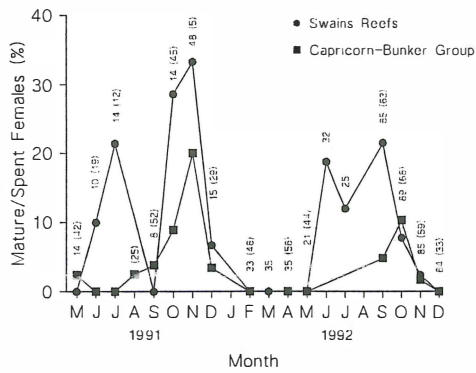


**Figure 72** Seasonal change in the sex ratio of *L. miniatus* from the Swains Reefs and the Capricorn-Bunker Group.

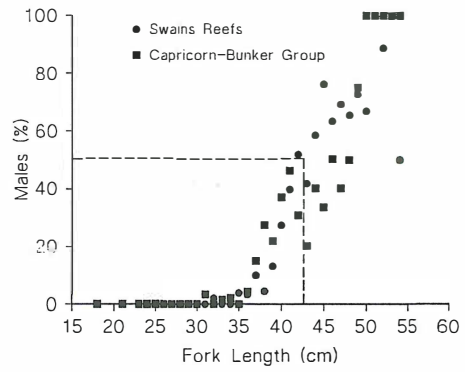
examination of gonads failed to adequately provide features which could be used to consistently distinguish resting females from virgins. This made it difficult to determine the size or age at sexual maturity.

However, by plotting the size and age of fish of various gonad stages during the presumed spawning season (July - November) it was possible to gain some idea of the size and age at which *L. miniatus* are capable of spawning. These data are presented in Figures 76 and 77.

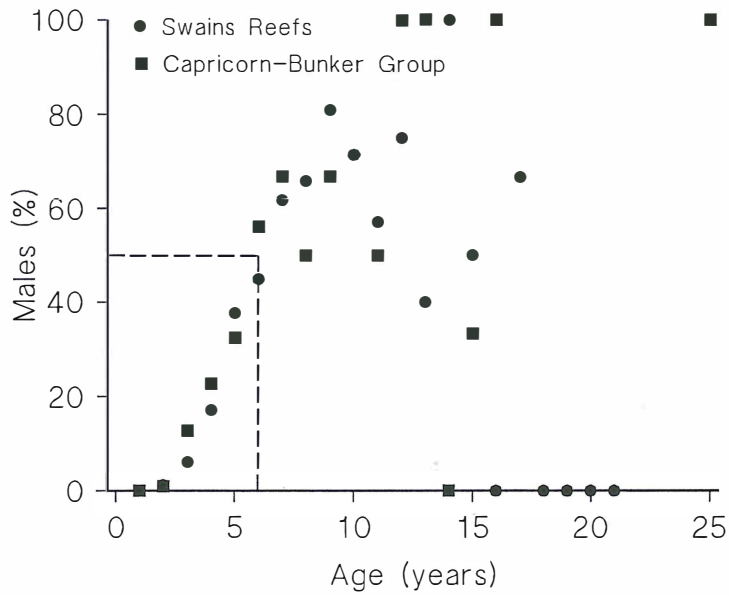
There were no 1-year old fish or fish less than 30 cm (FL) which showed any sign of vitellogenesis (stage 3 oocytes) during the spawning season and likewise there were few 2-yr olds or fish between 30 and 34 cm FL which had vitellogenic oocytes (stage 3). It was not until age 6 (40 cm FL) that the majority of fish caught during the spawning season had active gonads and most of these were males.



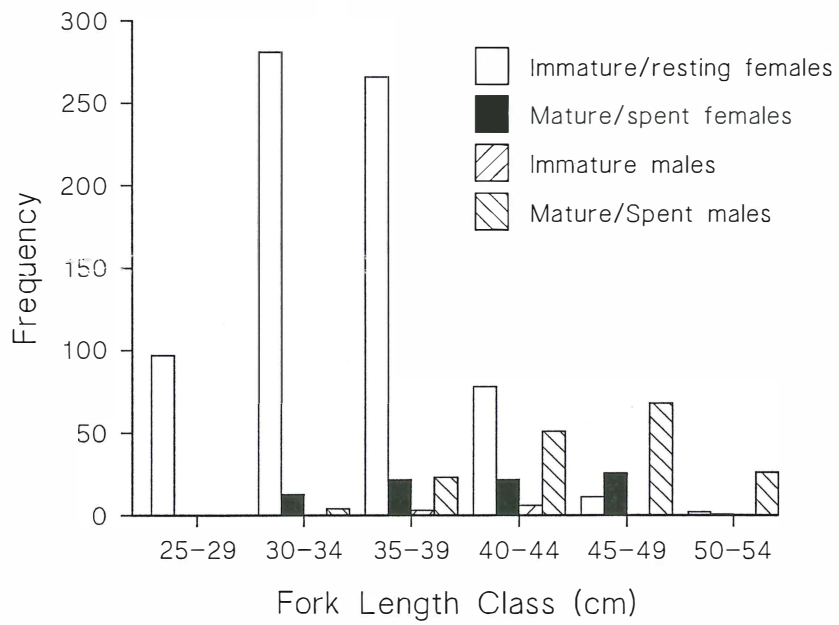
**Figure 73** Seasonal change in the ratio of mature to spent females. Sample sizes are shown (Capricorn-Bunkers in brackets).



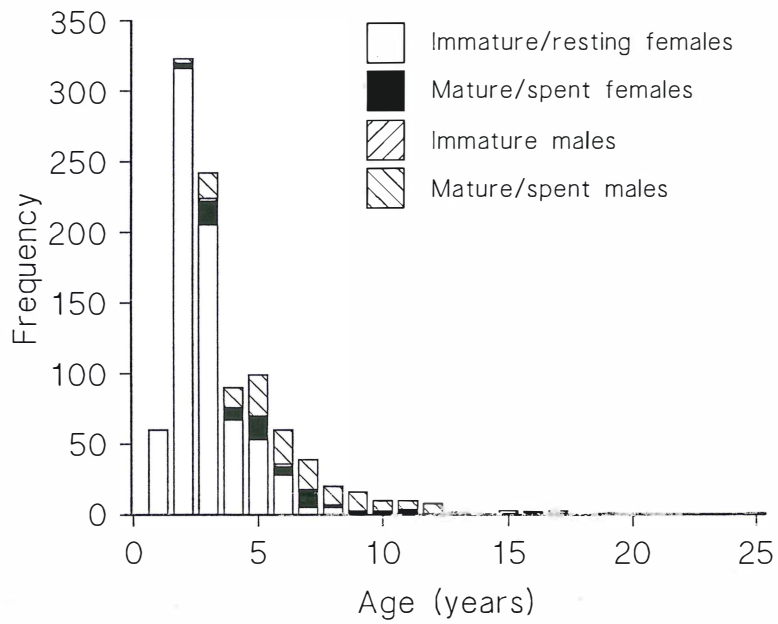
**Figure 74** Relationship between size (FL) and sex ratio in *L. miniatus* from the southern GBR.



**Figure 75** Age-related changes in the sex-ratio of *L. miniatus* from the southern GBR.



**Figure 76** Frequency of gonad development stage of *L. miniatus* related to different size classes.



**Figure 77** Frequency of *L. miniatus* gonad stages in relation to age.

### 3.3.2 Age estimation and validation

#### 3.3.2.1 Analysis of readability

Whole otoliths (under oil and with incident lighting) displayed a reasonably discernable series of growth rings and bands. The allometric growth characteristics of lethrinid otoliths (Loubens 1978) make it somewhat more difficult to discriminate the outer rings in old fish (the structure increases in thickness more quickly than in length or width), but only about 2% of the whole otoliths were totally unreadable.

A clear ring structure was also apparent in sections viewed under incident light with a black background. Broad zones of clear crystalline material alternated with narrow milky-white bands or rings. The broad clear zones are interpreted as growth zones and the milky rings as growth checks. The seasonal periodicity of deposition of these structures has not yet been determined. In some cases the rings cutting the longitudinal axis of the section (corresponding to the dorso-ventral axis of the otolith in situ) were quite distinct, but frequently they anastomosed resulting in false rings which were not consistent in position or shape. A series of bands was regularly visible along the ventral wall of the *sulcus acousticus*, but there was very little contrast between growth zones and checks in this region.

