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Review of Data on Fishes of Commercial and Recreational Fishing Interest in the Great Barrier Reef

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A REPORT TO THE GREAT BARRIER REEF MARINE PARK AUTHORITY

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EXECUTIVE SUMMARY

Aim of Project

The first aim of this project was to synthesise and review all available data, both published and unpublished, relevant to the management of fish species of commercial and recreational interest on the Great Barrier Reef (GBR). The second was to make recommendations on research priorities based on the review.

Scope of the Review

The review was restricted to the major taxa caught in the line fisheries: coral trout (Serranidae: *Plectropomus*); snappers or sea-perch (Lutjanidae) and emperors (Lethrinidae). All species in the latter two families were reviewed, despite only a few of them being of major importance at present. This was for two reasons. First, because we anticipate that as fishing pressure increases and the public becomes aware of the eating qualities of these smaller species, their importance will increase. Secondly, because an understanding of the ecology of juveniles is very important to the management of species and there is a good deal of confusion in the identification of smaller individuals of these two families.

Aspects of these species and their fisheries that were examined in depth include: distributions and habitats; early life histories; reproduction; age, growth, mortality and longevity; catch and effort; movements and migrations; management measures. The review includes information and studies available to December 1991.

Each major section of the review highlights major gaps in knowledge and includes a summary of relevant studies in progress at the end of 1991. These gaps and some approaches to filling them are listed in the final section. Rather than repeat them verbatim, here we summarise some of those gaps we consider of the highest research priority within particular management contexts.

Effects of Zoning: Management by Reefs

The Great Barrier Reef is comprised of many individual reefs: nearly 3,000 of more than a kilometre in individual length. The Great Barrier Reef Marine Park Authority (GBRMPA) manages the system, on the whole, by zoning use patterns on individual reefs. The effectiveness of such a zoning strategy is dependent to a large degree on the amount of biological connectivity between reefs. We highlight a number of serious gaps in our knowledge of this connectivity:

1. A lack of fundamental knowledge of the 'off-reef' distributions of many species, particularly (a) the significance of nearshore and inter-reefal habitats for juvenile fishes and (b) the distribution and abundance of all species below normal SCUBA diving depths (<20m).

2. Poor knowledge of the degree and way in which reef populations are connected by larval dispersal. Preliminary models are being used to predict 'source' and 'sink' reefs but there has been no validation of their biological reality. The inability to identify larvae and post-larvae of major species is a serious impediment to such studies.

3. The degree of inter-reefal movement of adult fishes and how this is influenced by the kind of habitat between reefs is very poorly understood.

Partial Closures of Reefs

Partial closures of reefs is a management strategy that has proved successful elsewhere but has been little applied by the GBRMPA. A major impediment to making such closures effective is a lack of knowledge of movements of fish within reefs.

Determining Effects of Fishing

1. Catch and Effort Data

Catch and effort data are used for monitoring the status of a fishery but require good quality and long-term data from all sectors of the fishery. A good start has been made with the recent introduction of Queensland Fisheries Management Authority (QFMA) log books for the commercial fishery but we also recommend:

1. Seeking historical records of catch and effort data from individual fishermen.

2. More extensive and regular boat-ramp surveys to improve knowledge of the small-boat recreational fleet.

3. Documentation and analysis of time-series of catch-effort data based on competition records of fishing clubs and ensuring that such information continues to be collected.

4. More use of aerial surveillance to validate estimates of the numbers of boats (from all sectors) fishing the reef and their visitor patterns.

5. The development of suitable ageing techniques (see below) and adequate sampling techniques to enable time-series of the age-structure of populations to be determined.

6. Continued use of underwater visual censuses as an effective means of monitoring coral trout densities in depths of <20m and the development of alternative sampling techniques for fisheries-independent assessments of other species and of deeper waters.

2. Experimental Studies

The most direct and effective means of determining the effects of fishing on reefs and of the effectiveness of zoning plans in influencing these effects is undoubtedly a well-designed, long-term manipulative experiment as has been proposed by the GBRMPA. Such a study would involve comparisons of fished and unfished areas, depletion experiments and studies of the long-term recovery of reefs closed to fishing. A well-designed experiment would, however, first require the filling of some of our gaps in ecological understanding including:

1. A better understanding of natural variability between reefs, particularly in rates of natural replenishment.

2. The development of suitable sampling techniques.

3. The connectivity problems mentioned above.

1 TAXONOMY

1.1 *Lethrinus* spp.

Species of *Lethrinus* are often difficult to identify. Many species have very similar colour patterns and most species are capable of rapidly adopting a dark mottled or reticular colour pattern and can switch it off with equal rapidity (Randall et al. 1990). While only sweetlip (*L. miniatus*) and spangled emperor (*L. nebulosus*) are presently of significant commercial and recreational value on the GBR, we have provided notes on all species likely to occur on the GBR to aid in identification of these species.

The maximum sizes and most widely used common names for *Lethrinus* spp. likely to occur on the GBR are given in Table 1. To aid comprehension of this complex group of fishes, they have been divided here into a number of functional sub-groups based on size, colouration and body shape. A key to the names used here and those in the references most likely to be used by workers on the GBR is given in Table 2. The best references to aid in identification of *Lethrinus* spp. on the GBR are Carpenter and Allen (1989) and Randall et al. (1990).

One species whose taxonomic position is not completely clear is worthy of note. *L. choerorhyncus* is a species of major commercial importance in north western Australia (Whitelaw et al. 1991). Whether it occurs on the GBR is unknown. Carpenter and Allen (1989) synonymised this species with *L. nebulosus* and Randall et al. (1990) suggest that this species is a misidentification of *L. laticaudis* but fisheries scientists carrying out studies on all three of these 'species' (Dr Keith Sainsbury of CSIRO and Dr Mike Moran of WA Fisheries) have pointed out to us numerous morphological (see Sainsbury et al. 1984) and ecological differences between the three. Persons working with *L. nebulosus* on the GBR should be aware that '*L. choerorhyncus*' could also occur here.

1.2 *Lutjanus* spp.

Five species of *Lutjanus* are of outstanding commercial and recreational importance on the GBR: *L. argentimaculatus*, *L. erythropterus*, *L. johnii*, *L. malabaricus* and *L. sebae*. Smaller species such as *L. carponotatus* are readily caught and good eating and are receiving increasing attention from fishermen (McPherson et al. 1988). For this reason and because of confusion in identification of juveniles, we outline here all species of *Lutjanus* likely to be seen on the GBR.

The maximum sizes and most widely used common names for *Lutjanus* spp. likely to occur on the GBR are given in Table 3. A key to the names used here and those in the references most likely to be used by workers on the GBR is given in Table 4. Taxonomy and identification of species of this genus is less difficult than that for *Lethrinus*. Randall et al. 1990 is a useful guide to identification but Gerry Allen's FAO Species Catalogue (Allen 1985) and Allen and Talbot (1985) are more comprehensive.

1.3 *Plectropomus* spp.

A complete revision of species of *Plectropomus* has been prepared by Randall and Hoese (1986). Four species are recognised from the GBR: *P. areolatus* (=*P. truncatus*), *P. laevis* (=*P. melanoleucus*), *P. leopardus* and *P. maculatus*. A single specimen of *P. oligacanthus* was reported from Cape York by Castelnau (1875). This is the only record of this species from Australia (Randall and Hoese 1986). The major difficulty in taxonomy of GBR species has been the identification of *P. melanoleucus*. *P. laevis*, the blue-spot, was for a long time recognised as a separate species but known only as *Plectropomus* sp.. Debate has concerned whether the Chinese Footballer, *P. melanoleucus*, is a separate species or a colour variation of

P. laevis. They are now accepted to be colour variations of the same species (see Randall and Hoese 1986, for a discussion).

The maximum sizes and most widely used common names for *Plectropomus* spp. known to occur on the GBR are given in Table 5. A key to the names used here and those in the references most likely to be used by workers on the GBR is given in Table 6. All GBR species (including *P. oligacanthus*) are pictured in Randall et al. (1990) and Myers (1989). The most comprehensive guide to identification is Randall and Hoese (1986).

1.4 Studies in Progress

None of which we are aware.

2 DISTRIBUTIONS AND HABITATS

2.1 *Lethrinus* spp.

2.1.1 Known GBR Distributions

The primary source of information on distributions of *Lethrinus* spp. on the GBR are Dr Mike Walker's (1975) PhD thesis and previously unpublished underwater observations of Dr A.M. (Tony) Ayling (Sea Research).

2.1.1.1 Long-nosed Emperors

1. *L. olivaceus*

Known from Bundaberg to Cairns in Queensland (Walker 1975). Occasionally seen from Townsville to Cape York, more frequently on outer shelf reefs (A.M. Ayling pers. comm.). Not uncommonly caught by line fishing in waters deeper than 20m on mid- and outer shelf reefs of the central GBR (D.McB. Williams pers. obs.).

2.1.1.2 Nebulosus-like Emperors

2. *L. laticaudis*

Widely distributed. Moreton Bay to Cape York. Off north Queensland occurs only on island and mainland reefs. Usually associated with coral reefs but will occur over sand and mud. Not recorded from the Barrier Reef itself (Walker 1975). Of particular importance in Tin Can Bay area. Younger fish are often captured in mangrove creeks and over beds of eel-grass (Zostera) (Grant 1982).

3. *L. nebulosus*

Recorded from Capricorn-Bunkers to Cape York. Usually associated with coral reefs (Walker 1975) but also caught in 'inter-reef' waters (J. Sikora pers. comm.). Wheeler (1961) concluded that *L. nebulosus* [in Mauritius] spend the first two years of their life in shallow water and then move to deeper water, greater than 10 fathoms. 'This would appear to also be the case in north Queensland, as during this study juveniles were collected only inshore and adults only on the Barrier Reef' (Walker 1975). McPherson et al. (1988) report a significant positive correlation between the length of *L. nebulosus* and depth of capture by handline. Juveniles common in Sargassum and seagrass dominated habitats in shallow water on fringing reefs (A.M. Ayling pers. comm.)

2.1.1.3 Small (<50cm), shallow-bodied, no thumbprint

4. *L. lentjan*

Recorded from Gladstone to Darwin (Walker 1975). Usually found on north Queensland island reefs and occasionally on the GBR itself (Walker 1975). Caught regularly in fish traps on outer slopes of central GBR mid-shelf reefs (D.McB. Williams pers. obs.).

5. *L. genivittatus*

Found along whole Queensland coast (Walker 1975). A common inshore and island fish in north Queensland, penetrating rivers and mangroves and often in prawn trawls. Not recorded from the GBR itself (Walker 1975).

6. *L. rubrioperculatus*

Occasionally caught at Flinders Reef (Moreton Is.) (Grant 1982). Caught regularly.

7. *L. variegatus*

Recorded from the GBR and Coral Sea by Randall et al. (1990) but never seen underwater by us or by A.M. Ayling. We believe this species has been widely confused on the GBR with

Lethrinus sp.2 of Carpenter & Allen (1989). Juveniles of *L. variegatus* have been caught in seagrass beds at Green Is. off Cairns by G. Wilson (Marine Biology Dept., J.C.U.).

8. *Lethrinus* sp.2 (Carpenter & Allen 1989)
Common on the GBR, Capricorn-Bunkers to Torres Strait (Walker 1975). The most common species in fish traps on central GBR mid-shelf reefs in 20-40m (D.McB.Williams pers. obs.). We believe that previous records on the GBR to '*L. variegatus*' generally refer to this species. May have been confused in underwater surveys with *L. semicinctus* (A.M. Ayling pers. comm.).

2.1.1.4 Thumbprints

9. *L. harak*
GBR distribution unknown but noted to be extremely abundant at Orpheus and Green Islands (Walker 1975). A shallow water fish usually associated with sand and sea-grass zones bordering coral reefs (Walker 1975). Common on mid-shelf reefs north of Cairns (A.M. Ayling pers. comm.). Juveniles common in Sargassum and seagrass dominated habitats in shallow water on fringing reefs (A.M. Ayling pers. comm.)

10. *L. semicinctus*
Common on the GBR. Not recorded inshore or on island reefs (Walker 1975).

2.1.1.5 Striped species

11. *L. obsoletus*
Common in northern Barrier Reef waters (Grant 1982). Common to abundant on mid- and outer shelf reefs from Townsville north (A.M. Ayling pers. comm.). Juveniles common in Sargassum and seagrass dominated habitats in shallow water on fringing reefs (A.M. Ayling pers. comm.)

12 *L. ornatus*
Not common in Australian waters but found from at least Townsville to Torres Strait (Walker 1975). Regularly caught in fish traps on central GBR mid-shelf in 20 to 40m (D.McB. Williams pers. obs.). Juveniles common in Sargassum and seagrass dominated habitats in shallow water on fringing reefs (A.M. Ayling pers. comm.)

2.1.1.6 Other species

13. *L. atkinsoni*
Widespread on the GBR. Moderately common everywhere (A.M. Ayling pers. comm.). Juveniles common in Sargassum and seagrass dominated habitats in shallow water on fringing reefs (A.M. Ayling pers. comm.)

14. *L. erythracanthus*
A deep water species rarely encountered in Australian waters (Walker 1975). Individuals commonly encountered around Myrmidon Reef on the edge of the continental shelf off Townsville (D.McB. Williams pers. obs.). Occasionally seen on mid- and outer shelf reefs from Townsville north (A.M. Ayling pers. comm.).

15. *L. miniatus*
In north Queensland only encountered on the GBR itself, never on islands or inshore coral reefs (Walker 1975). Common on the southern GBR (16 fish/ha in the Swains, based on 12 reefs) although only moderately common in the Capricorn-Bunkers (4.4/ha based on 11 reefs). Moderately common on reefs off Townsville (7.7/ha based on 3 reefs). Very rare between Cairns and Cooktown (only 2 seen in 10 years of censusing). Absent north of Cooktown. [All data are previously unpublished data of A.M. Ayling]. *L. miniatus* is extremely abundant in the sub-tropical waters of Norfolk Island, 1,725km south-east of the GBR ($29^{o}02'$S, $167^{o}57'$E)

where it grows to a considerably larger size than on the GBR. Interestingly no other lethrinids or lutjanids are abundant at Norfolk (A. Church pers. comm.)

16. *L. xanthochilus*
Not recorded on GBR by Walker or Grant. Observed on several mid-shelf reefs off Townsville (D.McB. Williams pers. obs.). Occasionally seen on mid- and outer shelf reefs north of Cairns (A.M. Ayling pers. comm.).