The most consistently distinct banding was found in the ridged dorsal wall of the *sulcus acousticus* (see Fig. 78), and it was this part of the otolith which was used primarily for age estimation. Here the milky-white growth checks each expanded slightly, creating the appearance of a series of bright dots along the *sulcus* wall. In contrast to the situation with whole otoliths, the outer rings in sections of otoliths from old fish were easier to count and interpret than the innermost ring. It is probable that in this first analysis some two-year old fish were misclassified as age 1 because one of the first two growth checks was indistinct.

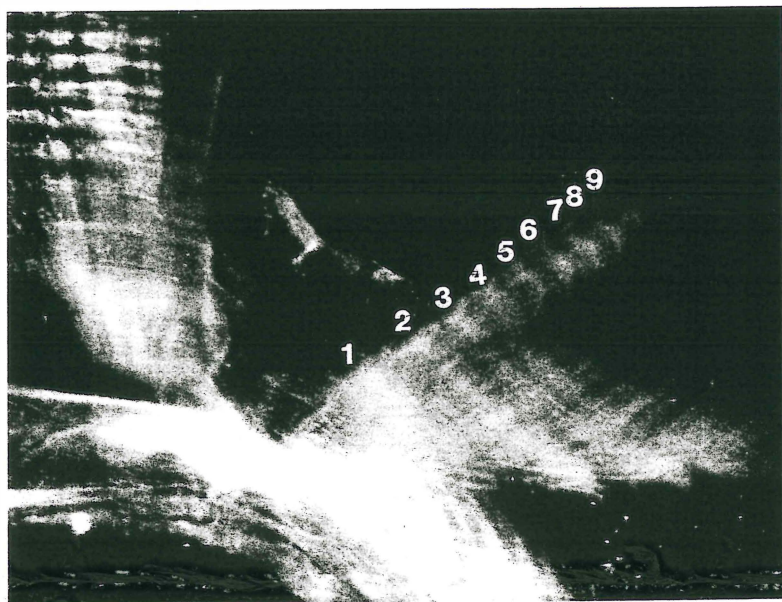


Figure 78 Photograph of a section through the focal region of the sagittal otolith of a 9-yr old *L. miniatus* from the Swains Reefs.

Early comparisons of age estimates derived from whole and sectioned otoliths (SFC) suggested that there was a consistent bias at older ages (greater than about 6 yr), with whole otoliths giving lower estimates than the sections. A number of

studies have shown that sections are likely to provide more accurate age estimates than whole otoliths because of the tendency in larger fish for the thickness of the otolith edge to obscure its internal structure. For this reason it was decided that age estimates for *L. miniatus* would be based on otolith sections. However to confirm the significance of the differences between the two methods, all otoliths were aged whole as well.

The bias in age estimates between whole and sectioned otolith readings is depicted in Figure 79. The vertical axis represents the mean difference (in years) between section and whole ages for each section age. Prior to age 3 there was a tendency for whole otoliths to give slightly *higher* age estimates than the sections, possibly because of the lack of clarity of the first annulus referred to above. From age 3 to 7 the two methods provided very similar estimates, with D only marginally greater than zero. However above 7 years there was a consistent upward trend in D, signifying a progressively larger discrepancy between estimates provided by the two methods. Despite the wide confidence limits associated with low sample sizes, there is little doubt that, in older fish, ages determined from whole otoliths may be as much as 3-4 years lower than those derived from sections.

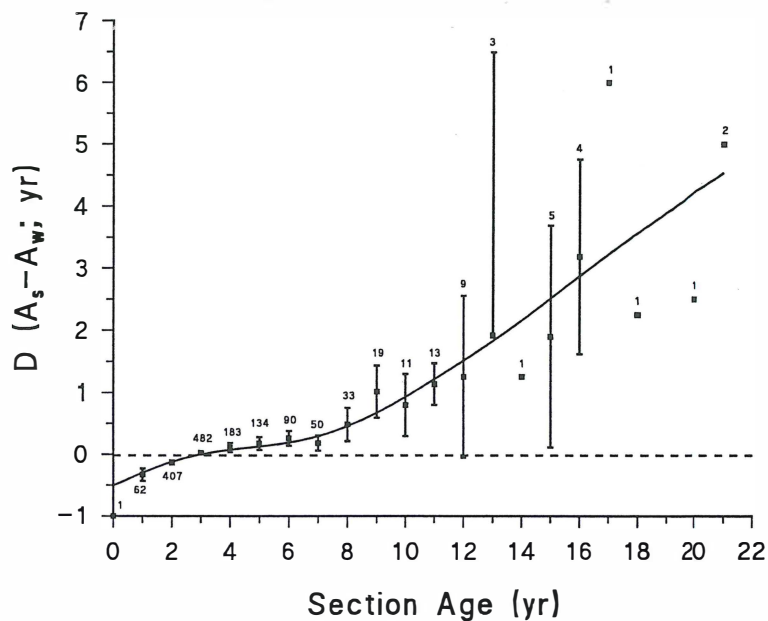


Figure 79 Bias between age estimates for southern GBR *L. miniatus* based on whole otoliths ( $A_w$ ) and sectioned otoliths ( $A_s$ ).

### 3.3.2.2 Precision estimates

The precision of redthroat age estimates carried out at the Southern Fisheries Centre on material from the Capricorn-Bunker Group and the Swains Reefs was calculated according to the index of average percentage error (IAPE) of Beamish and Fournier (1981). IAPE was calculated for all fish ( $n=373$ ) where four readings were made on the whole otoliths and three on the sectioned otoliths. Interestingly, the IAPE was substantially lower for the whole otolith readings (0.0528) than for the sections (0.1387).

### 3.3.2.3 Otolith exchange programme

In order to ensure that the two laboratories (SFC and JCU) involved in age and growth estimates for the redthroat emperor were producing consistent results, a small subset of otoliths was read at both labs and the results compared. Eighteen sections were selected from Trips 39 (May 1992) and 41 (June 1992), both from commercial samples from the Swains Reefs. Neither otolith reader had access to any ancillary information (e.g. on fish size) and naturally the second set of readings was done without any reference to the results of the first set. The results of the exchange, shown in Table 35, indicated a very high level of concordance between the two laboratories.

Differences in age estimates occurred in only four of the 18 specimens, and in none of those four cases was the difference greater than one year. However a paired t-test showed that the mean difference between readings from the two labs was significantly different from zero ( $t = 2.20$ ;  $p = 0.042$ ), because the direction of variation was evidently non-random. A similar test showed that the two readers essentially agreed upon the readability of the otoliths ( $t = 1.05$ ,  $p = 0.310$ ) although there was some variation due to the subjective nature of the 0-5 rank readability scale.

**Table 35.** Comparison between laboratories (Southern Fisheries Centre [SFC] and James Cook University [JCU]) in the estimation of age of the redthroat emperor *Lethrinus miniatus* from sectioned otoliths. Readability indices (RI) for each section are also shown.

TRIP	ID No	SFC		JCU	
		AGE	RI	AGE	RI
41	2	5	2	5	2
41	5	12	2	13	3
41	6	13	2	13	2
41	9	5	4	6	2
41	12	3	4	3	3
41	14	9	3	9	4
41	19	21	2	21	3
41	21	3	3	3	3
41	23	3	3	3	3
41	24	3	3	3	1
41	27	4	4	4	2
41	28	3	4	3	3
41	30	2	2	2	3
41	31	4	4	4	3
41	33	4	4	4	3
39	17	5	3	5	4
39	36	2	2	3	1
39	64	4	2	5	3

### 3.3.2.4 Otolith weight-age relationship

To assist with present and future interpretation of differences in age determinations between readers and between laboratories, ages were referred to an independent variate (otolith weight). This can be estimated with greater precision than total fish length and is likely to be less subject to natural variability.

The otolith weigh frequency distribution for all redthroat emperors aged from the southern GBR region, regardless of date of collection, is shown in Fig. 80. The distribution is, as expected, skewed to the right, no doubt as a result of the age-structure of the population. Otolith weights ranged from about 20 mg to 600 mg, with a mode at around 150 mg. The absence of clearly-defined multimodal peaks (which might indicate distinct age-classes) is undoubtedly due to the fact that the data were pooled temporally.

The relationship between otolith weight and age in *L. miniatus* was not rectilinear. An initial plot of the two variables suggested a decaying exponential relationship not unlike the three-parameter von Bertalanffy growth model. This model was found to be an exceptionally good fit to the data (Figure 81), and the relationship is defined by the following equation:

$$W_0 = 0.693 * (1 - e^{-0.061(A + 1.293)})$$

where  $W_0$  is the otolith weight (g), and  $A$  is age (yr). The goodness of fit is indicated by the regression  $R^2 = 0.896$  (d.f = 1992).