2.1.2 Habitats Elsewhere

2.1.2.1 Long-nosed Emperors

1. *L. olivaceus*
Often caught in deeper waters over 200m. Reported to go into rivers (Walker 1975). Inhabits coral reef and sandy coastal waters to about 185m depth (Sato et al. 1984).Typically caught in approximately 100m depth on Pacific Island reefs (Mead 1979). Juveniles found in shallow sandy areas (Carpenter and Allen 1989).

2.1.2.2 Nebulosus-like

2. *L. laticaudis*
Coastal reefs, usually over adjacent sand or rubble areas (Allen and Swainston 1988). Associated, in small numbers, with Okera's (MS) 'hard-bottom' assemblage in northern and north-western Australia. Recorded in depths of 20 to 60m in latter study, most fish at 20 to 30m. Juveniles inhabit seagrass beds and mangrove swamps while adults are found mostly on coral reefs (Carpenter and Allen 1989).

3. *L. nebulosus*
Caught by traps among coral reefs but often on lines above rocky reefs down to 60m (Smith 1986). Inhabits coral reefs and inshore waters to 50m depth; also found in mangrove creeks and around jetties and wharves. Juveniles occur inshore and adults in deeper waters (Sato et al. 1984). Juveniles form large schools in shallow, sheltered, sandy areas (Carpenter and Allen 1989). Sivalingam (1969) concluded that there was a general movement of *L. nebulosus* individuals to deeper water as they increased in size. He observed small specimens up to 15cm SL in shallow waters (large bays in Sri Lankan waters (cited in McPherson et al. 1988). Around South Pacific Islands this species tends to be caught around shallow banks or in large lagoons, in contrast to *L. olivaceus* which is commonly caught at depths around 100m (Mead 1979).

2.1.2.3 Small, shallow-bodied, no thumbprints

4. *L. lentjan*
Sandy areas next to coral reefs (Allen and Swainston 1988). Inhabits coastal and coral reefs, usually over sand (Sato et al. 1984). Associated, in small numbers, with Okera's (MS) 'hard-bottom' assemblage in northern and north-western Australia. Also associated with the 'offshore sandy bottom' assemblage in 80 to 90m on the Sahul shelf (Okera MS). Found over sandy bottom in coastal areas, deep lagoons and near coral reefs to depths of around 50m. Juveniles and small adults commonly in loose aggregations over seagrass beds, mangrove swamps and shallow sandy areas while adults are generally solitary and found in deeper waters (Carpenter and Allen 1989).

5. *L. genivittatus*
Inhabits sand-weed areas, sometimes in estuaries (Allen and Swainston 1988). In New Caledonia, generally restricted to waters close to the coast on sandy-muddy bottom (Loubens 1978). A characteristic member of the 'inner shelf assemblage' (10 to 40m depth) of fishes on the northern and north-western continental shelf of Australia. Generally found over 'harder'

bottoms such as coralline rubble and sand, algal-seaweed beds (Okera MS). Recorded in depths of 20 to 60m in latter study, most fish at 20 to 30m.

6. *L. rubrioperculatus*

Coral reefs and trawling grounds (Allen and Swainston 1988). Coral reef waters (Sato et al. 1984). Sand and rubble areas of outer reef slopes to 160m (Carpenter and Allen 1989).

7. *L. variegatus*

Juveniles sometimes abundant in shallow weedy areas, adults more solitary, down to 150m (Smith 1986). Inhabits coral reef waters to 160m depth (Sato et al. 1984). Inhabits sandy and weedy areas near coral reefs (Carpenter and Allen 1989).

8. *Lethrinus* sp.2

'Nothing is recorded about the biology of this species. All that is known is that in the Philippines it is caught together with smaller specimens of such species as *Lethrinus* olivaceus, *L. reticulatus* and *L. semicinctus*; it presumably has habitat characteristics similar to these species' (Carpenter and Allen 1989).

2.1.2.4 Thumbprints

9. *L. harak*

Inhabits coastal and coral reef waters to 50m depth, usually associated with sand and sea grass beds bordering coral reefs (Sato et al. 1984). Inhabits shallow sandy [sic], coral rubble, mangroves, lagoons, channel and seagrass areas inshore and adjacent to coral reefs (Carpenter and Allen 1989).

10. *L. semicinctus*

Shallow seagrass beds, reef flats, lagoons and sandy areas near coral reefs (Carpenter and Allen 1989).

2.1.2.5 Striped species

11. *L. obsoletus*

Prefers shallow, weedy areas (Smith 1986). Coral reefs and coastal waters, especially shallow, weedy areas (Sato et al. 1984). Inhabits seagrass beds and sand and rubble areas of lagoons and reefs to depths of around 30m (Carpenter and Allen 1989). Often seen sheltering among branching corals during the day while assuming a strong mottled pattern (Randall et al. 1990).

12. *L. ornatus*

Inhabits sandy and soft bottoms and seagrass beds in inshore bays, lagoons and areas adjacent to coral reefs (Carpenter and Allen 1989).

2.1.2.6 Other species

13. *L. atkinsoni*

Outer reef slopes, sandy areas in lagoons and seagrass beds to depths of around 30m (Carpenter and Allen 1989).

14. *L. erythracanthus*

A deep water species. Often sighted on outer reef drop-offs (Allen and Swainston 1988). Deepish water down to 120m (Smith 1986). Inhabits coastal and coral reef waters somewhat deeper than most other *Lethrinus* species occurring in the area [Western Indian Ocean], to depths of 80 to 120m (Sato et al. 1984).

15. *L. miniatus*

Inhabits coral reefs during the daytime where it feeds occasionally in sand and rubble areas between coral heads. At night-time they move out over the sandy sea floor surrounding the reef and forage actively. Found at depths between 5 and 30m, usually in small schools (Carpenter and Allen 1989).

16. *L. xanthochilus*

Coral reefs (Sato et al. 1984). Inhabits seagrass beds and sand and rubble areas of coral reefs, deep channels and lagoons. Often found in shallow water but recorded to depths of 150m (Carpenter and Allen (1989).

2.1.3 Summary

Lethrinus spp. are widespread from coastal to outer shelf habitats. While a number of species are often associated with coral or hard bottom (*L. miniatus, L. atkinsoni, L. obsoletus, L. xanthochilus, L. erythracanthus*), most species tend to occur over sand and mud areas in lagoons or at the base of reefs rather than over hard bottom. Juveniles of many species have been recorded in areas dominated by seagrasses and Sargussum (including *L. laticaudis, L. nebulosus, L. variegatus, L. harak, L. semicinctus, L. obsoletus, L. ornatus, L. atkinsoni*). These habitats may be important nursery areas for a large number of lethrinid species but testing of this hypothesis requires more extensive surveys of these areas together with close examination of the correct taxonomic identifications.

We have no confirmed records of juvenile sweetlip (*L. miniatus* <20cm). G. Wilson (Ph.D. student, Department of Marine Biology, JCU) has collected what may be juveniles of *L. miniatus* (seagrass beds in shallow water at Green Island. Specimens have been sent to K. Carpenter (FAO, Rome) for confirmatory identification. Their 'nursery' areas remain unknown. It is probable that they occur in waters deeper than those usually examined by SCUBA divers (as suggested by Walker 1975). The major habitat of juvenile *L. miniatus* may be amongst rubble at the base of mid-shelf (and outer shelf?) reefs. Given the commercial importance of this species and concerns expressed by fishermen of declining numbers, we consider the definition of nursery areas of this species a priority area for future research.

A number of lethrinids appear to vary significantly in abundance between the northern and southern halves of the GBR. At least *L. ornatus, L. obsoletus* and *L. harak* appear to be more common from Townsville northward than they are further south. These distributions may reflect a dependence of these species on seagrass areas as nursery grounds and the greater availability of seagrass beds adjacent to reefs in the northern GBR. The distribution of the commercially most important species, *L. miniatus*, is strikingly different from any of the other species, with maximum densities being reached on the southern GBR (north of the Capricorn-Bunkers) and very few fish occurring north of Cairns.

2.2 *Lutjanus* spp.

2.2.1 Distributions and Habitats

There has been no specific study of the GBR lutjanids equivalent to Walker's studies of the Lethrinidae or Ayling's of *Plectropomus*. The following is a summary from various sources with some anecdotal notes from the GBR.

1. *L. adetii*

This species has one of the most restricted geographic distributions of all Australian lutjanids. It is found only on the east coast of Australia and in New Caledonia. In Australia it is found primarily between Cape Moreton and the Capricorn-Bunkers (Allen 1985). Although it is extremely common in the Capricorn-Bunkers it is rarely seen by divers north of this region. It is, however, common in fish traps set overnight on mid-shelf reefs of the central GBR (D.McB. Williams pers. obs.). Mainly a coral reef species, sometimes forming large aggregations around rocky outcrops during daylight hours (Allen 1985).

2. *L. argentimaculatus*

Juveniles and young adults found in mangrove estuaries and in the lower reaches of freshwater streams. Eventually they migrate offshore to deeper reef area, sometimes penetrating to depths in excess of 100m (Allen 1985). Habitat frequently consists of areas of abundant shelter in the form of caves and overhanging ledges (Allen 1985). Characteristic of Okera's (MS) 'Hard-bottom' assemblage northern Australia ['these isolated patches, as seen on the echo-sounder, were in the form of either small ridges or depressions along a relatively smooth sea bed']. In Vanuatu where there is no continental shelf, this species is caught in depths exceeding 100m but even so is usually found close to mangroves and rivers (Brouard and Grandperrin 1985). The proportion of the population that does move out to the GBR, whether this is mandatory for spawning, and the distribution of these fish is unknown.

3. *L. biguttatus*

Inhabits coral reefs at depths between about 5 and 25m. Sometimes occurs in large schools of more than 100 individuals (Allen 1985). Observed occasionally in wide range of habitats on the GBR north of Townsville (D.McB. Williams pers. obs., A.M. Ayling, pers. comm.).

4. *L. bohar*

Inhabits coral reefs, including sheltered lagoons and outer reefs, usually at depths between 10m and 70m. Usually found solitarily, often adjacent to steep outer slopes (Allen 1985). On the GBR, red bass are found on mid-shelf reefs but tend to be most abundant on outer shelf and Coral Sea reefs. An aggregation of over 500 individuals was observed in 23m depth off Myrmidon Reef in November, 1989 (D.McB. Williams pers. comm.).

5. *L. carponotatus*

Inhabits coral reefs in both sheltered lagoons and on outer reef slopes in depths between 2m and 35m. Also trawled to about 80m depth. Often seen in schools of up to 20 to 30 individuals (Allen 1985). Also found in the vicinity of rocky coastal outcrops and headlands (Grant 1982). The most abundant lutjanid on nearshore reefs of the GBR. Also common on mid-shelf reefs but less common on the outer shelf reefs. Particularly abundant in lagoons of the Capricorn-Bunkers but widely distributed throughout the GBR.

6. *L. decussatus*

Inhabits coral reefs usually at depths between about 5 and 30m. Occurs both solitarily and in schools (Allen 1985). On the GBR, found only rarely in the far northern GBR and Coral Sea (Randall et al. 1990).

7. *L. ehrenbergi*

Inhabits coral reefs at depths between about 5 and 20m. Juveniles frequent inshore areas over sand, silt or coral rubble bottoms, occasionally in mangrove-lined streams and estuaries (Allen 1985). Observation of a school of these fish on Hicks Reef (A.M.Ayling, pers. comm.) is the only known record of this species on the GBR. Further observations may reveal it to be more widespread, however, since underwater it can readily be confused with *L. fulviflamma* (D.McB. Williams pers. obs., A.M. Ayling pers. comm.).

8. *L. erythropterus*

Inhabits trawling grounds and reefs to depths of at least 100m (Allen 1985). Forms mixed-species schools with *L. malabaricus* in inter-reefal waters of the GBR. Characteristic of Okera's (MS) 'Hard-bottom' assemblage northern Australia (see *L. argentimaculatus* above). Juveniles as small as 2.5cm TL are regularly trawled in shallow water (Bay off Townsville (authors pers. obs.). In an extensive trawl survey of the Central GBR, juveniles of this species formed part of a 'coastal' assemblage of species found only in the shallowest stations sampled (15 to 24m) (Jones and Derbyshire 1988). These sites, and only these sites of all sampled, had high silt and clay fractions, presumably of terrigenous origins (Dredge 1988). Juveniles ranging in size from 6 to 22cm form part of the by-catch of prawn trawlers on the northern GBR (Jones and Goeden 1985).

9. *L. fulviflamma*

Inhabits coral reefs at depths between 3 and 35m. Juveniles sometimes found in brackish waters of mangrove estuaries or in the lower reaches of freshwater streams (Allen 1985). Commonly found in shallow water on the seaward side of reef slopes. Probably the most widespread of all GBR lutjanids. Talbot (1960) also considered this the most widely distributed of all lutjanid species in East Africa. Abundant in habitats ranging from coastal estuaries to the outer slopes of outer shelf reefs (D.McB. Williams pers. obs.). Often confused with *L. russelli* and misidentified as the juvenile of *L. johnii*.

10. *L. fulvus*

Coral reefs in lagoons and on outer reef slopes in about 2 to 40m. Juveniles sometimes found in shallow mangrove swamps and the lower parts of freshwater streams (Allen 1985). Rare on the GBR but widespread north of Cairns (D.McB. Williams pers. obs., A.M. Ayling pers. comm.). Has been caught in fish traps at both Orpheus and Lizard Islands (G.R. Russ pers. obs.).

11. *L. gibbus*

Mainly inhabits coral reefs, sometimes forming large aggregations which are mostly stationary during daylight hours. Normal depth distribution from about 6m to at least 30m (Allen 1985). Most abundant on outer slopes of outer shelf and Coral Sea reefs.

12. *L. johnii*

'Little information on habitat of adults, although they probably frequent coral reef areas. Juveniles in brackish mangrove estuaries. Large adults trawled to depths of 80m' (Allen 1985). In the South China and North Andaman Seas, trawl areas where *L. johnii* is most abundant are usually characterised by shallow waters (30 to 40m) and are under the influence of nearby rivers (Anon 1975). Off the Queensland coast this species is usually caught by anglers at the entrance to estuaries and off rocky outcrops and headlands (Grant 1982). Smaller fish are caught in the estuaries. Unlike *L. argentimaculatus*, fingermark are not caught by fishermen targeting 'reds' (*L. erythropterus*, *L. malabaricus*, *L. sebae*) in inter-reefal areas of at least the Central GBR (J. Sikora, pers. comm.). We have no records of this species being caught on coral reefs of the GBR. A limited number of reliable observations of juvenile fingermark in Queensland are all from the lower reaches of estuaries. Reports of juvenile *L. johnii* usually turn out to be *L. russelli* or *L. fulviflamma*. 'Golden snapper' are a major cultured species in Singapore and Malaysia. Wild fingerlings for the Penang fishery are caught in the turbid, high current areas of the Middle Bank in the South Channel of Penang Island (Seng and Yong 1987).

13. *L. kasmira*

Inhabits coral reefs, occurring in both shallow lagoons and on outer reef slopes to depths of at least 60m, but occurring in 180m and 265m at the Marquesas Islands and Red Sea respectively. Frequently found in large aggregations around coral formations, caves or wrecks during daylight hours (Allen 1985). Easily confused with *L. quinquelineata* which has five bright blue stripes on its side instead of four. On the GBR, largely restricted to outer shelf reefs where it is common and appears to replace

14. *L. lemniscatus*
'Inhabits offshore reefs to depths of 70 to 80m. Juveniles sometimes encountered in the vicinity of coral reefs, often located close to the shore where silting is moderate and visibility reduced' (Allen 1985). Individuals 20 to 35 cm (TL) commonly seen on nearshore reefs and coastal areas of the GBR. Rarely seen further offshore (D.McB. Williams pers. obs., A.M. Ayling pers. comm.) but individuals larger than 50cm (TL) are occasionally caught at night by line or traps around mid-shelf reefs off Townsville (D.McB. Williams pers. obs.).

15. *L. lutjanus*
'Inhabits offshore coral reefs and trawling grounds to depths of at least 90m. Frequently seen in large schools of more than 100 individuals' (Allen 1985). Infrequently seen on mid- and outer shelf reefs of the GBR (D.McB. Williams pers. obs.).

16. *L. malabaricus*
'Inhabits both coastal and offshore reefs. In Australia it frequently forms mixed-species schools with *L. erythropterus*. Depth range from about 12m to 100m' (Allen 1985). In Vanuatu, maximum catch-rates of this species were at 160 to 240m depth (Brouard and Grandperrin 1985). Generally considered an 'inter-reefal' species on the GBR. The deeper the water, the larger the fish (McPherson et al. 1988, Fred Brooks (ex professional 'red' fisherman) pers. comm.). A dominant member of the 'mid-shelf' assemblage (60 to 110m) in northern and north-western Australia (Okera MS). Juveniles trawled regularly in shallow waters of Cleveland Bay off Townsville (authors pers. obs.). In an extensive trawl survey of the Central GBR, juveniles of this species and *L. erythropterus* formed part of a 'coastal' assemblage of species found only in the shallowest stations sampled (15 to 24m) (Jones and Derbyshire 1988). Juveniles ranging in size from 4 to 20cm form part of the by-catch of prawn trawlers on the northern GBR (Jones and Goeden 1985).

17. *L. monostigma*
Superficially very similar to *L. russelli* but restricted to coral reefs with large amounts of shelter (Talbot 1957). Solitary in habit or occurring in small groups (Allen 1985). Widespread on the GBR especially on outer shelf reefs but nowhere common (A.M. Ayling pers. comm.).

18. *L. quinquelineata*
'Inhabits sheltered lagoons and exposed outer slopes of coral reefs ranging from about 2 to 40m. Frequently encountered in large aggregations including 100 or more individuals' (Allen 1985). Widespread and common on the GBR.

19. *L. rivulatus*
'Occasionally encountered on coral reefs or shallow inshore flats. Also occurs in deeper water to at least 100m' (Allen 1985). Generally seen as solitary individuals. Observed in wide range of habitats ranging from coastal Queensland to exposed slopes of Coral Sea, Vanuatu and French Polynesian reefs (D.McB. Williams pers. obs.).

20. *L. russelli*
Like *L. fulviflamma* which it closely resembles, this species is widespread throughout the GBR. 'Large adults are sometimes trawled well offshore in depths to about 70 to 80m. Juveniles frequent brackish mangrove estuaries and lower reaches of freshwater streams' (Allen 1985). Associated in small numbers with Okera's (MS) 'hard-bottom' assemblage in Northern and north-western Australia (see *L. argentimaculatus* above).

21. *L. sebae*

'Occurs in the vicinity of coral reefs, often over adjacent reef flats. Also trawled in deeper water on relatively flat bottoms. Small juveniles are frequently commensal with sea-urchins, or sometimes found in mangrove areas. Adults range in depth from about 10m to at least 100m depth' (Allen 1985). Associated in small numbers with Okera's (MS) 'hard-bottom' assemblage in Northern and north-western Australia (see *L. argentimaculatus* above). On the GBR red emperor are generally regarded as 'inter-reefal' species. The deeper the water, the larger the fish (McPherson et al. 1988, Fred Brooks (ex professional 'red' fisherman) pers. comm.). Juveniles ('Government bream') of 20 to 40cm are commonly seen in turbid, shallow (5m to 15m) nearshore waters. Juveniles in the same size range are also caught on lines and in traps at a wide range of reef habitats across the shelf. Unlike the other 'reds' juvenile *L. sebae* do not commonly turn up in trawls in shallow nearshore waters (Queensland Department of Primary Industry (QDPI) in the Central GBR caught juvenile *L. sebae*, throughout the depth range sampled (15 to 62m) (Jones and Derbyshire 1988, Watson and Goeden 1989). Juveniles ranging in size from 4 to 18cm form part of the by-catch of prawn trawlers on the northern GBR (Jones and Goeden 1985).

22. *L. semicinctus*

'Inhabits coral reefs at depths ranging from about 10 to 30m. Usually found solitarily or in small groups' (Allen 1985). On the GBR, apparently restricted to the outside of outer shelf reefs north of Cairns (D.McB. Williams pers. obs., A.M. Ayling pers. comm.).

23. *L. vitta*

'Inhabits the vicinity of coral reefs, also in areas of flat bottom with occasional low coral outcrops, sponges and sea-whips at depths of about 10 to 40m' (Allen 1985). Distribution on the GBR complementary to that of the superficially similar *L. adetii*. A dominant member of the 'mid-shelf' assemblage (60 to 110m) in northern and north-western Australia (Okera MS). Associated in small numbers with Okera's (MS) 'hard-bottom' assemblage (see *L. argentimaculatus* above). Found in depths ranging from 10 to 120m in latter study.

2.2.2 Summary

Most of the coral reef species of *Lutjanus* are encountered in depths shallower than 30 - 40m. Whereas the largest species such as *L. argentimaculatus*, *L. monostigma* and *L. rivulatus* are generally found as solitary individuals, the smaller reef species (e.g. *L. carponotatus*, *L. fulviflamma*, *L. gibbus*, *L. kasmira* and *L. quinquelineatus*) are frequently seen in aggregations, particularly during the day (Allen and Talbot 1985). During daylight they typically occur close to the surface of the reef e.g. in caves, under ledges or at the bottoms of ravines. These relatively stationary organisations tend to disperse at night as individuals or small groups which forage mainly on fishes and crustaceans (Allen and Talbot 1985, Parrish 1987).

The 'reds', including the two economically most important species of lutjanid on the GBR (*L. malabaricus* and *L. sebae*) appear to have an 'inter-reefal' distribution that is relatively distinct from that of the 'coral reef' species. In general, the deeper the water, the larger the fish (see Williams 1991). They are caught down to considerable depths (at least 280m). Details of the distributions of these species, including depth distributions and favoured bottom type on the GBR, are called for. On the North-West Shelf Sainsbury (1987) found these species to be associated primarily with 'large epibenthos' (>25cm). This hypothesis regarding habitat would be a good starting hypothesis for GBR studies.

Juveniles of two of the three reds (*L. erythropterus* and *L. malabaricus*) have been regularly observed by us in trawl samples in shallow waters (especially sea-grass beds?) in Cleveland Bay. The hypothesis that nearshore sea-grass beds are the primary 'nursery' habitat of these 'offshore' species warrants further study. Juvenile red emperor (*L. sebae*) are frequently observed in turbid, shallow (nearshore waters but rarely in these depths at more offshore locations. Trawl surveys suggest that juveniles of this species may also occur offshore but at depths greater than those usually explored by SCUBA divers and/or in inter-reefal areas.

Two 'inshore' species, *L. argentimaculatus* and *L. johnii*, are of major importance to recreational fishermen and potentially to commercial fishermen. The life histories of both of these species are poorly known. Major questions requiring further research with respect to both species are those mentioned above: What proportion of the population does move out to the GBR or inter-reefal waters? What determines these migrations (e.g. Age? Size?). Are these movements essential for spawning? Where exactly do the fish go?

2.3 Plectropomus spp.

2.3.1 Known GBR Distributions

The distributions of *Plectropomus* spp. on the GBR are better known than those of any other species of commercial or recreational importance because of extensive underwater surveys carried out by Dr Tony Ayling for GBRMPA. Marked cross-shelf distributions are similar to those of a large number of reef species (Williams 1982, 1983, 1991). In particular *P. maculatus* can be described as a 'nearshore' species, *P. leopardus* as a 'mid-shelf' species and *P. laevis* as primarily an 'outer shelf' species.

1. *P. areolatus*

Rarely observed. Ayling has observed about 15 individuals. Most of these were seen in the Northern GBR (north of Cairns) and found only on the inside of the outer barrier reefs. Usually found in thickets of staghorn Acropora (*L. Squires* pers. comm., A.M. Ayling pers. comm.).

2. *P. laevis*

'Most common on outer reefs of the GBR. Small individuals have also been taken on mid-reefs' (Hoese et al. 1981).

3. *P. leopardus*

Most abundant on mid-reefs and less abundant on outer barrier reefs and inshore reefs (Hoese et al. 1981). This species forms the bulk of commercial and recreational catches. Ayling has demonstrated a striking increase in the density of *P. leopardus* on mid-shelf reefs from north to south on the GBR and particularly between the central GBR and the Swains (see Fig. 3 in Munro and Williams 1985).

4. *P. maculatus*

Most abundant on turbid nearshore reefs (Hoese et al. 1981) but occasionally found on the siltier mid-shelf reefs, especially north of Cairns (Ayling (1983).

2.4 Studies in Progress

(i) Williams, Cappo, Newman, Kramer and Sheaves at AIMS have a long-term (1990-96) program, partly supported by the joint AIMS-JCU ARC-funded project 'The Life Cycles of Reef Fish of Commercial and Recreational Fishing Interest in the GBR Region' aimed at better determining the distribution and habitats of all these species, with particular emphasis on the Lutjanids. Three areas are receiving particular attention:

(a) Establishing the age- and size- dependent distributions of all the common species of lutjanid.

(b) Determining the significance of nearshore habitats (particularly estuaries and seagrass beds) as nursery areas for lutjanids.

(c) The use of fish traps as a means of determining depth- and habitat-stratified distributions of fish in the deeper waters (>20m) of GBR reefs and inter-reef habitats.

(ii) G. Wilson (Ph.D. student, Department of Marine Biology, JCU) has data on abundances of juvenile lethrinids in seagrass beds at Green Island. This study may provide the first guide to identification of newly settled species of *Lethrinus*.

Table 1 Species of emperor (*Lethrinus* spp.) likely to be encountered on the Great Barrier Reef: their maximum reported sizes and most widely used common names. Species names and maximum sizes are derived primarily from Carpenter and Allen (1989).

	Species	Max Size (TL)	Widely-used Common Names
Long-nosed Emperors*:			
1.	*L. olivaceus*	100 cm	long-nosed emperor
Nebulosus-Like:			
2.	*L. laticaudis*	60 cm	blue-spotted/red-finned/grass sweetlip/emperor/snapper
3.	*L. nebulosus*	86 cm	spangled emperor, yellow/sand/ norwest emperor/snapper
Small (<50cm), shallow-bodied, no thumbprint:			
4.	*L. lentjan*	40 cm	pink-eared/purple headed emperor
5.	*L. genivittatus*	25 cm	threadfin emperor, lancer
6.	*L. rubrioperculatus*	50 cm	red-eared emperor
7.	*L. variegatus*	20 cm	variegated emperor
8.	*Lethrinus* sp. 2	35 cm	drab emperor
Thumbprints:			
9.	*L. harak*	60 cm	thumbprint
10.	*L. semicinctus*	35 cm	reticulated emperor
Striped:			
11.	*L. obsoletus*	40 cm	orange-striped emperor
12.	*L. ornatus*	45 cm	yellow-striped emperor
Others:			
13.	*L. atkinsoni*	43 cm	yellow-tailed emperor
14.	*L. erythracanthus*	60 cm	yellow-spotted emperor
15.	*L. miniatus*	90 cm	sweetlip, lipper, red-throat, tricky snapper, sweetlip emperor
16.	*L. xanthochilus*	60 cm	yellow-lip emperor

* *L. microdon* and *L. amboinensis* may be readily confused with small *L. olivaceus*. Although both of the former species have been recorded from Papua New Guinea and North west Australia, neither species has yet been positively identified from the Great Barrier Reef.

Table 2 A key to commonly seen synonyms and misidentifications of Great Barrier Reef emperors, cf. Carpenter and Allen (1989). The following synonymies are common to all these references: *L. kallopterus* = *L. erythracanthus* (sensu Carpenter and Allen 1989); *L. nematacanthus* = *L. genivittatus*; *L. mahsena* = *L. atkinsoni* and *L. chrysostomus* = *L miniatus*

	Common Synonyms / Misidentifications	Carpenter and Allen (1989)
Walker 1975		
	Lethrinella miniata	*Lethrinus olivaceus*
	L. leutjanus	*L. lentjan*
	L. ramak	*L. obsoletus*
	L. reticulatus	*L. semicinctus*
	L. variegatus	*Lethrinus* sp. 2
Grant 1982		
	L. fletus	*L. laticaudis*
	L. ramak (Plate 201)	*L. obsoletus*
	L. reticulatus (Plate 202)	*L. atkinsoni*
	L. variegatus (Plate 199)	*L. semicinctus*
	L. variegatus (p. 400)	*Lethrinus* sp. 2
Grant 1975		
	L. rhodopterus	*L. harak*
Sainsbury et al. 1984		
	Lethrinella miniata	*Lethrinus olivaceus*
	L. fraenatus	*L. laticaudis*
Allen and Swainston 1988		
	Lethrinus elongatus	*L. olivaceus*
	L. fraenatus	*L. laticaudis*
Masuda et al. 1984		
	L. ramak	*L. obsoletus*
	L. miniatus	*L. olivaceus*

Table 3 Species of snapper (*Lutjanus* spp.) likely to be encountered on the Great Barrier Reef: Their maximum reported sizes and most widely used common names.