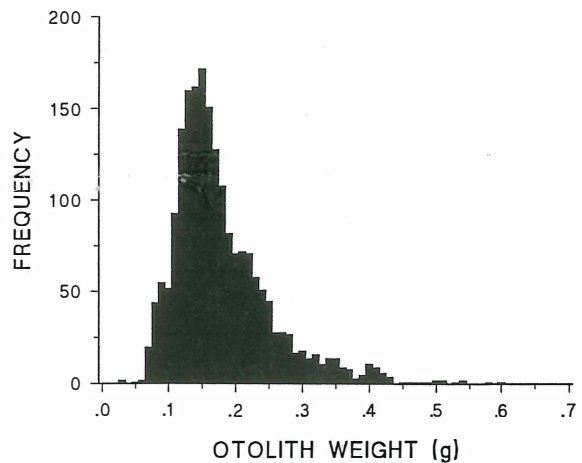


Figure 80 Otolith weight frequency distribution for all southern GBR *L. miniatus* samples pooled.

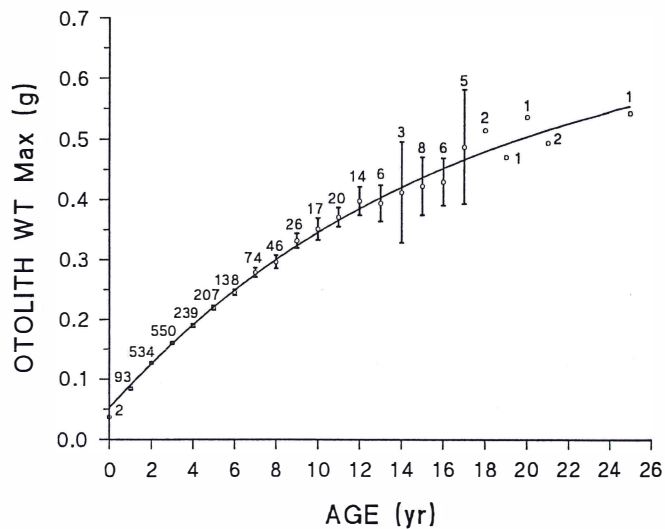
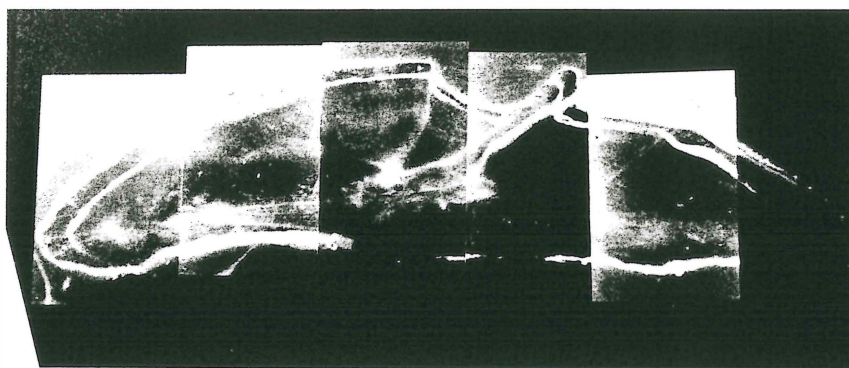


Figure 81 Relationship between otolith weight and age of *L. miniatus* from the southern GBR. Sample sizes and 95% confidence intervals are shown.



### 3.3.2.5 Validation of age estimates

Age estimates for *L. miniatus* have not yet been validated directly. Between 2.8.89 and 29.1.93 some 667 redthroat emperors, along with other demersal reef species, were tagged with dart or t-bar anchor tags (Hallprint, Sth Australia), injected with oxytetracycline (25-35 ml kg<sup>-1</sup> body weight) and released in various parts of the Capricorn-Bunker Group (SFC). One of the main release sites was along the north-west face of Llewellyn Reef. At the dosage administered the tetracycline is incorporated into the otoliths of proximal growing surface of *L. miniatus* otoliths, forming a clear narrow fluorescing band parallel to the margin (Fig. 82). While marked and tetracycline-labelled coral trout (*Plectropomus leopardus*) were recaptured after periods at liberty of up to 18 months, the only *L. miniatus* recaptured to date had been tagged less than 12 months previously, making attempts to validate the annual periodicity of otolith growth checks in this species inconclusive.



**Figure 82** Montage of photofluoromicrographs of a sectioned *L. miniatus* otolith showing the narrow fluorescing band parallel to the edge resulting from the injection of tetracycline.

Instances of poaching on Llewellyn Reef (closed to fishing) are strongly suspected to have occurred, and there is anecdotal evidence that at least on one occasion significant number of tags were removed from fish and destroyed. Non-reporting of tags would, however, have applied equally to the two species. We believe that the paucity of long-term redthroat emperor returns was more likely due to dispersal of these fish into deeper water away from the reef, in contrast to coral trout which tend to remain site-associated.

A validation program involving capture with traps, injection with tetracycline, external tagging and release-recapture was also attempted at Orpheus Island (JCU). This program failed to validate that checks in the sectioned otoliths were annuli.

An indication (albeit indirect) of the validity of our age determinations is, however, given by the otolith weight-frequency distributions for each of the first ten supposed age-classes, shown in Fig. 83. There was some evidence of "smearing" of adjacent age-classes in ages 6-8, but the distributions were essentially unimodal and the differences in position

between successive peaks (as given by the significance of pairwise t-tests in Table 36) strongly indicate annual segregation of the otolith weight samples and therefore correct otolith interpretation.

### 3.3.3 Growth Parameter Estimation and Regional Comparisons

Von Bertalanffy growth parameters were estimated for *L. miniatus* from four regions of the Great Barrier Reef (Cairns, Townsville, Swains Reefs and Capricorn-Bunker Group) separately. As the otoliths from which the Cairns data were derived had been collected some years prior to the commencement of this study, they are not "temporally" comparable with the other areas. In some cases the reliability of the length measurements was somewhat suspect, and the circumstances surrounding the capture of the particular fish are not well documented. However, because of the type of collecting done from Cairns (NFC) during the present study, no samples of *L. miniatus* were obtained from that region, and the earlier material provides our only insight into populations of this species north of Townsville.

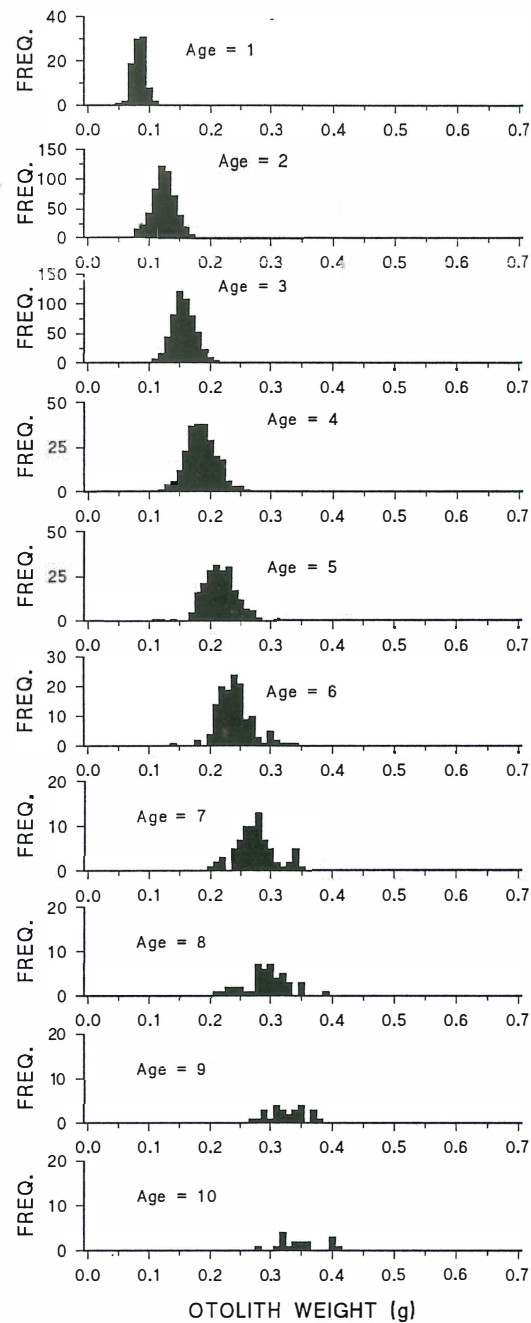


Figure 83 Otolith weight-frequency distribution for the first 10 age-classes of *L. miniatus* from the southern GBR.