Species (Allen 1985)	Max size (TL) Allen 1985	Grant 1982	Widely-Used Common Names
L. adetii	50 cm	45 cm	hussar, yellow-banded hussar / sea-perch
L. argentimaculatus	120 cm	16 kg	mangrove jack, red chopper, creek / reef red bream
L. biguttatus	20 cm	-	2-spot banded snapper
L. bohar	75 cm	90 cm	red bass, kelp bream
L. carponotatus	40 cm	38 cm	stripey, spanish flag
L. decussatus	30 cm	-	checkered sea–perch
L. ehrenbergi	30 cm	-	black–spot snapper
L. erythropterus	60 cm	10 kg	small-mouthed nannygai, saddle -tailed sea-perch
L. fulviflamma	35 cm	50 cm	black-spot snapper / sea-perch , moses perch
L. fulvus	40 cm	60 cm	black-tail snapper, yellow-margined sea-perch
L. gibbus	50 cm	60 cm	paddle-tail, red snapper, humpback, red snapper
L. johnii	70 cm	90 cm	fingermark, spotted-scale sea-perch, red bream, big-scale red
L. kasmira	35 cm	38 cm	blue-banded hussar / sea-perch, moonlighter
L. lemniscatus	65 cm	60 cm	dark-tailed / yellow-streaked sea-perch
L. malabaricus	100 cm	14 kg	large-mouth nannygai, scarlet sea-perch, red jew
L. monostigna	60 cm	58 cm	one-spot sea-perch, moses perch
L. quinquelineatus	38 cm	38 cm	5-lined snapper, blue-banded hussar / sea perch, moonlighter
L. rivulatus	65 cm	71 cm	maori snapper / sea-perch / bream
L. russelli	45 cm	50 cm	moses perch, fingermark bream, red bream fingerprint
L. sebae	100 cm⁺	22 kg	red emporer, government bream, king snapper, red kelp
L. semicinctus	35 cm	-	black-banded snapper
L. vitta	40 cm	38 cm	striped sea-perch, brown-striped snapper

Table 4 Commonly seen synonyms and misidentifications of Great Barrier Reef snappers, with particular emphasis on Grant 1982.

Common Synonyms / Misidentifications		Allen 1985
Grant 1982		
	L. amabilis	*L. adettii*
	L. chrysotaenia	*L. carponotatus*
	L. janthinuropterus	*L. lemniscatus*
	L. kasmira (Plate 170)	*L. quinquelineatus*
	L. sanguineus	*L. erythropterus*
	L. vaigiensis	*L. fulvus*
Others		
	L. altifrontalis	*L. erythropterus*
	L. coatesi	*L. bohar*
	L. lineolatus	*L. Lutjanus*
	L. malabaricus (in part)	*L. erythropterus*
	L. marginatus	*L. lemniscatus*
	L. sanguineus (in part)	*L. erythropterus*

Table 5 Species of coral trout (*Plectropomus* spp.) known to occur on the Great Barrier Reef: their maximum reported sizes on the GBR and most widely-used common names.

Species	Max Size (TL)	Widely-used Common Names
P. areolatus	53 cm	Passionfruit trout
P. laevis	110 cm	Blue-spot, Oceanic/Tiger trout, Chinese Footballer
P. leopardus	70 cm*	Coral/leopard trout, Strawberry
P. maculatus	70 cm	Island/Bar-cheeked/Inshore trout

* 90 cm in Capricorn-Bunker Group.

Table 6 Commonly seen synonyms and misidentifications of Great Barrier Reef coral trout.

Common Synonyms / Misidentifications	Randall and Hoese 1986
P. leopardus (Plates 92, 93 in Grant 1982)	*P. laevis*
P. melanoleucus	*P. laevis*
Plectropomus sp.	*P. laevis*
P. truncatus	*P. areolatus*

3 EARLY LIFE HISTORIES

3.1 *Lethrinus* spp.

Very little is known of the early life histories of *Lethrinus* species. *Lethrinus* larvae do, however, make significant contributions to light trap collections (P. Doherty, M. Milicich, S. Thorrold pers. comm.) and ongoing studies in this area may significantly advance our knowledge.

3.1.1 Descriptions and Identification of Larvae and Eggs

Pelagic eggs of *Lethrinus* and the closely related genus *Gymnocranius* are spherical and small (0.68 - 0.83 mm in diameter) (Mito 1963, Renzhai and Suifen 1980, both cited in Leis and Rennis 1983).

Larvae of lethrinids are distinguished by their distinctive head spination, in particular by an early forming supra-occipital crest with a long, serrate spine. See Leis and Rennis (1983) for a detailed description.

Figures of *Lethrinus* larvae (probably more than one species) at different stages of development are given in Leis and Rennis (1983).

3.1.2 Ecological Information

The very little data that are available on horizontal and vertical distributions of lethrinid larvae suggests that they are very similar in behaviour to lutjanid larvae.

3.1.2.1 Horizontal Distributions

In shallow waters around Lizard Island, Leis (1986) found pre-flexion larvae more abundant on the downstream side of the island than on the windward side of the lagoon. Williams et al. (1988) found lethrinid larvae more abundant at mid- and outer shelf waters between reefs off Townsville than in nearshore waters or the Coral Sea. Cross-shelf light-trapping off Townsville has shown maximum abundance of lethrinids in the outer half of the GBR lagoon and mid-shelf reefs (Doherty unpubl. data).

3.1.2.2 Vertical Distributions

In very shallow waters (to prefer the deepest depth sampled (6m cf. surface and 3m) during the day, but were more evenly distributed at night (Leis 1986). In contrast, Doherty (unpubl. data) has found that pelagic (= pre-settlement) juveniles of this family are aggregated in the upper 5m of the water column, at least at night.

3.1.2.3 Seasonality

Lethrinids have been prominent in light-trap catches from Lizard Island (Milicich and Meekan unpubl. data) and the cross-shelf transect off Townsville (Doherty unpubl. data), especially during spring months (September, October). It is possible that some species reach peak abundance earlier, before the start of sampling.

3.1.2.4 Growth and Length of Larval Period

Brothers et al. (1983) give an age of 37 days at settlement for a single individual of *L. nebulosus* (SL=19.1mm) based on assumed daily growth increments in the otolith of a newly-settled fish.

3.2 *Lutjanus* spp.

The following is almost entirely excerpted from Leis's (1987) review.

3.2.1 Descriptions and Identification of Larvae and Eggs

Lutjanids spawn spherical, pelagic eggs ranging in diameter from 0.65 to 1.02mm, with the majority single colourless to slightly yellowish oil droplet of 0.12 to 0.20mm diameter is present. Incubation times range from 17 to 36 hours depending on species and incubation temperature.

The most striking features of larval lutjanids are the spination of their fins and head (see Figs in Leis and Rennis 1983). Lutjanid larvae are relatively easy to identify to family (Leis and Rennis 1983) but it is much more difficult to distinguish species. General descriptions of eggs and larvae are given in Leis (1987). Leis (1987) gives a useful table (Table 4.3) of characters used in separating larvae of four lutjanid subfamilies.

Partial descriptions of the eggs or larvae of the following GBR species of *Lutjanus* are available:

Eggs (summarised in Leis 1987)	*L. erythropterus* (Lu Suifen 1981) *L. kasmira* (Suzuki and Hioki 1979) *L. Lutjanus* (Lu Suifen 1981) *L. vittus* (=L.vitta) (Lu Suifen 1981)
Larvae	*L. (*bohar?) (Fourmanoir 1976) *L. (*fulvus or kasmira) (Leis and Rennis 1983) *L. johnii* (Lim et al. 1985) *L. kasmira* (Suzuki and Hioki 1979) *L. sebae* (Leis 1987) *L. vittus* (Lu Suifen 1981, Mori 1984)

3.2.2 Ecological Information

Relatively little information is available on any aspect of lutjanid early life history. The most intensively studied Indo-Pacific species appears to be *L. vitta* (Mori 1984).

3.2.2.1 Horizontal Distributions

GBR lagoon waters, rather than reef waters, appear to be the nursery area of lutjanid larvae (Leis and Goldman 1983, 1987). Larvae of *Lutjanus* spp are also more abundant in the GBR lagoon (i.e. on the continental shelf) than in the Coral Sea (Leis and Goldman 1984). Leis and Goldman found no cross-shelf variation in the distribution of lutjanid larvae across short transects in the lagoon near Lizard Is. but Williams et al. (1988) found lutjanid larvae concentrated in mid- and outer shelf waters off Townsville, rather than in nearshore waters or the Coral Sea.

3.2.2.2 Vertical Distributions

Based on just three studies (Powles 1977, Leis 1986, Leis and Goldman unpub. 3), lutjanid larvae, at least in relatively shallow coastal waters (appear to prefer the greatest available depth during the day and to migrate upward at night, to a uniform vertical distribution. In contrast, greatest catches of pre-settlement lutjanids have been taken from deep light-traps set close to the bottom (Doherty unpubl. data).

3.2.2.3 Seasonality

In shallow waters in the immediate vicinity of reefs of the GBR lagoon, lutjanid larvae were present year-round but were most abundant in spring and summer (Leis 1982, 1986). In more open, deeper waters of the GBR lagoon, highest abundances were found in summer (Leis 1987). Williams et al. (1988) sampled ichthyoplankton in the central GBR every 2 weeks from late January to late March and found maximum concentrations of lutjanid larvae in the late February and mid-March collections. Light-trap collections of pelagic juveniles show a similar distribution, with good catches recorded in Nov./Dec./Jan. (Doherty unpubl. data).

3.2.2.4 Growth and Length of Larval Period

The only significant data on growth rates of a larval lutjanid are for laboratory-reared specimens of the Tropical-Western Atlantic species *L. griseus* and the Indo-Pacific *L. johnii* (Lim et al. 1985). Larvae of *L. johnii* metamorphose at 30 to 35 days under laboratory conditions (Lim et al. 1985). Size at settlement seems to vary considerably with species. *L. vitta* settles at about 30mm (Mori 1984), and most pelagic lutjanids taken by light-traps are at least this size (Doherty unpubl. data); however *L. griseus* appears to settle as small as 10mm in sea-grass beds (Starck 1970). The duration of the pelagic period of lutjanids has been directly measured only three times (*L. fulvus*, *L. griseus* and unidentified spp.) and ranged from 25 to 47 days.

3.3 Plectropomus spp.

3.3.1 Descriptions and Identification of Larvae and Eggs

The eggs of *Plectropomus* have not been described but those of three other genera of epinepheline serranids are pelagic, with a smooth chorion, unsegmented yolk and a diameter of 0.75 to 1.20mm (Leis 1987). A single colourless-to-slightly-yellowish oil droplet of 0.13 to 0.22mm diameter is present. Incubation takes from 20 to 45 hours (Leis 1987).

Plectropomus larvae are identified as epinepheline serranids by their characteristic head spination, kite-shaped body and elongate, ornamental dorsal and pelvic spines. Larger (Australian) larvae are identified as *Plectropomus* by their fin meristics, particularly the dorsal fin counts of VIII, 11 and a single predorsal bone (Leis 1986).

More complete species-specific identifications exist for *Plectropomus* spp. than for any other genus of commercial or recreational interest on the GBR. Characters used include tail pigment, structure of the pelvic spine and head spination. Details are given in Leis (1986).

3.3.2 Ecological Information

Although epinepheline larvae have been recognised for a longer time than lutjanid larvae, no more is known of their early life history than that of lutjanids (Leis 1987).

3.3.2.1 Horizontal Distributions

The limited available data indicate that the cross-shelf distributions of *Plectropomus* larvae are similar to the distributions of the adults. The following comments refer to those specimens examined by Leis (1986). *P. maculatus* larvae were generally captured closer to the shore than were larvae of *P. leopardus*. The distribution of *P. leopardus* larvae was 'generally consistent with the adult distribution' i.e. 'most abundant on mid-reefs and less abundant on outer barrier reefs and inshore reefs' (Hoese et al. 1981). All five *P. laevis* larvae collected by Leis were taken along the edge of the GBR continental shelf in the Coral Sea. Leis did not collect any larvae of *P. areolatus* from the GBR. Epinepheline larvae (including *Plectropomus*) do not appear to remain in the immediate vicinity (i.e. 100 to 200m) of reefs or to disperse large distances in the offshore direction from the adult habitat (Leis 1987).

3.3.2.2 Vertical Distributions

Very little data is available on the vertical distributions of larvae of *Plectropomus* spp.. Leis (1987) suggests that they prefer mid-depths, at least in a study of vertical distributions in 25m of water off Lizard Is.. During the day no *Plectropomus* larvae were found in the neuston and only one in the 0 to 6m stratum, but eight were found in the 6 to 13m stratum and four in the 13 to 20m stratum. Only a single *Plectropomus* larva was taken at night, in 6 to 13m (Leis 1987). Pelagic juveniles of *Plectropomus leopardus* have been caught in both shallow (1m) and deep (20m) light-traps set at Arlington Reef, Cairns Section (Doherty unpubl. data), with greatest catches near the surface.

3.3.2.3 Seasonality

Off Lizard Island, *Plectropomus* larvae were more abundant in summer than at any other time (Leis 1987). Pre-settlement coral trout have been caught in light-traps in all months from October to January, apparently sourced from reproduction during the previous month (Doherty unpubl. data).

3.3.2.4 Growth and length of Larval Period

Larvae of *Plectropomus* apparently settle at about 20mm (Leis 1987). A. Fowler (pers. comm.) has determined the mean duration of the pre-settlement stage of *P. leopardus* as 25.2d +/- 0.46 (SE), based on otoliths of 38 newly settled fish collected from Arlington Reef off Cairns.

3.4 Recruitment Variability

Understanding natural variability in rates of replenishment (or recruitment) of fish to reef populations is critical for interpreting among- and within-reef variability in fish density. It is also critical in determining reef-specific responses to disturbance such as fishing. A great deal has been learnt of natural variability in rates of replenishment of reef fishes over the last 10 to 15 years (reviewed in Doherty and Williams 1988). Long-term monitoring of reef fish recruitment in the central and southern GBR (since 1981) has (1) identified regional differences in recruitment dynamics, (2) shown that within regions significant variability in year-class formation among reefs is generated by transient pulses of a few days, possibly associated with patches of larval fish and (3) shown that variations in year-class strength among reefs can be preserved in the age structure of demersal populations and may affect abundance for at least a decade (Doherty and Fowler, in press).