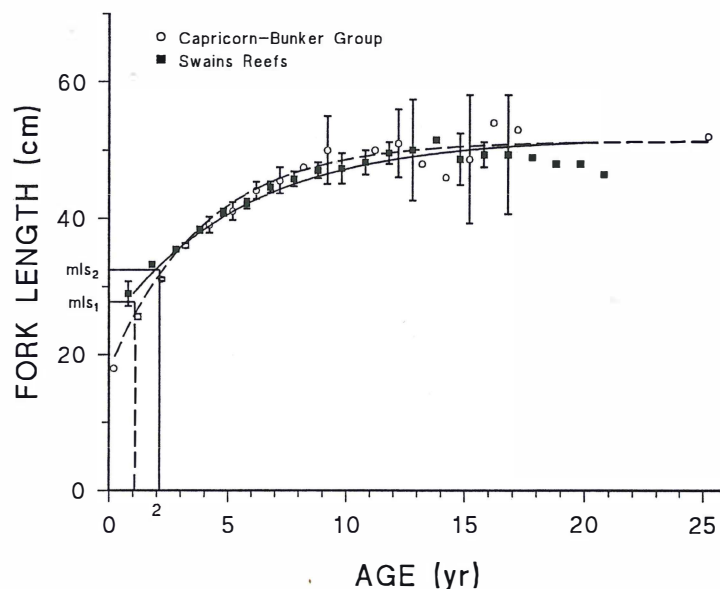
Growth parameters for *L. miniatus* from the Swain Reefs, the Capricorn-Bunker Group, Cairns and Townsville are presented separately in Table 37. Although the  $L_{\infty}$  values for the Swain and Capricorn-Bunker samples were almost identical (52.2 and 51.8 cm respectively), the estimates of  $k$  and  $t_0$  were somewhat divergent. The growth curves in Fig. 84 show a clear statistical difference in the mean lengths of one- and two-year-olds between the two localities, suggesting that fish from the Swains grow much more rapidly

during their first three years than do those from the Capricorn-Bunker population.

**Table 36.** Pairwise t-tests of the significance of differences in mean otolith weight between successive presumed age-classes. Note that all comparisons apart from ages 9 x 10 were highly significant at the 95% probability level.

AGE CLASSES		t	d.f.	p
1	2	-20.26	616	<0.0001
2	3	-28.44	1071	<0.0001
3	4	-17.78	777	<0.0001
4	5	-12.66	434	<0.0001
5	6	-8.18	336	<0.0001
6	7	-7.71	208	<0.0001
7	8	-2.71	118	0.0076
8	9	-4.20	70	0.0001
9	10	-1.92	41	0.0623

The apparent difference in growth characteristics is most likely an artifact of the sampling method. Samples from the Swains were largely derived from commercial catches, and thus (unlike the samples from the Capricorn-Bunker Group) included few fish less than the minimum legal size. To test whether the observed differences in mean length-at-age could have been the result of size-selectivity due to commercial vs. research sampling strategies, we recalculated the mean length of two-year-olds from the Capricorn-Bunkers, using only data for fish of  $FL \geq 32$  cm. The resulting mean length (33.2 cm) was almost identical to that of the Swain Reefs two-year-olds (33.3 cm), strongly suggesting that the Swains sample was biased through selectivity.



**Figure 84** von Bertalanffy growth curves for *L. miniatus* from the Swain Reefs and the Capricorn-Bunker Group.

We do not believe that these data provide any evidence of a significant difference in the growth patterns of *L. miniatus* between the Swain Reefs and the Capricorn-Bunker Group. Because of the sampling bias referred to above we suggest that the growth parameters estimated for the Capricorn-Bunker population should be considered typical of the

**Table 37.** Estimates of von Bertalanffy growth model parameters for *L. miniatus* from the Swain Reefs and the Capricorn-Bunker Group (southern Great Barrier Reef), Townsville (Central GBR) and Cairns (northern GBR), based on age readings from sectioned otoliths.

AREA	$L_{\infty}$	k	$t_0$	$R^2$	d.f.
Swain Reefs	52.25	0.174	-3.719	0.691	1043
Capricorn-Bunker Group	51.80	0.247	-1.782	0.797	707
Townsville	48.02	0.200	-3.510		
Cairns	46.02	0.371	-0.892	0.512	96

southern GBR stock of *L. miniatus*. The mean observed lengths-at-age for Capricorn-Bunker fish were very close to those predicted by the von Bertalanffy relationship (Table 38). This accords with the high value of  $R^2$  (0.797) in Table 37, which provides a measure of the growth model's goodness of fit.

**Table 38.** Comparison between predicted and observed mean lengths at age (with sample sizes and standard errors) for *L. miniatus* from the Capricorn-Bunker Group, southern Great Barrier Reef.

Age (yr)	Observed Length (FL; cm)			Predicted Length (FL; cm)
	Mean	n	s.e.	
1	25.6	86	0.21	25.7
2	31.1	357	0.13	31.4
3	36.0	195	0.18	35.9
4	39.1	44	0.58	39.4
5	41.1	32	0.65	42.1
6	44.1	28	0.62	44.2
7	45.5	11	0.88	45.9
8	47.5	2	2.50	47.2
9	50.0	3	1.15	48.2
10	n.d.	0		49.0
11	50.0	2	1.00	49.6
12	51.0	3	1.15	50.1
13	48.0	1		50.5
14	46.0	1		50.8
15	48.7	3	2.19	51.0
16	54.0	1		51.2
17	53.0	1		51.3

Size at maturity information (Brown, unpubl. data) was the basis of an increase in the minimum legal size of *L. miniatus* in Queensland waters from 30 cm TL (= 27.7 cm FL) to 35 cm TL (= 32.4 cm FL). The effect of this has been to increase the mean age at first capture from 1.3 yr to 2.2 yr (Fig.84).

The small size of the sample from Cairns ( $n = 112$ ), uncertainty about the reliability of the length records, and the absence of small fish ( $<3$  yr old) means that the results from this area cannot be considered as reliable as those from the southern GBR.  $L_{\infty}$  was about 5 cm lower than in either of the two southern GBR samples (Table 37). On the other hand, because of the under-representation of young fish (Fig. 85), the estimated value of  $k$  was larger by a factor of two, and  $t_0$  was correspondingly smaller. The relatively large standard error of the estimate of  $k$  (0.09) and the low model  $R^2$  (0.512; Table 37) indicates the lack of precision of this growth curve in contrast to those from the Swain Reefs and the Capricorn-Bunker Group.

Growth parameters estimated from a sample of 225 fish taken from the Townsville area (JCU) are shown in Table 37, and the corresponding growth curve in Fig. 86.

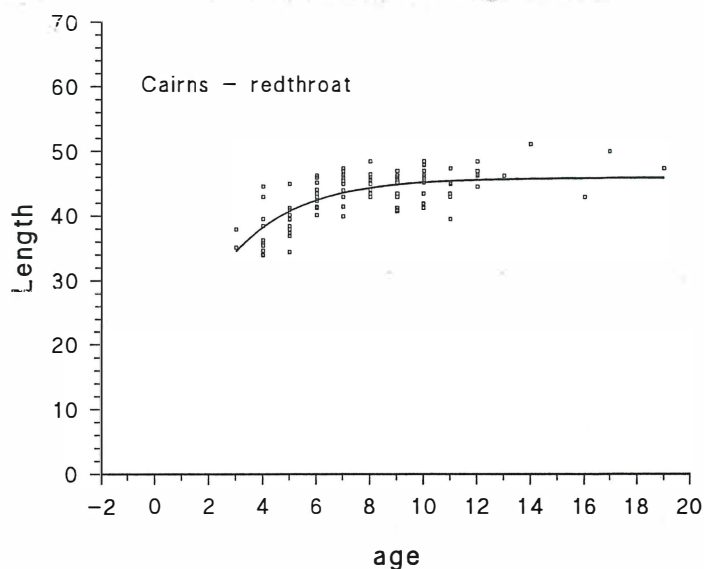


Figure 85 Growth curve for *L. miniatus* from the Cairns area.