None of these studies of reef fish recruitment have concerned species of commercial or recreational importance simply because newly settled individuals of these species are not often encountered by SCUBA divers. Recent studies have shown that a more effective means of quantifying variability in replenishment of species with cryptic, pelagic or rare juveniles is to sample the pre-settlement stages using light-traps (Doherty 1987).

A cross-shelf study of larval fish off Townsville using light-traps (started in 1988/89) has identified nearshore nursery areas for all of the common mackerels and suggested substantial interannual variability in larval abundance of these species. Such variability has been shown even more clearly in a FIRDC-funded coral trout study including light-trapping at Green Island and Arlington Reefs off Cairns. In 1990/91, replenishment of coral trout (*P. leopardus*) populations on Green and Arlington reefs was restricted to a single 3 week period around the new moon in November. Work in progress indicates that recruitment at the same sites in 1991/92 will consist of 3 or 4 monthly episodes. In both years, the periodicity of the larval catches has been validated by comparisons with back-calculated settlement dates from collections of newly-settled juveniles (P. Doherty, pers. comm.). Monitoring of spawning activity on adjacent reefs by QDPI suggests that these temporal patterns in recruitment are related to reproductive activity and occur at least over regional scales.

The light-trap program off Cairns has further revealed consistent differences in larval supply between adjacent reefs which may be related to reef topography or different dispersal paths to these reefs. Further elucidation of these patterns will be an important consideration in designing experiments on the effects of fishing. Confounding different experimental treatments with fixed and unknown differences in replenishment rates among reefs could seriously compromise the power of most experimental work (P. Doherty, pers. comm.).

3.5 Studies in Progress

(i) Leis at the Australian Museum is carrying out a taxonomic study of larval lutjanids.

(ii) Doherty at AIMS is monitoring the distribution of pelagic juvenile fish along a 160km cross-shelf transect off Townsville using light-traps. Catches include large numbers of lethrinids, relatively few *Lutjanus* and *Plectropomus*.

(iii) Doherty is also monitoring pelagic juvenile fish and recruitment in a second light-trap study based at Arlington and Green Reefs, Cairns Section. This is part of a larger joint study (QDPI-AIMS-JCU) into the biology of *Plectropomus leopardus* and *Lethrinus miniatus* that has been funded by FIRDC.

4 REPRODUCTION

4.1 *Lethrinus* spp.

4.1.1 Sexuality

Examination of the size/sex relationships, gonad structure and histology of eight species of Lethrinidae (*L. nematacanthus* (= *genivittatus*), *L. choerorhyncus*, *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:

> A linear relationship between size and sex ratio, in which females predominate at smaller sizes and males at larger sizes, was demonstrated for the five species for which sufficient data was available. All five of these species showed considerable overlap in the size distribution of the sexes but there was no evidence for the occurrence of primary males in the populations sampled. The testes of all species examined showed typical 'secondary male' morphology and the presence of atretic ovarian material ('brown bodies'). Individuals with intersex gonads were observed in five species.' (Young and Martin 1982).

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. Ferreira (pers. comm.) and Brown (pers. comm.) have demonstrated a predominance of females in small size classes of *L. miniatus* from the GBR. Ferreira has observed intersex gonads in this species. Loubens (1980b) found size-related bias in sex ratios in *L. miniatus* and concluded that this may be due to sequential hermaphroditism. Tony Church (pers. comm.) has confirmed protogynous hermaphroditism in the Norfolk Island population of *L. miniatus*.

Interestingly Young and Martin (1982) could not demonstrate a linear relationship between sex ratio and length in *L. nebulosus* like they could in the other species. Larger samples (approximately 300 individuals) from North-Western Australia have confirmed the lack of any clear relationship between sex and size in *L. nebulosus* in that region (M.Moran, pers. comm.). Geoff McPherson (pers. comm.) has confirmed from histological studies that *L. nebulosus* is a protogynous hermaphrodite on the northern GBR. Working on *L. nebulosus* from Okinawa, Ebisawa (1990) described ovarian development based on histology. He suggests that *L. nebulosus* is a juvenile hermaphrodite with sex being determined at 24 to 30cm FL but the fish not maturing until approximately >40cm FL.

As pointed out by Young and Martin (1982), the mechanisms controlling sex change are not known in any of the lethrinids.

4.1.2 Size and Age at Maturity

Minimum size and age at maturity and size and age at which 50% of each sex are mature have been determined for five lethrinids in New Caledonia by Loubens (1980b) (Table 7). Walker (1975) concluded that *L. miniatus* were mature at 3 years (35cm SL) and could be mature at 2 years (31cm SL), that *L. nebulosus* matured at 28cm SL, *L. semicinctus* (=*L. reticulatus*) at approximately 19cm SL and *Lethrinus* sp.2 (= variegatus) 22cm SL). These estimates of size at first maturity for *L. miniatus* and *L. nebulosus* are below the current legal minimum sizes of

30cmTL (see Section 12). Ebisawa (1990) found that *L. nebulosus* in Okinawa matured at approximately 40cm FL.

4.1.3 Seasonality

On the basis of gonado-somatic-indices (GSI's) and maximum ova diameters, Walker (1975) concluded that reproduction of *L. miniatus* in the central GBR (off Townsville) peaked in July-August, the coldest months of the year. Based on smaller numbers of fish, reproductive activity of *L. nebulosus* peaked in June to July, *L. semicinctus* in December-January and *Lethrinus* sp.2 in September-October (Walker 1975). McPherson et al. (1988) reported monthly GSI's of *L. nebulosus* 'between about May and October'. In New Caledonia GSI's of *L. nebulosus* peaked in August and September and of *Lethrinus* sp.2 in December and January (Loubens 1980b).

4.1.4 Spawning

Little published data is available on whether lethrinids are serial or annual spawners. Nor is data available on time of day or behaviour during spawning. Ebisawa (1990) determined that - *L. nebulosus* in Okinawa is a serial spawner.

4.1.5 Fecundity

No data available.

4.2 *Lutjanus* spp.

4.2.1 Sexuality

Unlike *Lethrinus* and *Plectropomus* spp., lutjanids in general appear to be **gonochoristic** i.e. following sexual differentiation, sex remains fixed throughout life (Grimes 1987). Population sex ratios as well as sex ratio at size is frequently skewed. However, this appears to result from differential growth and mortality rates between sexes, rather than hermaphroditism. Growth of male and female *L. sebae* and *L. malabaricus* on the northern GBR, for example, differ in the older year classes with males being the larger (McPherson et al. 1988).

4.2.2 Size and Age at Maturity

Sexual maturity in lutjanids generally occurs at approximately 40 - 50% of maximum length (Grimes 1987). Druzhinin (1970) reports male and female *L. johnii* from the Andaman Sea as reaching maturity at 30.1 and 29.1cm LCF respectively. Age of both sexes is given as 2 years. Lim et al. (1985) indicate considerably larger and older sizes at maturity for the same species in Singapore: females attain maturity at the age of about 3 to 4 years (3.5 to 4.5kg), while males mature at about 2.5 to 3 years (2.3 to 3.0kg).

Talbot (1960) gives the following lengths at maturity for the larger species of lutjanid in East Africa: *L. bohar* 45cm (6 to 7 years), *L. sebae* 49cm SL, *L. argentimaculatus* 35cm. Further sizes and ages at maturity for the smaller species of lutjanid are given in Talbot (1960) and Loubens (1980a).

Allen (1985) gives the following (unsourced) estimates of size (Total Length) at maturity in *Lutjanus*: *L. adettii* 20 to 30cm; *L. bohar* 50 to 55cm; *L. ehrenbergi* approx. 12cm; *L. fulviflamma* 20 to 25cm; *L. fulvus* 20 to 30cm; *L. gibbus* 30cm; *L. kasmira* 20-25cm; *L. lutjanus* 12cm; *L. rivulatus* 50cm; *L. vitta* 20cm.

4.2.3 Seasonality

Raised monthly gonad indices of *L. sebae* and *L. malabaricus* females from September to January indicate that these species reach peak reproductive activity [on the northern GBR] during the spring and summer months' (McPherson et al. 1988). Reproductive activity of the smaller lutjanids, *L. fulviflamma*, *L. quinquelineatus* and *L. vitta*, in New Caledonia peaks in November to January (Loubens 1980).

4.2.4 Spawning

Distributions of egg diameters provides consistent evidence that lutjanids in general are serial or batch spawners (Grimes 1987). This has been verified for at least *L. vitta* on the North West Shelf (T. Davis pers. comm.). Egg diameters of *L. johnii* are also clearly polymodal (Anon 1975). The number of batches of eggs produced each spawning season under natural conditions has not been evaluated for any lutjanid species (Grimes 1987).

4.2.5 Fecundity

Lutjanids are highly fecund with large females (approximately 100cm TL) producing up to at least 5 to 7 million eggs per season (Grimes 1987).

4.3 *Plectropomus* spp.

4.3.1 Sexuality

All serranids that have been closely studied have proven to be **protogynous hermaphrodites** (Shapiro 1987). *P. leopardus* is the only *Plectropomus* spp. whose reproductive biology has been examined closely and, as expected, it proves to be a protogynous hermaphrodite (Goeden 1978). It has been confirmed recently that *P. maculatus* is also a protogynous hermaphrodite (Ferreira and Russ, MS). It is likely that the other species will prove similar.

4.3.2 Size and Age at Maturity

The smallest mature female *P. leopardus* found by Goeden (1978) was 205mm SL. *All* mature females were estimated to be 2 to 4 years old (except one that was 4 or older). The smallest mature male was 303mm SL and estimated to be 3 years old. Goeden thought that sex reversal generally occurred when fish were 3 or 4 years old. The Heron Island population examined by Goeden had a strong sex ratio bias overall (2.9 females for every male) and a strong bias in sex-ratio with age. All 2 y.o. fish were believed to be females, 93% of fish in their sixth year to be male.

Ferreira and Russ (MS) suggested that age at first reproduction of *P. maculatus* may be 2 years (around 25cmTL). Age at sex change appeared to be variable with females as old as 7 years and males as young as 3 years.

4.3.3 Seasonality

Spawning of *P. leopardus* at Heron Island occurred in November-December (Goeden 1978). Based on GSI's, September to November appear to be the months of peak reproductive activity of this species on the northern GBR (McPherson et al. 1988). Johannes and Squire (1988) report that spawning aggregations of *P. laevis* occur from September to January. Timing of these aggregations is site-specific and may vary by one month from year-to-year and gets progressively later the further north the location.

4.3.4 Spawning

Goeden (1978) believes *P. leopardus* to be a serial spawner. 'Courtship' behaviour of this species is described in Goeden (1978) and the spawning aggregations of this and other species of *Plectropomus* are described in Johannes and Squire (1988) and referred to elsewhere in this report. Spawning appears to be concentrated around the new moon (Samoilys and Squire unpubl. data).

4.3.5 Fecundity

Goeden (1978) determined the following equation for the relationship between total number of eggs and the standard length of *P. leopardus*:

$$\text{Log}_{10}\ \text{Total Eggs} = 3.712 + 0.0046\ \text{SL (mm)}.$$

4.4 Hermaphroditism and the Effects of Fishing

Management of a fishery is considerably complicated by the presence of sequential hermaphrodites such as *Lethrinus* and *Plectropomus* spp.. This is particularly so when the mechanism of sex-change is unknown (e.g. Young and Martin 1982, Munro and Williams 1985) as it is for the GBR species. One scenario is that if these species only turn into males at a certain large size or age, heavy fishing may seriously limit the number of males in the population with potentially disastrous results. An entirely different scenario is that sex-change may be socially controlled and the removal of males from the population simply causes a female to change sex at a smaller size and earlier age. The reality is unlikely to be as simple as either scenario and the effects of fishing are likely to be much more difficult to predict.

Bannerot et al. (1987) have recently modelled the consequences of protogynous hermaphroditism and gonochorism on fisheries management of groupers (Serranidae) and snappers (Lutjanidae) in the Caribbean. They conclude that:

> Generally, there are parametric regions where hermaphroditism is more resilient to exploitation than is gonochorism; this parametric space is increased if hermaphrodites exercise some social behaviour during spawning which decreases randomness in gamete encounters'. (Bannerot et al. 1987).

These authors point out that, in particular, there is a definite risk if grouper populations are managed strictly by Yield-per-Recruit models at high fishing mortality and in the absence of knowledge about population compensation mechanisms for sperm limitation.

Bannerot et al.'s comments are particularly relevant to management of coral trout and lethrinids:

> Populations under exploitation should be monitored to deduce whether or not a significant proportion of eggs go unfertilised as...[fishing]...mortality increases, and to follow any change in population sex ratio over a range of exploitation levels. Specific research is needed to characterise population compensatory mechanisms for avoiding sperm limitation, and to determine the time required for hermaphroditic individuals to change sex and the range of sizes capable of changing sex. In addition to these parameters, studies of mating strategies, as indicated by spawning behaviour and gonad condition over time, would be valuable for making inferences about potential fishing-induced disruption of spawning. Until field data show otherwise, the predictions of both static and dynamic models indicate that the management decision environment [sic!] of exploited ...[hermaphroditic]... populations should be conservative'. (Bannerot et al. 1987).

4.5 Studies in Progress

(i) McPherson, Squire, O'Brien and colleagues from the Northern Fisheries Research Centre (NFRC QDPI) in Cairns have been involved in reproductive studies within the Demersal Reef Fish Project of NFRC. They have examined gonad material from 9 species of lutjanid, 15 serranids 9 lethrinids plus *Diagramma pictum* and *Choerodon schoenlieni*. A paper has been submitted on the reproductive biology of *Lutjanus sebae*, *L. malabaricus* and *L. erythropterus* (Asian Fisheries Science).

(ii) A joint QDPI-JCU-AIMS project entitled 'Growth, reproductive strategies and recruitment of the dominant demersal food fish species on the Great Barrier Reef' is presently being funded by FIRDC. The project is coordinated by Ian Brown (QDPI-Deception Bay) and aims to examine reproductive biology (as well as age and growth) of *Plectropomus leopardus* and *Lethrinis miniatus* in the northern, central and southern GBR.

(iii) Beatrice Ferreira (JCU) is carrying out a PhD project on reproductive biology (as well as age and growth) of *Plectropomus* (3 spp.), *Lethrinus miniatus* and *L. nebulosus*, principally in the Townsville and Lizard Is. areas of the GBR (in collaboration with (ii)).