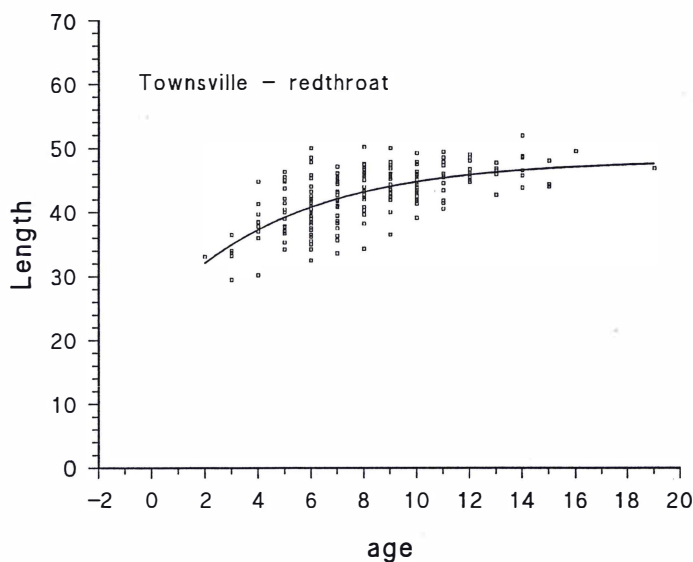


Figure 86 Growth curve for *L. miniatus* from the Townsville area.

### 3.3.4 Total Mortality Rate Estimation

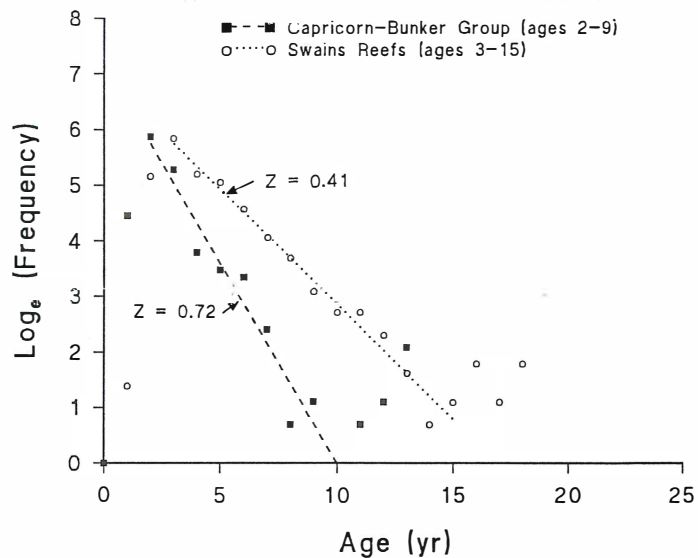
Preliminary estimates of the rate of total mortality of *Lethrinus miniatus* in the Townsville area calculated from an age-based catch curve are given in Table 39. Instantaneous total mortality rates ( $Z$ ) of *Lethrinus miniatus* from the Swain Reefs and the Capricorn-Bunker Group were estimated from age-based catch curves (Fig 87), using standard linear regression techniques. The age at which the populations were fully recruited to the fishery was determined by inspection of the log-transformed frequency-at-age data. The youngest fully-recruited age class was 3 yr in the Swain sample but only 2 yr in the

Capricorn-Bunker sample. This difference is due to size-selectivity as a result of different sampling methods as described above.

Fig. 87 clearly shows a clear difference in the slopes of the descending limbs of the catch curves from the two localities. The instantaneous coefficients of total mortality ( $Z$ ) were calculated on the basis of age groups 2-9 in the Capricorn-Bunkers and 3-15 in the Swain Reefs. These upper cut-off age classes were chosen because in both populations there were more very old fish than might have

been expected on the basis of the mid-life mortality gradient. This may have been due to selective targetting of areas likely to yield larger fish (a possibility in the case of the commercial catch samples, but less so in the case of the research samples), or a real and quite dramatic change in the total mortality rate above a particular age.

The mortality estimate for the Capricorn-Bunker population of *L. miniatus* ( $Z = 0.72$ ;  $R^2 = 0.94$ ) was almost twice that of the Swains population ( $Z = 0.41$ ;  $R^2 = 0.98$ ), the difference in regression slopes being very highly significant ( $t = 4.133$ ;  $p = 0.0007$  with 17 d.f.).



**Figure 87** Catch curves for *L. miniatus* from the Swain Reefs and the Capricorn-Bunker Group, with estimates of  $Z$ .

**Table 39.** Preliminary estimates of rates of total mortality for *Lethrinus miniatus* in the Townsville area. All estimates of total mortality ( $Z$ ) are calculated from age-based catch curves.

Age Span of Catch Curve	$Z$	95% CI
4 - 16 yr	0.205	0.08 - 0.32
5 - 16 yr	0.271	0.17 - 0.37
6 - 16 yr	0.326	0.22 - 0.43

### 3.3.5 Other morphometric relationships

#### 3.3.5.1 Length - total, standard and fork

The relationships between length measurements for *L. miniatus* from the southern part of the GBR (Swains and Capricorn-Bunker Groups) were estimated using each variate in each pair as the independent variable separately, to allow for an approximate conversion formula in either direction. The parameters of the linear regression models are shown in Table 40.

**Table 40.** Parameters (*a* and *b*) of the linear regression  $Y_1 = b*Y_2 + a$  between several basic length measurements (standard, fork and total length) in redthroat emperor from the southern GBR. Standard errors (in brackets),  $R^2$  values and the probability levels associated with the regression *F*'s are also shown. In all comparisons  $n > 1300$ .

$Y_1$	$Y_2$	<i>a</i> (S.E.)	<i>b</i> (S.E.)	$R^2$	<i>p</i>
FL	SL	0.596 (0.136)	1.143 (0.004)	0.982	<0.001
SL	FL	0.061 (0.119)	0.858 (0.003)	0.982	<0.001
SL	TL	0.097 (0.156)	0.794 (0.004)	0.968	<0.001
TL	SL	1.109 (0.191)	1.219 (0.006)	0.968	<0.001
LF	LT	-0.101 (0.080)	0.928 (0.002)	0.991	<0.001
LT	LF	0.461 (0.085)	1.067 (0.002)	0.991	<0.001

#### 3.3.5.2 Length-weight relationship

The relationship between body weight and fork length is given by the formula

$$\ln(W) = -4.196 + 3.061 * \ln(L)$$

where *W* = total body weight (g) and *L* = fork length (cm).

#### 3.3.5.3 Fillet weight recovery rate

The proportion of the total body weight recovered as fillets from the redthroat emperor was estimated using the total weight - fork length relationship shown above (for southern GBR fish) and frame weight from samples supplied by commercial fishermen. Firstly the total weight of fish supplied as frames was computed from the frame FL, then the frame weight subtracted to produce an estimated fillet weight. The frames were supplied with viscera intact (to enable sampling of reproductive organs), and were filleted by competent

fishermen, so we believe the estimates are reliable. The only factor not taken into consideration is the weight of the skin and scales (which would be normally be removed from the fillets before freezing), but this is not likely to represent a significant fraction of the fillet weight and has been ignored.

A scatter plot of the relationship between estimated fillet weight and estimated total weight was examined by eye for non-linearity (i.e. in case the proportional meat return varied with fish size). However the relationship appeared to be rectilinear, and linear regression parameters were therefore estimated ( $R^2=0.942$ ,  $n=800$ ). The resulting formula relating fillet weight to total body weight (both measured in grammes)

$$W_{\text{fillet}} = 0.43 * W_{\text{whole}} - 12.28$$

indicates that, on average, the fillets of *L. miniatus* comprise a little over 40% of the total weight of the fish, a somewhat lower return rate than that estimated for coral trout (Section 2.3.8.3).

## 3.4 DISCUSSION

### 3.4.1 Reproduction

A number of results of the present study support earlier suggestions of protogynous hermaphroditism in *L. miniatus*. Young and Martin (1982) examined eight *L. miniatus* collected from the Gulf of Carpentaria and observed crypts of spermatogonia in gonads which also had degenerating oocytes. Likewise, Church (1989) found the length frequency distribution of male *L. miniatus* at Norfolk Island was displaced to the right. Both of these findings suggesting protogyny. Sadavoy and Shapiro (1987) have reviewed the criteria for diagnosing hermaphroditism in fishes and noted that bimodality in size-frequency distributions on its own is not a reliable indicator of sex reversal. They suggested that a number of indicative features such as brown bodies, sperm sinuses, a remnant lumen and transitional individuals need to be observed. Here we have recorded the presence of brown bodies, sperm sinuses and a remnant lumen in the histological sections of the majority of male gonads, as well as the collection of a gonad which had both male and female tissues. Sexual bimodality in both age and length frequency distributions was further strong evidence of protandrous hermaphroditism. It was not until approximately age 6 (40 - 45 cm FL) that the number of males in samples equalled the number of females. It was interesting to note the sampling of a few 2 year old males. These fish were all close to 3 years old because they were all sampled after June and there was a large marginal increment between the last opaque band and the edge of the otolith. It appears that these fish spawned as females at the end of their second year and had changed into functional males just prior to their third birthday when they were apparently capable of spawning as males. The mechanism that triggers sex reversal in these fish is unknown, but it is clear that there is no particular size or age at which sex change occurs since primary females over 20 years of age, and secondary males less than 3 years old were caught.



Age and size of first reproduction derived for *L. miniatus* from the southern Great Barrier Reef were 3 yr and 35-40 cm FL (equivalent to approximately 30-35 cm SL). Despite this some fish as small as 30 cm FL were sexually mature. Walker (1982) suggested that sexual maturity in *L. miniatus* from the central Great Barrier Reef was attained by fish as small as 35 cm FL, a size considerably larger than the smallest mature female sampled by the present study. However the estimates of average age and size of first reproduction were in broad agreement between the two studies.

Spawning activity of *L. miniatus* from the southern Great Barrier Reef takes place over an extended period from July to November, with the bulk of spawning occurring during the latter three months of this period. There was also evidence of fish spawning earlier at the Swains Reefs than at the Capricorn Bunker Group. Walker (1975) concluded that *L. miniatus* from the central Great Barrier Reef spawned predominantly during July and August. This suggests that spawning is initiated earlier at lower latitudes, a well documented feature of fish reproduction.

Size and age of first reproduction for *L. miniatus* in the Townsville area (30-35 cm SL, 2-3 years) estimated here agrees well with estimates made by Walker (1975) (35 cm SL, 3 years). Walker (1975) also noted that *L. miniatus* could mature at 31 cm SL. The present study has recorded mature fish in the 25-30 cm SL range.

On the basis of gonosomatic indices and maximum ovum diameters Walker (1975) concluded that reproduction of *L. miniatus* in the central Great Barrier Reef (off Townsville) peaked in July-August, the coldest months of the year. The limited amount of information available from this study based on histological examination of gonads from 334 fish supports this interpretation.

Information on the distribution of sexes by length and histological evidence including the presence of transitional fish, support the contention of protogynous hermaphroditism for *L. miniatus*. Examination of the size/sex relationships, gonad structure and histology of eight species of Lethrinidae (*L. nematacanthus* (= *genivittatus*), *L. choerorhynchus*, *L. lentjan*, *L. variegatus* (= *Lethrinus* sp.2) *L. rubrioperculatus*, *L. chrysostomus* (= *L. miniatus*), *L. nebulosus* and *L. fraenatus* (= *L. laticaudis*)) from the North-West Shelf and Gulf of Carpentaria led Young and Martin (1982) to conclude that protogynous hermaphroditism is the typical mode of sexuality in lethrinids.

Unfortunately Young and Martin had access to only eight *L. miniatus*. They did, however, observe small crypts of gonia adjacent to the germinal epithelium in mature ovaries of this species and some gonads exhibited proliferation of spermatogonia from these crypts concomitant with cellular infiltration and degeneration of oocytes. Loubens (1980) found size-related bias in sex ratios in *L. miniatus* and concluded that this may be due to sequential hermaphroditism. Church (pers. comm.) has confirmed protogynous hermaphroditism in the Norfolk Island population of *L. miniatus*.

### 3.4.2 Age and growth

A number of studies have shown that sections are likely to provide more accurate age estimates than whole otoliths because of the tendency in larger fish for the thickness of the otolith edge to obscure its internal structure (Irie 1960, Loubens 1978, Boehlert 1985). We confirmed this phenomenon in otoliths of the redthroat emperor *L. miniatus*. While whole otoliths can be used satisfactorily for fish less than five or six years old, at ages greater than this the whole otolith method consistently underestimated age by about 33% per year for each additional year. Our analyses revealed that the rate of otolith growth in this species declines with increasing age. This is consistent with a model in which otolith growth occurs mainly in one dimension (thickness) and reflects age-related changes in somatic growth patterns. Despite the wide confidence limits associated with low sample sizes, there is little doubt that, in older fish, ages determined from whole otoliths may be as much as 3-4 years lower than those derived from sections.

The higher precision for whole otoliths (IAPE = 5.3%) than sectioned otoliths (IAPE = 13.9%) was due to the fact that most of the whole otoliths were read by a single reader, while the sections were read by several different readers. Differences in interpretation between readers (some of whom had had no prior experience reading redthroat emperor otoliths) were anticipated during the early part of the project. It might also be expected that measurement variability from an otolith section would be greater than from the corresponding whole otolith, where (on average) fewer rings were in evidence. A similar result was found with the otoliths of coral trout (*Plectropomus leopardus*) from north Queensland (JCU) with IAPEs of 6.7% and 12.1% for whole and sectioned otoliths respectively.

The differences in growth parameter estimates for *L. miniatus* between the Swain Reefs and the Capricorn-Bunker Group suggested initially that the two populations may represent separate reproductive stocks. However by making adjustments to compensate for selectivity bias, we found that their growth characteristics are essentially identical. While the two areas are geographically distinct and differ in their geomorphology, they are connected by a relatively shallow (<100 m) inter-reef area which would not appear to present any physical barrier to the passage of eggs or larvae, and it seems unlikely that these two populations are genetically isolated.

Growth parameters estimated from the Cairns sample are characterised by a much larger  $k$ , a substantially lower  $L_{\infty}$  and a smaller (negative)  $t_0$  than that of the Capricorn-Bunker population. These estimates should be considered indicative only; the accuracy of the length data is not known, and the method of collection of the samples almost certainly means that they were not representative of the population.

Three previous studies (Walker 1975, Loubens 1980 and Church 1985) provide estimates of the growth parameters of *L. miniatus* from length-at-age data. Walker (1975) and Church (1985) used scales to age redthroat emperor from Townsville and Norfolk Is. respectively. Both authors obtained samples from the commercial catch, and found that scales bore what they considered to be annual growth rings, which they validated by marginal increment analysis. In the present study we examined many *L. miniatus* scales, but were unable to demonstrate the presence of consistent and convincing growth checks.

Marks in the form of darker circuli were reported to occur on scales (Walker 1975). By sampling at approximately monthly intervals over a 2 year period Walker demonstrated that the distance from the outermost circular mark to the scale margin on scales with 4 or 5 marks was minimal in October-November and maximal in June and July. He concluded that the marks were annuli laid down in October-November. Walker (1975) suggested that growth slowed down in the winter months and increased in spring, when annulus formation occurred. He did not nominate a particular environmental factor that was most likely to cause check formation but noted that "spawning is unlikely to be the cause for in this study annuli were found on scales of small fish which had not attained sexual maturity".

Walker (1975) first estimated  $L_{\infty}$  (58.5) from the Ford-Walford plot of  $L_{t+1}$  on  $L_t$ , then  $k$  (0.174) and  $t_0$  (-2.26) from the slope and intercept respectively of the regression of  $\log(L_{\infty}-L_t)$  on  $t$ . As Walker's (1975) growth data were expressed in terms of standard length rather than fork length, we converted his mean standard length-at-age data using the regression parameters shown in Table 41, and re-fitted the growth curve to the converted means to enable a direct comparison with our results. The growth parameters are approximated as  $L_{\infty}(\text{FL}) = 68.8$ ,  $k = 0.16$ , and  $t_0 = -2.47$ . Walker (1975) reported that the oldest fish in the Townsville population of *L. miniatus* (based on scale readings) was 7 yr, and the largest fish, a 7 yr-old, was 48.7 cm SL (56.3 cm FL equivalent). The relatively low maximum age, and the fact that the converted  $L_{\infty}$  was very much greater than the reported  $L_{\text{max}}$ , suggests that the ages of older fish may have been seriously underestimated as a result of the use of scales.

**Table 41.** Estimates of von Bertalanffy growth parameters for *L. miniatus* from Townsville and Norfolk Island. Standard errors where available are shown in brackets.