(iv) Studies of the reproductive biology of a wide range of *Lutjanus* spp. (excluding the three 'reds' in (a) above) is being carried out by Stephen Newman and Marcus Sheaves (both PhD students) at AIMS.

(v) An MSc (Qual.) project on reproductive biology (and age and growth) of several of the smaller species of *Lethrinus* by P. Laycock will begin at JCU (Marine Biology) in 1992.

Table 7. Age and size at maturity of lethrinids in the New Caledonia lagoon. l_m and a_m = minimum length and age at maturity. L_m and A_m = length and age at which 50% of the population is mature. Lengths in mm, ages in years (from Loubens 1980a,b). *L. olivaceus* was published as *L. miniatus*, *L. atkinsoni* as *L. mahsena*, *Lethrinus* sp. 2 as *L. variegatus*.

Species	Sex	l_m	L_m	a_m	A_m
L. olivaceus	M	352	370	5.1	6
	F	340		4.1	
L. lentjan	M	190	200	2.7	3.5
	F	181		2.0	
L. atkinsoni	M	233		3.7	
	F	282		5.0	
L. nebulosus	M	355	420	6.0	8
	F	408	450	7.0	9
Lethrinus sp.2	M	202	210	1.8	2.5
	F	175		1.8	

5 AGE, GROWTH, MORTALITY AND LONGEVITY

5.1 *Lethrinus* spp.

5.1.1 Studies on the Great Barrier Reef

Information on age, growth, mortality and longevity is available for 2 of the 17 species of *Lethrinus* known to occur on the Great Barrier Reef (GBR) (see Table 8). These species, *Lethrinus miniatus* and *L. nebulosus*, are by far the most important in terms of the catch of the commercial and recreational line fisheries on the GBR (see Section 6).

Walker (1975) used annuli on scales to determine age and growth of *Lethrinus miniatus* in the Townsville region. Otoliths were not available to Walker as most of his specimens came from fishing trips on charter boats and with recreational clubs. Removal of otoliths from fish caught by recreational fishermen was not acceptable to these recreational fishermen at the time of his study. Length-frequency analysis was of no use in differentiating age-classes in Walker's study either. Walker used scales taken from an area on each fish just beneath the lateral line and '... either above, or directly beneath, the posterior half of the pectoral fin'. He reported that a large number of regenerated scales were present and that such scales were more often on fish caught on outer barrier reefs than from fish caught on inner reefs. He used 3 to 4 of the most suitable scales per fish and found that it was possible using scales to assign ages to 89.9% of fish examined.

Marks in the form of darker circuli occurred on the scales. 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'. He did not comment on the suitability of scales or otoliths for determination of age of any other species of lethrinids on the GBR.

Walker (1975) reported a significant difference between the mean length of each sex in the fourth year class within his 1972-73 sample. However, this was the only significant different in size at age he could detect between the sexes and he concluded that growth rates did not differ significantly between the sexes. In contrast, both Loubens (1980b) working in New Caledonia and Church (1989) working at Norfolk Island reported quite different growth rates and longevities for males and females of this species (see Table 9). No information exists on growth rates of *L. miniatus* at different depths, nor on whether larger *L. miniatus* tend to move to deeper waters.

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 the first year of life. However, he noted the possibility that during the first year of life no annulus may have formed or that it was difficult to see, such that all fish in his study may have been one year older than he estimated. This doubt may be resolved when the habitat of juveniles of this species is determined (see Sections 3).

Based on a comparison of growth data on *Lethrinus nebulosus* from Sri Lanka (Sivalingam 1969), Walker (1975) suggested that the growth rate of *L. miniatus* was slower than that of *L. nebulosus*. Insufficient data from the GBR exists to confirm this suggestion (see Table 8).

Furthermore, no estimates of growth rate of *L. miniatus* have been made for regions other than Townsville. Regional comparisons of growth rates await further study.

A single estimate of total mortality rate (Z) was calculated by us (using an age-based catch curve) from the catch at age data provided in Walker (1975) (see Table 8). The figure of $Z = 0.74$ is probably realistic for the early 1970's off Townsville and is slightly higher than estimates of M (by the empirical formula of Pauly 1980) for the same species in New Caledonia (Table 9). Maximum age of *L. miniatus* estimated by Walker (1975) for the GBR (7 to 8 years) is far less than estimates for New Caledonia (14 to 22 years) and Norfolk Island (15 to 18 years). This difference indicates the need for a more detailed examination of age determination and longevity of *L. miniatus* on the GBR.

McPherson et al. (1985, 1988) used whole otoliths to determine age, growth and longevity of *Lethrinus nebulosus* from the Cairns region (Table 8). They found that otoliths provided more reliable estimates of age than either scales or urohyals. They concluded also that sectioning of otoliths did not seem to offer significant improvement in readability over whole otoliths from fish up to five years of age. Twenty per cent of their total sample (n = 750) of whole otoliths of *L. nebulosus* were rejected as unreadable because of '... crowding of annuli in the distal otolith areas ...'. They also noted a '... progressive reduction in the proportion of otoliths successfully aged with increasing fish size ...' for *L. nebulosus*. By examining the monthly percentage of otoliths with hyaline edges they were able to establish that annual checks were laid down during the winter months. In contrast to the conclusion of Walker (1975) regarding the stimulus for annulus formation or scales of *L. miniatus*, McPherson et al. (1988) considered that gonad development and maturation were the primary reasons for formation of annual checks in the otoliths of *L. nebulosus*.

Validation that the checks in otoliths were annual was based on examination of the width of hyaline edges of otoliths throughout the year. Comparison of size-at-age information from otoliths with that obtained from length-frequency information (Cassie method) indicated that the two independent techniques provided similar estimates only for the first few years of growth. McPherson et al. (1988) concluded that the suitability of the otolith technique to age *L. nebulosus* was '... not well established'. It is likely that they were being unduly harsh on themselves, although it is true that unequivocal validation of annual checks awaits release and recapture of tetracycline-injected fish in the field (see comments later in this section).

McPherson et al. (1988) considered that their estimates of growth rate of *L. nebulosus* were tentative. They pointed out the relative paucity of samples available to them from deeper water. Furthermore, they noted the likelihood of larger size of *L. nebulosus* with depth. They felt that they may have aged '... only the smaller fish from progressively older age groups' and this could have over estimated K and underestimated L_∞. They were unable to show any significant differences in growth rate between the sexes. McPherson et al. (1988) were unable to confirm protogynous sex change in *L. nebulosus*, although McPherson has subsequently used histology to confirm this (see Section 4).

Regional comparisons of growth rates of *L. nebulosus* on the GBR are not yet possible (Table 8). *L. nebulosus* is however, one of the better studied species of coral reef fishes in terms of age and growth rates (Table 9). McPherson et al. (1988) do not provide enough detail about their estimates of K and L_∞ to permit detailed comparison with the studies of *L. nebulosus* listed in Table 9 although it is noted that the estimates of K from McPherson et al. (1985) is at the higher end of the range shown in Table 9. This may be a reflection of not sampling larger fishes in deeper water adequately, as they point out. In addition, estimates of K may become lower and estimates of longevity greater by examination of sectioned (rather than whole) otoliths of very large (and presumably older) fishes. Reliable estimates of mortality of

L. nebulosus on the GBR are virtually non-existent. The estimate of M for *L. nebulosus* in Table 8 (from Pauly's 1980 formula) is higher than those of *L. nebulosus* in Table 9 mainly because of the higher estimated K in Table 8. Maximum ages estimated for both species of *Lethrinus* in Table 8 are considerably less than those estimated for the same species in other parts of the Indo-West Pacific region.

5.1.2 Studies of GBR Species made Outside the GBR

Information on age, growth, mortality and longevity is available from studies outside the GBR for 15 of the 17 species of *Lethrinus* known to occur on the GBR (Table 9). Differences and similarities in information in Table 8 (GBR) and Table 9 (non-GBR) for the two species most important to the commercial and recreational line fisheries on the GBR (*Lethrinus miniatus*, *L. nebulosus*) have been made in (i) above. Most of the remaining 13 species in Table 9 may not be of major significance to commercial or recreational fishing, but many are likely to contribute substantially to catches of 'mixed reef fish' in the commercial fishery and to incidental catches in the recreational fishery. As fishing effort increases in the future (particularly in the recreational sector), such species may assume greater significance and require more attention from a management viewpoint. The information in Table 9 will hopefully form an impetus and a basis for future studies on age, growth, mortality and longevity of lethrinids on the GBR.

5.2 *Lutjanus* spp.

5.2.1 Studies on the Great Barrier Reef

Information on age, growth, mortality and longevity is available for 2 of the 23 species of *Lutjanus* known to occur on the Great Barrier Reef (Table 8). These species, *Lutjanus sebae* and *L. malabaricus* are by far the most important in terms of catch from the commercial and recreational line fisheries of the GBR (see Section 6). Note also that McPherson et al. (1988) report that age determinations have been completed for two other species of *Lutjanus* of importance to line fisheries on the GBR: *L. erythropterus* and *L. carponotatus.*

McPherson et al. (1988) used whole otoliths for age determination of *L. sebae* and *L. malabaricus* in the Cairns region and commented that the major difficulty in age determination was the tendency of some otoliths to be completely opaque, showing no signs of check formation or translucent banding. They rejected as unreadable 22% of *L. sebae* otoliths and 13% of *L. malabaricus* otoliths. They found otoliths more reliable for age determination than scales or urohyals and, as for *Lethrinus nebulosus*, considered that sectioning of otoliths provided no significant improvement in readability over whole otoliths from fish up to five years of age. As was the case for *Lethrinus nebulosus*, McPherson et al. (1988) did not comment on the possibility that sectioning of otoliths may well improve the ability to determine age of older fish.

Otolith marginal increments for age group 1 fish of both *L. sebae* and *L. malabaricus* were at a minimum between October and February and McPherson et al. (1988) considered the checks in otoliths to be annuli formed during spring and summer months. They suggested that gonad development was the primary reason for formation of these annual checks.

McPherson et al. (1988) found that length frequency analysis (Cassie method) provided estimates of growth rate very similar to those provided by otolith readings at least for the younger year classes of both *L. sebae* and *L. malabaricus*. In addition, growth of juvenile fishes of both species in aquaria confirmed that their growth estimates made from otolith readings were realistic. They concluded that the reliability of length-at-age estimates from otoliths of both species was confirmed.

McPherson et al. (1988) recorded differential growth between the sexes in both *L. sebae* and *L. malabaricus* (Table 8). There were no differences in growth rate between sexes in age groups 1 to 5 for *L. sebae*. Males were significantly larger than females in age groups 6 and 7. Similarly for *L. malabaricus*, males were larger than females in age groups 5 to 7. Thus, males were considered to grow faster than females in both species. They reported a significant correlation between fish size and depth of capture for both species. Although samples from deeper water may have been slightly under-represented, they felt that the growth estimates obtained were appropriate to the stocks presently fished in north Queensland.

No information on mortality rates of *L. sebae* or *L. malabaricus* are available (Table 8) and regional comparisons of growth or longevity on the GBR are not possible at this stage. Both *L. malabaricus* and *L. sebae* are particularly well studied outside the GBR (Table 10). An extensive set of information exists on age, growth, mortality and longevity of *L. malabaricus* from N.W. Australia. In general the estimates of both L_∞ and longevity made by McPherson et al. (1988) for the GBR are quite similar to those obtained in N.W. Australia. McPherson et al. (1988) do not provide sufficient information to allow comparisons of K, L_∞ or mortality rates. Similar estimates of rate of total mortality (Z) have been made from N.W. Australia (Yeh and Chen 1986) and Vanautu (Brouard and Grandperrin 1985) (see Table 10) and Yeh (1988) has provided one of the few estimates of the rate of natural mortality in Tables 8 to 10 which is not based on Pauly's (1980) empirical formula. Estimates of L_∞ and longevity of *L. sebae* made by McPherson et al. (1988) are similar to those made in N.W. Australia (Table 10) but their estimate of maximum longevity is considerably less than that made by Loubens (1980a) in New Caledonia (Table 10). No comparisons of K, L_∞ or mortality of *L. sabae* between the GBR and elsewhere are available currently.

5.2.2 Studies of GBR Species made Outside the GBR

Information on age, growth, mortality and longevity is available from studies outside the GBR for 17 of the 23 species of *Lutjanus* known to occur on the GBR (Table 10). Differences and similarities in information in Table 8 (GBR) and Table 10 (non-GBR) for the two species studied on the GBR have been made in (i) above. Of the remaining 15 species in Table 10 *L. argentimaculatus*, *L. carponotatus*, *L. erythropterus* and *L. johnii* have significance in either reef or inshore commercial and recreational line fisheries in the GBR region. As was the case with lethrinids, many of the species in Table 10 may become of increasing significance to the recreational line fishery in future years. Table 10 may hopefully form an impetus and a basis for future studies of age, growth, mortality and longevity of lutjanids on the GBR.

5.3 *Plectropomus* spp.

5.3.1 Studies on the Great Barrier Reef

Information on age, growth, mortality and longevity is available for 2 of the 4 species of *Plectropomus* known to occur on the GBR (Table 8). One of these species, *P. leopardus*, is by far the most important in terms of catch of the commercial and recreational line fisheries on the GBR (see Section 6).

The early work on growth of *Plectropomus leopardus* by Goeden (1974, 1977, 1978) was based on length frequency information from samples collected at Heron Island. Using the Petersen method, Goeden was quite successful in identifying length cohorts and assigning likely ages to them, up to age 5+ years. Goeden produced size at age estimates but did not fit a growth curve to the data. Pauly and Ingles (1981) used Goeden's data with the Elefan length-frequency package to produce an estimate of L_∞ and K (Table 8). Ralston (1987) used the same data to produce an estimate of K almost half that of Pauly and Ingles (1981).

McPherson et al. (1988) were able to determine age and growth of *P. leopardus* in the Cairns region by counts of annuli in whole otoliths. They rejected 15% of otoliths as unreadable due to crowding of outer annuli. Nevertheless, they reported no marked reduction in the proportion of otoliths aged with increasing size of fish. They did, however, state that the maximum size of fish observed in their sample (n = 424) was substantially larger than for the 'aged sample'. McPherson et al. (1988) did not report any attempt to examine sectioned otoliths of *P. leopardus*, nor comment on the possibility that determination of age of old fish may have been more effective by examination of sectioned otoliths.