Reference	Sex	$L_{\infty}$	$k$	$t_0$	Comments
1 Tsv	m+f	58.5	0.174	-2.26	SL
2 Tsv	m+f	68.8	0.163	-2.47	SL converted to FL
3 N.I.	f	65.70 (2.67)	0.109 (0.009)	-2.30 (0.12)	FL, back-calculated
3 N.I.	m	68.33 (1.65)	0.111 (0.006)	-2.26 (0.10)	as above
3 N.I.	m+f	69.90 (1.56)	0.103 (0.005)	-2.30 (0.08)	as above
4 N.I.	f	117.54	0.038	-5.04	From tabulated data
4 N.I.	m	90.26	0.071	-2.53	as above

1 Walker 1975 (Townsville)

3 Church 1985 (Norfolk Island)

2 after Walker 1975 (Townsville)

4 after Church 1985 (Norfolk Island)

Church (1985) used FL in his scale-based estimation of growth rates in *L. miniatus* populations around Norfolk Is. Growth parameters were derived for male and female fish (sexed by macroscopic examination of gonads) from back-calculated lengths using a single scale from each fish. The relationship between fish length and scale age presented in Church's (1985) Tables 1 and 2 showed relatively little curvature. We fitted the von Bertalanffy growth model to these data using standard nonlinear procedures and found unusually elevated asymptotic lengths ( $\bar{\mu}$ : 117.5 cm;  $\bar{\sigma}$ : 90.3 cm) and correspondingly large negative values of  $t_0$  ( $\bar{\mu}$ : -5.04;  $\bar{\sigma}$ : -2.53). Not unexpectedly, the lack of curvature in the data also produced very small  $k$  values ( $\bar{\mu}$ : 0.04;  $\bar{\sigma}$ : 0.07). Church's (1985) growth

estimates, however, were based on back-calculated lengths-at-age, which resulted in parameter values far less extreme than those obtained by our analysis of the raw length-at-age data. For example  $L_{\infty}$ ,  $k$ , and  $t_0$  for female *L. miniatus* were estimated (from standard length-at-age data) to be 65.7 cm, 0.109, and -2.3 yr respectively. Even so, the asymptotic lengths were still greater than  $L_{\max}$  (by 11.3% and 3.5% for females and males respectively), again suggesting that there may have been some underestimation of the age of larger fish.

Loubens (1980) estimated growth parameters for *L. miniatus* (= *L. chrysostomus*) in New Caledonia using adjusted back-calculated length-at-age data derived from whole otolith examination. The estimates of standard length  $L_{\infty}$  (48.9 and 45.7 cm for males and females respectively) approximated fork lengths 55.7 and 52.2 cm respectively using the regression parameters listed in Loubens' (1980) Table A-II. These were consistent with our results for the Swains and Capricorn-Bunker Group but considerably lower than those of Walker (1975) from Townsville and Church (1985) from Norfolk Island. Estimates of  $K$  (0.263 and 0.272 for males and females respectively) were not greatly dissimilar to those we obtained for the Capricorn-Bunker population (0.247), but differed by up to a factor of two from the other data sets.

Walker (1975) commented that growth of *L. miniatus* was "... extremely rapid during the first two years of life", reaching a mean length of 25.24 cm (SL) at the end of year 1. He noted the possibility that during the first year no annulus may have formed or that it was difficult to see, so that all fish in his study may have been one year older than he estimated. The observed mean length at age 1 for the Capricorn-Bunker population (25.6 cm FL) was somewhat less than the 29.4 cm FL equivalent of Walker's estimate. However it is probably still an overestimate of the actual size of one-year-olds because of the likelihood of size-selectivity of the handline fishing method with respect to small size classes. The probability of capture amongst one-year-old redthroat emperor is almost certainly a function of size, with larger, faster-growing members of the cohort being more vulnerable to the particular fishing method. Unbiased estimates of the mean lengths of the first couple of age classes will probably not be available until the juvenile habitat of this species is discovered and representative samples can be obtained.

Assuming that natural mortality rates are similar in the two areas, this suggests that the Capricorn-Bunker population is subject to a very much higher level of fishing mortality ( $F$ ) than that in the Swain Reefs. If the exploitation rate of the Swain population were assumed to be 0.25 (a not unreasonable estimate, considering the area's very extensive habitat and relative inaccessibility), then  $M_S = 0.4 - 0.1 = 0.3$ . If  $M_S = M_{C-B}$ , then  $F_{C-B} = 0.7 - 0.3 = 0.4$ . The only independent estimate of total mortality for *L. miniatus* was calculated by Williams and Russ (1991) from Walker's (1975) original data. Their estimate (0.74) is considerably higher than the range (0.20-0.33) reported here for present Townsville and Swains populations, but it is almost identical to the estimate from the Capricorn-Bunker population. While the Townsville population was probably heavily fished during the time of Walker's study, fishing mortality is likely to have been significantly less than it is now, two decades later. We attribute Walker's (1975) high  $Z$  to a significant underestimation of potential the ages of larger fish, as a result of the use of scales rather than otoliths.

## 4 STOCK STRUCTURE

### 4.1 SPECIFIC OBJECTIVES

- 1) To accumulate a collection of material that could be incorporated into population genetic studies of reef fish species.
- 2) To determine optimum conditions for allozyme electrophoresis for each species.

The ultimate aim is the identification of stock structure, and aspects of taxonomy and recruitment processes in the three species of fish mentioned above, that are associated with tropical commercial fisheries. The finalisation of this aim will be subject to successful grant applications to funding bodies in the future. The proposed project will directly address management requirements, by supplying information on the stock structure of populations and examination of recruitment processes and breeding aggregations.

### 4.2 MATERIALS AND METHODS

The strength and eventual success of a population genetics study rests on the ability to identify a sufficient number of polymorphic genes and to detect, interpret and quantify the patterns of genetic variation characteristic of each variable gene locus in each species. Therefore the primary objective of this extension of the FRDC Project was to conduct a pilot study that examined experimental variables; gel medium, buffers, tissues and enzymes, necessary to conduct a thorough study for each species.

A prerequisite of determining genetic heterogeneity of stocks is the collection of suitable material. As part of FIRDC Project 90/18, Dr Ian Brown and others collected frozen material of coral trout and red-throat emperor from throughout the GBR. Tissue samples of these species were also collected from locations in Western Australia by Dr Mike Moran. Similarly, Ms Julie Lloyd made available samples of gold-band snappers from the Timor and Arafura Seas and Western Australia, with the assistance of CSIRO. All samples collected to date are listed in Table 42.

Adequate samples sizes, large enough to show significant levels of heterogeneity for medium frequency alleles, have been collected from some areas. However, additional sampling is required from particular locations to boost sample numbers above 100 per location so that a broad scale population comparison can be made, i.e. for *P. leopardus* from the southern GBR and of *L. miniatus* from the north GBR. Additional fresh material is also required for *Pristipomoides multidens* because of the denaturation of some earlier samples. This additional collection and the costs involved in the collection of sample data and analysis will be a component of a QDPI application for 1995/96.

**Table 42.** Details of the origin of samples collected for genetic analysis.

Species	Location	Number	Date
<i>Plectropomus leopardus</i>	north GBR	103	8/89 - 1/90
	south GBR	32	4/91 - 6/91
	Abrolhos Is, W.A.	116	3/90
<i>Plectropomus maculatus</i>	south GBR	3	8/91
	W.A. coast	33	6/91
<i>Lethrinus miniatus</i>	north GBR	18	11/89
	south GBR	181	10/91 & 9/92
	Ningaloo Reef, WA	92	9/91
	Abrolhos Is, W.A.	65	10/91
	other WA locations	118	6/91 - 19/91
<i>Pristipomoides multidens</i>	Arafura Sea, N.T.	105	9/91
	Timor Sea, N.T.	53	2/92
	Western Australia	40	8/91
<b>TOTAL</b>		959	

### 4.3 RESULTS

Screening of these samples for polymorphic loci has indicated moderate levels of genetic variation (Table 43). Fourteen possible polymorphic loci have been identified for coral trout (*P. leopardus*), with 9 possible polymorphic loci identified in red throat emperor (*L. miniatus*). Only limited research has been conducted on the gold-band snapper (*Pristipomoides multidens*) samples.

### 4.4 DISCUSSION

There has only been limited research conducted on the population genetics of tropical fish species in Australia (Johnson *et al.* 1993). The above results are the first to describe polymorphic loci in these particular species and will provide a sound basis for the future examination of population subdivision of these species from tropical Australian waters.