Percentage hyaline margin data for all age groups combined of *P. leopardus*, showed a tendency for hyaline margins to be at a minimum during winter (McPherson et al. 1988). They considered that checks formed on otoliths during the late winter and spring months. Their estimates of length-at-age from the otolith sample were consistently lower than those identified from examination of length-frequency information (Cassie method). They considered that the age estimates made from otoliths '... remain invalidated ...' and that age and growth estimates were preliminary. They stressed also that the bulk of their sample was obtained from spear fishing and thus that larger fish, which were more common in deeper water, may have been under-sampled. Nevertheless, they provided sufficient data to allow a preliminary calculation of K and t_o form their data (Table 8). The estimate of K obtained was identical to that obtained by Pauly and Ingles using Goeden's data. McPherson et al. (1988) confirmed protogyny in *P. leopardus* and all sexes were combined for age and growth analysis.

Little information exists on mortality rates of *P. leopardus* on the GBR. Goeden (1977) estimated age-specific natural mortality for *P. leopardus* at Heron Island. Data in his Table 2 translate into estimates of instantaneous natural mortality (M) of 0.30 for 2 to 3 year olds, 0.67 for 3 to 4 year olds and 2.12 for 4 to 5+ fish. Goeden (1977) concluded that the chance of *P. leopardus* surviving from the 2nd to 5th birthday was about 4% even in the absence of significant fishing pressure. He estimated maximum longevity at 5 to 6 years. These estimates are surprisingly high but still stand as our only published estimate of M for *P. leopardus*

P. leopardus is the only species of commercial and recreational fishing interest on the GBR for which there are estimates of growth characteristics in different regions of the GBR. McPherson et al. (1988 - Table 5) compared size at age estimates for north Queensland (their estimates based on otoliths) and Heron Island in the Capricorn-Bunkers (Goeden estimates based on length frequency). The size at age and L_{max} estimates are very similar for the two areas. The information in this Table contrasts with information on maximum size of *P. leopardus* in the two regions based on visual surveys. A.M. Ayling (pers. comm.) suggests, based on visual surveys, that L_{max} may be up to 80 cm TL in the Capricorn Bunkers but of the order of 62 cm TL for the rest of the GBR. Further research on age, growth, mortality and longevity of *P. leopardus* in different regions of the GBR is required.

Ferreira and Russ (MS) used otoliths to estimate age and growth of *P. maculatus* in the Townsville region (see Table 8). They used annuli in sagittae (both whole and sectioned). From age structure data they calculated Z = .569 (from ages 2 to 8). One fish of 12 years old was sampled. Annuli were validated with tetracycline banding and mark-release-recapture. Both K, L_∞ and t_o estimates are comparable to those for *P. leopardus* on the GBR.

There is no doubt that *P. leopardus* is by far the dominant component of catches of *Plectropomus* by both commercial and recreational line fishermen on the GBR. Nevertheless

P. maculatus is a species caught commonly on inshore reefs and around coastal islands of the GBR and *P. laevis* is caught commonly on outer barrier reefs. No information on age, growth, mortality or longevity has been published for either species. Both species are likely to be particularly vulnerable to overfishing; *P. maculatus* because of its proximity to the coast, *P. laevis* because of its larger size and presumed slower growth and greater maximum longevity than *P. leopardus.*

5.3.2 Studies of GBR Species made Outside the GBR

The only study of age, growth, mortality and longevity of a species of *Plectropomus* is the study of *P. leopardus* in New Caledonia by Loubens (1980b). Loubens used otoliths to estimate L_∞ = 50.05?L, K = 0.16, Longevity = 19 years (male), 14 years (female). Munro and Williams (1985) used this data and Pauly's (1980) formula to estimate M = 0.44. Comparing these estimates to those in Table 8 suggests that *P. leopardus* may grow more quickly and to a larger size and live for a much shorter period on the GBR than in New Caledonia. Loubens (1980b) estimated maximum longevities consistently higher than those recorded for all species in Table 8. Further studies of age determination of *Plectropomus* are required to determine reliable estimates of longevity of *Plectropomus* on the GBR.

5.4 Other Genera

No attempt has been made here to review age, growth, mortality or longevity information for genera known to be important in incidental catches by commercial and recreational line fishermen on the GBR or that potentially may be important in the future e.g. *Epinephelus, Cephalopholis, Gymnocranius, Monotaxis, Aprion, Etelis, Macolor, Pristipomoides, Plectroryhncus, Diagramma, Cheilinus* etc. Few if any studies on age, growth, mortality or longevity of species in these genera exist for the GBR. A large amount of such data does exist for these genera from studies carried out outside the GBR. For reviews of these studies consult Munro and Williams (1985), Manooch (1987), Ralston (1987), Ralston and Williams (1988b) and Dalzell et al. (1989).

5.5 A Comment on Validation of Checks on Otoliths and the Use of Mark Release Recapture Techniques

Opaque ('milky') bands have been recorded in whole or sectioned otoliths (almost invariably sagittae) of a large number of reef fish on the GBR. In almost all cases these bands are likely to be annuli based on evidence from examination of marginal increments or the percentage of otoliths with hyaline edges at different times of the year (e.g. McPherson et al. (1988) - *Plectropomus leopardus, Lutjanus* spp., *Lethrinus* spp.; Ferreira (pers. comm.) *Plectropomus* spp., *Lutjanus* spp., *Lethrinus* spp., Ferrell (1988) *Pseudochromis queenslandica*; Fowler (1990), *Pomacentrus moluccensis*). Fowler has been able to capture fish, administer tetracycline to the captured fish (by injection), release back into the natural environment for a sufficient period (in this case 12 months), recapture the marked fish and confirm unequivocally that the opaque bands in the otoliths of *P. moluccensis* were laid down annually. The success in this case was facilitated by the fact that *P. moluccensis* is a small, easily-captured and site-attached damselfish.

Attempts to carry out similar procedures for large reef fish of commercial and recreational fishing significance on the GBR are being made by QDPI (NFRC and SFRC, coordinated by Noel Moore) and JCU (at Orpheus and Lizard Islands). QDPI are organising research trips in which recreational line fishing clubs assist in the capture, tagging, tetracycline injection and release of a whole range of species. Subsequent recapture at intervals ranging from 4 to 12 months would be achieved by organised follow-up fishing trips. Ferreira at JCU has used the trapping studies of Davies (JCU) at Orpheus and Lizard Islands to recapture 5 coral trout (3 *P. maculatus*, 2 *P. leopardus*) one spangled emperor (*Lethrinus nebulosus*) which had been tetracyclined 12 months before. On recapture these fish are reinjected with tetracycline ('double-banded') and subsequently kept for up to 4 to 6 months in aquaria at the Orpheus Island research station. Ferreira (pers. comm.) has recently managed to validate the opaque bands in sagittae of *P. maculatus* and *P. leopardus* as annuli using trap-caught fish, tetracycline injections and mark-release-recapture techniques in the field. A number of fish of each species were recaptured after 12 months in the field. Both the line-fishing and trapping procedures are likely to pay dividends in eventually validating unequivocally that the opaque bands in otoliths of many species of large reef fish represent annuli.

One under-utilised technique in the study of growth and mortality of reef fish on the GBR is Mark-Release-Recapture (MRR) (Davies 1989). Davies (Department of Marine Biology, JCU) has used Antillean Z-traps in MRR programs at both Orpheus Island (since April 1989) and Lizard Island (since August 1990). At Orpheus Island he has captured approximately 120 different species of reef fish (about 85% of all species of trappable size in the area). Over a 30 month period at Orpheus Island he has captured a total of 51 *Plectropomus maculatus* (recapture rate 19%), 11 *P. leopardus* (recapture rate 9%) and 98 *Lutjanus carponatatus* (recapture rate 27.6%). At Lizard Island he has captured 3,686 fish (103 spp.). At this site he has captured a total of 49 *P. leopardus* (recapture rate 19.67%), 98 *Lethrinus nebulosus* (recapture rate 1%) and 224 *L. carponotatus* (recapture rate 19.13%). Such recapture rates offer great promise for collection of length increment data. Davies has made preliminary estimates of growth for *P. leopardus* (see Table 8). Such recapture rates also provide high probabilities of recapture of tetracycline-injected fishes for validation (Ferreira and Russ, MS). Davies (1989) concluded correctly that both trapping and MRR were under-utilised techniques on the GBR.

Williams, Cappo, Newman and Sheaves are carrying out extensive trapping and mark-release-recapture programs for lutjanids and lethrinids on mid-shelf and outer shelf reefs and in estuarine areas in the central GBR.

5.6 Summary

Determination of age and age-structure are the keys to good estimates of rates of growth and mortality. Growth and mortality estimates are key elements in many fisheries models. A myth has persisted for some time that tropical fishes could not have their ages determined at all or, if age could be determined, it could be achieved only with great difficulty. The work of Walker at JCU and of McPherson, Squire, O'Brien and others in the QDPI Demersal Reef Fish Project have demonstrated clearly that reef fish on the GBR, particularly those of commercial and recreational fishing significance, can have their age determined by marks or checks in their hard parts (principally otoliths and scales). These checks are very likely to be annuli. These findings have subsequently been supported by work of Ferrell, Fowler, Ferreira, Cappo and others.

Research to date indicates that reef fish of commercial and recreational fishing significance on the GBR are generally slow-growing and relatively long-lived. Very limited information exists on rates of either natural or total mortality. Estimates of maximum longevity are considerably less than those from nearby locations such as New Caledonia and Norfolk Island. There is a strong need for unequivocal validation of growth checks in hard parts as annuli, with tetracycline injection and Mark-Release-Recapture offering the most promising avenues to this validation. We need a good deal more information on stocks in deeper waters of the GBR and on growth and mortality in different regions of the GBR.

Information on age, growth, mortality, and longevity exists for only 2 of 4 species of *Plectropomus* on the GBR, 2 of 17 species of *Lethrinus* on the GBR and 2 of 23 species of *Lutjanus* on the GBR. Fortunately, the 6 species for which we have some data are by far the most important in terms of commercial and recreational fishing. Nevertheless, the fact that such information exists from studies outside the GBR for 15 of the 17 species of *Lethrinus* and 17 of the 23 species of *Lutjanus* that occur on the GBR indicates clearly that reef fish biologists on the GBR have been very slow in addressing questions of basic demography of large reef fish. Current trends suggest that such questions are beginning to be addressed but from a management viewpoint, a strong need persists for more studies of age, growth, mortality and longevity of large reef fish on the GBR.

5.7 Studies in Progress

(i) McPherson, Squire, O'Brien and colleagues from the Northern Fisheries Research Centre (NFRC QDPI) in Cairns have been involved in age and growth studies with the Demersal Reef Fish Project of NFRC. This project commenced in mid-1981 (McPherson et al. 1988). These researchers have carried out age studies (examination of whole otoliths) on 4 species of *Lutjanus* (*sebae*, *malabaricus*, *erythropterus* and *carponotatus*), 1 species of *Plectropomus* (leopardus), 2 species of *Lethrinus* (*nebulosus*, *miniatus*) and a species of haemulid (*Diagramma pictum*). Sample sizes of otoliths examined for these species range from 69 to 1046, with sample sizes for most species well in excess of 300 (McPherson pers. comm.). In addition they have collected otolith and gonad samples from a further 6 species in the family Lutjanidae, 20 species in the family Serranidae, 8 species in the family Lethrinidae, 2 species in the family Haemulidae and 2 species in the family Labridae.

(ii) A QDPI-AIMS-JCU project entitled 'Growth, reproductive strategies and recruitment of the dominant demersal food-fish species on the Great Barrier Reef' has been funded by the Fishing Industry Research and Development Council for 3 years, beginning in mid-1990.

Dr. I.W. Brown (SFRS-QDPI, Deception Bay) is the coordinator of the project which aims to determine growth and reproductive strategies of *Plectropomus leopardus* and *Lethrinus miniatus* in 4 areas of the GBR (Lizard Island, Cairns, Townsville, Mackay). The project will build on the extensive work carried out to date in the Cairns region by NFRC, the development of a laboratory to determine ages of large reef fishes at JCU and sampling programs at Lizard Island and in the Townsville region, the development of a similar facility at SFRC to service samples from the Mackay (and/or perhaps Capricorn Bunker region). The work will involve age determination of larval and juvenile *Plectropomus* by Fowler and Doherty at AIMS.

(iii) A JCU-AIMS project entitled 'The Life Cycles of Reef Fish of Commercial and Recreational Fishing Interest in the GBR Region' has been funded by the Australian Research Council and commenced in January 1990. The project aims to 'close' life cycles of species of *Plectropomus*, *Lutjanus* and *Lethrinus* and includes studies of age determination, and estimates of growth and mortality of these species. JCU (Choat, Russ, Ferreira, Davies, Laycock) has taken most of the responsibility for age, growth and mortality studies of *Plectropomus* and *Lethrinus* species in the Townsville and Lizard Island areas. AIMS (Williams, Cappo, Newman, Sheaves) is concentrating on age and growth of species of *Lutjanus* spp., particularly in the Townsville area. Both JCU and AIMS have established facilities for preparation and reading of otoliths for age determination.

(iv) B.P. Ferreira began a Ph.D. on age determination, growth, mortality and reproductive status of *Plectropomus* species (*leopardus*, *maculatus*, *laevis*) and *Lethrinus* species (*miniatus*, *nebulosus*) in the Department of Marine Biology, James Cook University, in 1989. Her studies concentrate on the Townsville and Lizard Island areas and involve collection of specimens by commercial and recreational fishermen plus systematic collection of specimens on JCU field trips. Good progress has been made in techniques of sectioning and reading otoliths of all species and validation of annuli by use of traps (Davies), tetracycline injections and mark-release-recapture.

(v) M.J. Kingsford is carrying out a project on age and growth of coral trout funded by the Australian Research Council. The project is being carried out in the Zoology Department, University of Sydney, and commenced in January 1990. A major aim is to examine Calcium/Strontium ratios in the otoliths of *Plectropomus leopardus* and their species of prey at One Tree Island, Capricorn Bunkers.

(vi) N. Baillion, of the Department of Oceanography, ORSTOM, New Caledonia has been carrying out age determination of *Lethrinus nebulosus* and *Diagramma pictum* by the daily growth increment (DGI) density technique since the mid-1980's. She has applied this technique to age determination of *Lethrinus* nebulosus from the GBR (McPherson, pers. comm.) but no reports from this work are currently available.

(vii) P. Laycock has made preliminary field trips in an MSc study at JCU on age, growth and reproduction of several species of small lethrinid (e.g. *L. obsoletus*, *L. ornatus*, *L. sp.2*, *L. semicinctus*) in the central GBR. This project will run through 1992 and 1993.