In addition to these population genetic studies, the genetic relatedness of different colour forms of coral trout has been questioned (Shaklee and Keenan, 1986). Shaklee and

**Table 43.** Results of initial screening for polymorphic loci.

SPECIES	ENZYME	TISSUE	BUFFER
<i>P. leopardus</i>	GPI (2 loci)	liver/eye & muscle	TM & TC-1
	PGM (2 loci)	liver & muscle	TM & TC-1
	IDH	liver/muscle	CAME, TC-1
	G3PDH	muscle	TM, EBT
	Parvalbumin	muscle (cooked)	LiOH(PAGE)
	Transferin	eye	LiOH(PAGE)
	ADA	muscle	TM, CAME
	LDH	muscle	Poulik
	Esterase	eye	LiOH(PAGE)
	GAPDH	liver	CAME
	Esterase D	liver	TC-1
	Peptidase	eye/muscle	Poulik/TC-1
	<i>L. miniatus</i>	GPI	liver
ME		muscle	CAME
AAT		liver	TM
G3PDH		liver	EBT, TC-1, TM
LDH (2 loci)		muscle & eye	TC-1 & TM
MDH		muscle	TM & TC-1
Esterase	eye	LiOH(PAGE)	

Keenan (1986) found that there was considerable confusion in the morphological identification of specimens from the genus *Plectropomus*. They concluded that a cryptic species of coral trout, previously unidentified, may exist, in addition to different colour forms of the same species. If correct, the implications could be very significant for the management of this fishery, depending on the relative abundance of cryptic species and its biology. During the screening process for polymorphic loci, some samples that had been identified as *P. leopardus* displayed fixed differences similar to those described by Shaklee and Keenan (1986), and analogous to fixed differences observed between *P. maculatus* and *P. leopardus*. Unfortunately, only the tissue samples were available so that morphological comparisons were not possible. Further research will be required to

establish the identities of these cryptic species. The most recent reference on the taxonomy of corai trout, Randall and Hoese (1986) provides a basis for morphological correlation. It is interesting to note that there are substantial differences between this work and an earlier preliminary publication by Hoese *et al.* (1981). Because information on the presence of cryptic speciation and/or colour morphs of a single species is essential for the successful management of this significant resource, this is expected to be an objective of a future QDPI study.



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## **6. ACKNOWLEDGMENTS**

### **6.1 Northern Fisheries Centre**

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Lyle Squire and his son Lyle Jr provided most of the speared samples. Jeff Bibby was responsible for reading the otoliths of coral trout from the Cairns and southern GBR regions, and Patti and Kristy Semmens carried out the histological processing. Prof. Terry Quinn (University of Alaska) provided assistance and unpublished data on growth rate determinations and integrated yield-per-recruit models. Dr David Die (SFC) performed the total mortality estimations. Special thanks are due to David Reid (Biometrician, QDPI) for statistical advice and analyses, especially the unbalanced ANOVA and growth rate comparisons.

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### **6.2 Southern Fisheries Centre**

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Project staff recognise the contribution made by those mentioned above, in many different ways, to the ultimate success of the investigation. Without their help it would have been very difficult indeed to address the objectives effectively, and our sincere thanks are extended to all.

## 7. PUBLICATIONS ARISING FROM THIS STUDY TO DATE

Ferreira, B.P. and G.R. Russ 1992. Age, growth and mortality of the Inshore Coral Trout *Plectropomus maculatus* (Pisces:Serranidae) from the Central Great Barrier Reef, Australia. *Aust. J. Mar. Freshwater Res.* **43**: 1301-12.

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Brown, I.W. and W.D. Sumpton (submitted) 1994. Age, growth and mortality of redthroat emperor (*Lethrinus miniatus*; Lethrinidae) from the southern Great Barrier Reef, Queensland. *Bull. Mar. Sci.*

## 8. IMPLICATIONS AND RECOMMENDATIONS

As has been mentioned in various sections of this report, the implications of the research work have already been recognised by industry and the management sector. As a consequence, there has been a continuous application of project results, including those of a preliminary nature, in the development of strategies for the management of reef line fisheries. These strategies relate primarily to the coral trout and redthroat emperor stocks, which constitute the mainstay of the commercial fishery. Recommendations on biologically-appropriate minimum legal sizes, for instance, which were based firmly on the results of this Project have already been incorporated into Queensland fisheries legislation, and will almost certainly become established in the Reef Fishery Management Plan.

The confirmation of both species under investigation as protogynous hermaphrodites has implications with respect to the selection of appropriate legal sizes. At some stage it may be necessary to consider the possibility of introducing a *maximum* legal size if there is any evidence of an insufficient ratio of male to female spawners in the population and hence a problem of gamete limitation. Although we do not believe this is a problem at present we would support any attempt to monitor the sex ratios of fish on heavily-exploited reefs and quantify the relationship (if it exists) between fishing-induced decreases in average size and a reduction in the proportion of male fish in the population.

We have defined the spawning seasons for coral trout and redthroat emperor, and established that for both the period of greatest reproductive activity is later in the southern part of the GBR than it is in the north. This may well have implications for the specification of seasonal closures, suggesting that a synchronous GBR-wide closure may not be most appropriate.

Spawning aggregations appear to be a predictable feature of the reproductive behaviour of serranids in other parts of the world. In certain instances this behaviour has led to very serious depletion of local serranid stocks, as a result of fishing effort being concentrated temporally and spatially when the particular species is most vulnerable to capture. We have demonstrated that coral trout certainly *do* aggregate to spawn at known sites around the two reefs in the Cairns area that were investigated. This would suggest that aggregative behaviour could well be a characteristic phenomenon in coral trout throughout the whole of the GBR. If this is so, then there is a potential for exploitative pressure to become much more focussed, particularly with the possibility that GPS could be used very effectively to plot and record the exact location of aggregation sites.

The findings also have direct implications with regard to reef fish management in areas subject to exploitation by the emerging live-fish export industry. One of the main issues of contention in this sub-set of the reef line fishery relates to the concentration of fishing effort around particular reefs where live-carrier vessels are stationed for lengthy periods. It is not difficult to imagine the possibly devastating effects of having a carrier vessel anchored close to a known spawning aggregation site throughout the peak of the reproductive season.

The universality of aggregative behaviour is, however, questioned by some reliable and highly experienced commercial fishers, who either do not believe that it is a widespread phenomenon or else that it has little general impact on catch rates of coral trout. The issue needs further investigation to determine its ultimate significance to the GBR fishery as a whole.

## Recommendations

- a. **That the minimum legal size for *Plectropomus leopardus* remain at 38 cm TL.** It should be noted that the present legal size was established on the basis of early results of this Project. Final analyses do not provide any evidence that the earlier recommendation should be altered. We do recognise, however, that some change may be justified depending on the results of integrated yield-per-recruit modelling which incorporates data on the post sex-change growth spurt, seasonally varying mortality rates, batch fecundity and spawning frequency.
- b. **That the minimum legal size for *Lethrinus miniatus* remain at 35 cm TL.** Again, this mls was formulated from results early in the life of the Project, and there is no information acquired subsequently to suggest that any change is justified.
- c. **That consideration be given to the use of seasonal closures to protect spawning aggregations.** Since *P. leopardus* spawns on average over three months in the Cairns region, and this season varies slightly between years, and it incorporates the best weather for fishing, it is not recommended that the closure covers the whole season. An October closure would be a suitable solution because this month has consistently (over a period of 4 years) yielded the greatest numbers of aggregating trout. In southern GBR waters a November closure would be more appropriate, since the spawning season for coral trout is about a month later than in the north.
- d. That every effort should be made by Management to limit the potential for catching vessels servicing live-fish carriers to overfish local coral trout populations by remaining in the one area for an undue length of time.
- e. That the consideration of any potential seasonal closure should take into account the spawning asynchrony not only of the coral trout (see *c* above), but also that of the redthroat emperor, whose peak spawning period ranges from July-August in the north to September-November in the southern part of the GBR.
- f. That further investigations be carried out to determine whether spawning aggregations are a general feature of coral trout reproduction throughout the Great Barrier Reef.
- g. That additional work be done to estimate total and fishing mortality rates in redthroat emperor populations in the Central and Northern Sections of the Great Barrier Reef.

- h. That future management (by GBRMPA) of access to reefs by special-use zoning should take into consideration the demonstrated extent to which abundance of coral trout (and presumably other types of reef fish) can be driven by natural variation in recruitment.
- i. That, following from the results of the larval abundance/distribution component of this Project, research aimed at determining precise patterns of dispersal and the eventual fate of reef fish propagules be encouraged. Such research might make use of efficient new genetic techniques.

## **9. INTELLECTUAL PROPERTY ARISING**

With the exception of refinements to the larval light trap developed earlier by Dr Peter Doherty (Australian Institute of Marine Science), no patentable inventions or processes have been developed specifically as a result of this Project.

## **10. TECHNICAL SUMMARY OF DISCOVERIES, DESIGNS ETC.**

Not applicable (see above). Details of the Larval Light Trap can be found in the literature (e.g. Doherty 1987 *et subseq.*).