Table 8 Growth Parameters of the von Bertalanffy Growth Function (L_∞, K, t_0), Mortality Parameters (Z, M, F), Longevity and Method of Growth Determination of *Lethrinus*, *Lutjanus* and *Plectropomus* spp. on the Great Barrier Reef (GBR). All estimates of M from the empirical formula of Pauly (1980) unless marked with +.

Species	Growth Parameters L (cm)	Growth Parameters K	Growth Parameters t (yr.)	Mortality Parameters Z	Mortality Parameters M	Mortality Parameters F	Maximum Longevity (yrs)	Method of Growth Determination	Reference
Lethrinus:									
L. miniatus	58.5(SL)	.17	-2.26	.74*	-	-	7	Scales	Walker (1975)
L. nebulosus	48.0(SL)	.39	-	-	0.85	-	-	otoliths	McPherson et al. (1985)
L. nebulosus	55.6(FL)	-	-	-	-	-	12	otoliths	McPherson et al. (1988)
Lutjanus:									
L. malabaricus(f)	81.6(FL)	-	-	-	-	-	7	otoliths	McPherson et al. (1988)
L. malabaricus(m)	95.0(FL)	-	-	-	-	-	7	otoliths	McPherson et al. (1988)
L. sebae(f)	87.5(FL)	-	-	-	-	-	8	otoliths	McPherson et al. (1988)
L. sebae(m)	102.3(FL)	-	-	-	-	-	8	otoliths	McPherson et al. (1988)
Plectropomus:									
P. leopardus	47.35(SL)	-	-	-	-	-	7	otoliths	McPherson et al. (1988)
P. leopardus	59.79(SL)*	.25*	-.195*	-	-	-	-	otoliths	McPherson et al. (1988)
P. leopardus	64.7SL	.25	-	-	-	-	>5	Elefan	Pauly and Ingles (1981) (from Goeden 1977, 1978)
P. leopardus	-	.13	-	-	0.30+	-	>5	-	Ralston (1987) (from Goeden 1977)
P. leopardus	62.46(FL)	.166	-	-	-	-	-	mark-recapture (Gulland and Holt)	C. Davies (pers. comm.)
P. leopardus	65.00(FL)	.15	-	-	-	-	-	mark-recapture (Munro Plot)	C. Davies (pers. comm.)
P. maculatus	60.0(SL)	.206	-.945	.569	-	-	12	otoliths	Ferreira and Russ (MS)

* Recalculated from figures in original paper.

Table 9 Growth Parameters of the von Bertalanffy Growth Function ($L\infty$, K, t_0), Mortality Parameters (Z, M, F), Longevity and Method of Growth Determination of *Lethrinus* spp. known to occur on the Great Barrier Reef. Localities reviewed were restricted to the Indo-West Pacific region, excluding the GBR (see Table 8). All estimates of M made by formula of Pauly (1980) unless marked with +.

Species	Growth Parameters			Mortality Parameters			Maximum Longevity	Method of Growth Determination	Locality	Reference
	L (cm)	K	t_0 (yr.)	Z	M	F	(yrs)			
L. atkinsoni	32.7(SL)	0.29	-	-	0.73	-	23(m),24(f)	Otoliths	New Caledonia	Loubens (1980b)
L. atkinsoni	41.3(SL)	0.31	-	1.03	0.75	0.28	-	Length Frequency	Central Fiji	Dalzell et al. (1989)
L. atkinsoni	41.4(SL)	0.31	-	0.90	0.75	0.15	-	Length Frequency	Western Fiji	Dalzell et al. (1989)
L. atkinsoni	42.8(SL)	0.29	-	0.65	0.71	0	-	Length Frequency	Northern Fiji	Dalzell et al. (1989)
L. erythracanthus	51.7(SL)	0.20	-	-	0.53	-	-	Length Frequency	Northern Fiji	Dalzell et al. (1989)
L. genivittatus (m)	16.0(SL)	0.87	-	-	1.82	-	7	Otoliths	New Caledonia	Loubens (1980b)
L. genivittatus (f)	14.0(SL)	0.86	-	-	1.87	-	7	Otoliths	New Caledonia	Loubens (1980b)
L. harak	33.0(SL)	0.49	-	1.60	1.07	0.53	-	Length Frequency	Central Fiji	Dalzell et al. (1989)
L. harak	34.2(SL)	0.45	-	2.03	1.01	1.02	-	Length Frequency	Western Fiji	Dalzell et al. (1989)
L. harak	33.9(SL)	0.46	-	1.52	1.03	0.50	-	Length Frequency	Northern Fiji	Dalzell et al. (1989)
L. harak	-	-	-	-	-	-	15	Otoliths	New Caledonia	Loubens (1980a) (in Pauly 1984)
L. lentjan	29.2(SL)	0.33	-	-	0.82	-	15	Otoliths	New Caledonia	Loubens (1980a)
L. lentjan	64.0(TL)	0.27	-	-	0.61	-	5	Otoliths, Scales	India	Toor (1964)
L. lentjan	51.1(TL)	0.17	-	-	0.42	-	9	-	Red Sea	Carpenter and Allen (1989)
L. lentjan	42.6(FL)	0.48	-	-	-	-	-	Scales	Gulf of Aden	Aldorov and Druzhinin (1979)
L. microdon *	82.0(TL)	0.21	-	-	0.4	-	-	-	Djibouti	Carpenter and Allen (1989)
L. miniatus (m)	48.9(SL)	0.26	-	-	0.6	-	22	Otoliths	New Caledonia	Loubens (1980b)
L. miniatus (f)	45.7(SL)	0.27	-	-	0.63	-	14	Otoliths	New Caledonia	Loubens (1980b)
L. miniatus (m)	70.0(FL)	0.10	-2.36	-	-	-	18	Scales, Otoliths	Norfolk Island	Church (1989)
L. miniatus (f)	82.98(FL)	0.056	-4.6	-	-	-	15	Scales, Otoliths	Norfolk Island	Church (1989)
L. nebulosus (m)	50.9(SL)	0.22	-	-	0.54	-	24	Otoliths	New Caledonia	Loubens (1980b)
L. nebulosus (f)	54.3(SL)	0.21	-	-	0.51	-	27	Otoliths	New Caledonia	Loubens (1980b)
L. nebulosus	54.7(FL)	0.41	-	-	0.74	-	-	Petersen	Kavieng, PNG	Wright et al. unpubl.
L. nebulosus	55.8(FL)	0.31	-	-	0.56	-	-	Elefan	Kavieng, PNG	Wright et al. unpubl.
L. nebulosus	64.6(SL)	0.16	-	0.53	0.43	0.10	-	Length Frequency	Central Fiji	Dalzell et al. (1989)
L. nebulosus	62.3(SL)	0.17	-	0.51	0.45	0.06	-	Length Frequency	Western Fiji	Dalzell et al. (1989)
L. nebulosus	50.2(SL)	0.21	-	-	0.55	-	-	Length Frequency	Northern Fiji	Dalzell et al. (1989)
L. nebulosus	71.6(FL)	0.21	-	-	-	-	21	Scales	Gulf of Aden	Aldorov and Druzhinin (1979)
L. nebulosus	85.9(FL)	0.101	-	-	0.32	-	-	Scales, Ford-Walford Plot	Gulf of Aden	Aldorov and Druzhinin (1979)
L. nebulosus	87.0(FL)	0.09	+0.54	0.44	0.44	-	-	Otoliths	Gulf of Aden	Dalzell et al. (1989)

Table 9 cont.

Species	Growth Parameters L (cm)	K	t_0(yr.)	Mortality Parameters Z	M	F	Maximum Longevity (yrs)	Method of Growth Determination	Locality	Reference
L. nebulosus (m)	61.1(FL)	0.106	-0.88	-	0.37	-	-	Vertebrae	N.W. Australia	Kuo (1988)
L. nebulosus (f)	52.7(FL)	0.127	-1.16	-	0.37	-	-	Vertebrae	N.W. Australia	Kuo (1988)
L. nebulosus	62.7(FL)	0.19	-	-	0.47	-	20	Otoliths	Kuwait	Baddar (1987)
L. nebulosus	86.0(TL)	0.11	-	-	0.30	-	-	-	Northern Red Sea	Carpenter and Allen (1989)
L. nebulosus	87.0(FL)	0.1	-	-	0.88	-	21	-	Gulf of Aden	Carpenter and Allen (1989)
L. nebulosus	99.9(FL)	0.09	-	-	0.44	-	21	-	Gulf of Aden	Carpenter and Allen (1989)
L. obsoletus	-	-	-	-	-	-	14	-	New Caledonia	Loubens (1980a) in Pauly(1984)
L. olivaceus	75.0(FL)	0.25	-	-	0.59	-	-	Petersen	Kavieng, PNG	Wright et al. unpubl.
L. olivaceus	58.9(FL)	0.23	-	-	-	-	-	Scales	Gulf of Aden	Aldonov and Druzhinin (1979)
L. olivaceus	106.5(FL)	0.061	-	-	-	-	-	Scales, Ford-Walford Plot	Gulf of Aden	Aldonov and Druzhinin (1979)
L. olivaceus	[Paper not seen]		-	-	-	-	-	Otoliths	French Polynesia	Caillart et al. (1986)
L. ornatus	32.7(SL)	0.49	-	2.35	1.09	1.27	-	Length Frequency	Central Fiji	Dalzell et al. (1989)
L. ornatus	33.1(SL)	0.48	-	1.74	1.07	0.67	-	Length Frequency	Western Fiji	Dalzell et al. (1989)
L. ornatus	30.9(SL)	0.55	-	2.34	1.19	1.16	-	Length Frequency	Northern Fiji	Dalzell et al. (1989)
L. rubrioperculatus	30.8(FL)	0.22	-0.40	-	-	-	-	Otoliths	American Samoa	Ralston and Williams (1988a)
L. semicinctus	30.0(SL)	0.59	-	2.69	1.25	1.44	-	Length Frequency	Central Fiji	Dalzell et al. (1989)
L. semicinctus	26.4(SL)	0.76	-	1.93	1.53	0.40	-	Length Frequency	Western Fiji	Dalzell et al. (1989)
L. variegatus	30.3(SL)	0.43	-	-	0.96	-	15(m), 9(f)	Otoliths	New Caledonia	Loubens (1980b)
L. xanthochilus	55.5(FL)	0.30	-	-	-	-	-	Petersen	Kavieng, PNG	Wright et al. unpubl.
L. xanthochilus	56.0(FL)	0.20	-	-	-	-	-	Elefan	Kavieng, PNG	Wright et al. unpubl.
L. xanthochilus	62.2(SL)	0.14	-	0.35	0.39	0	-	Length Frequency	Central Fiji	Dalzell et al. (1989)
L. xanthochilus	64.0(SL)	0.17	-	0.73	0.45	0.28	-	Length Frequency	Western Fiji	Dalzell et al. (1989)
L. xanthochilus	53.9(SL)	0.18	-	-	0.49	-	-	Length Frequency	Northern Fiji	Dalzell et al. (1989)

* This species may not occur on the GBR

Table 10 Growth Parameters of the von Bertalanffy Growth Function (L_∞, K, t_0), Mortality Parameters (Z, M, F), Longevity and Method of Growth Determination of *Lutjanus* spp. known to occur on the Great Barrier Reef. Localities reviewed were restricted to the Indo-West Pacific region, excluding the GBR (see Table 8). All estimates of M made by formula of Pauly (1980) unless marked with +.

Species	Growth Parameters			Mortality Parameters			Maximum Longevity	Method of Growth Determination	Locality	Reference
	L (cm)	K	t_0 (yr.)	Z	M	F	(yrs)			
L. adetti (m)	33.4(SL)	0.26	-	-	0.67	-	40	Otoliths	New Caledonia	Loubens (1980b)
L. adetti (f)	29.3(SL)	0.34	-	-	0.83	-	37	Otoliths	New Caledonia	Loubens (1980b) (Longevities from Loubens 1980a)
L. argentimaculatus	82.7(FL)	0.26	-	-	0.65	-	-	Petersen	Kavieng, PNG	Wright et al. unpubl.
L. argentimaculatus	75.5(FL)	0.20	-	-	0.51	-	-	Elefan	Kavieng, PNG	Wright et al. unpubl.
L. argentimaculatus	105(TL)	0.187	-0.044	-	-	-	-	Length Frequency	Peninsula Malaysia	Ambak et al. (1985)
L. argentimaculatus	-	-	-	-	-	-	18	Otoliths	New Caledonia	Loubens (1980a)
L. bohar	52.0(SL)	0.11	-	-	0.34	-	-	Otoliths	New Caledonia	Loubens (1980b)
L. bohar	81.0(FL)	0.30	-	-	0.64	-	-	Petersen	Kavieng, PNG	Wright et al. unpubl.
L. bohar	81.7(FL)	0.27	-	-	0.59	-	10	Elefan/Petersen	Kavieng, PNG	Wright et al. (1986)
L. bohar	66.0(TL)	0.27	-	-	0.64 (Deep) 1.18 (Shallow)		13	Scales	Kenya	Talbot (1960)
L. carponotatus	56.0(FL)	0.31	-	-	-	-	-	Petersen	Kavieng, PNG	Wright et al. unpubl.
L. erythropterus	72.6(FL)	0.21	-0.714	-	-	-	>7	Vertebrae	N.W. Australia	Ju et al. (1988)
L. fulviflamma	24.8(SL)	0.30	-	-	0.80	-	23	Otoliths	New Caledonia	Loubens (1980b)
L. fulvus	[Paper not sighted]		-	-	-	-	-	-	French Polynesia	Caillart et al (1986)
L. gibbus	44.2(FL)	0.31	-	-	-	-	-	Petersen	Kavieng, PNG	Wright et al. unpubl.
L. gibbus	[Paper not sighted]		-	-	-	-	-	-	Kuwait	Mansour (1982)
L. gibbus	-	-	-	-	-	-	18	Otoliths	New Caledonia	Loubens (1980a) in Pauly (1984)
L. johnii	96.1(FL)	0.116	-	-	-	-	-	Scales	Andaman Sea	Druzhinin (1970)
L. kasmira	21.1(SL)	0.38	-	-	0.98	-	-	Otoliths	New Caledonia	Loubens (1980b)
L. kasmira	29.6(FL)	0.384	-1.35	-	-	-	-	Otoliths	American Samoa	Ralston and Williams (1988a)
L. kasmira	39.6(FL)	0.212	-0.75	-	-	-	-	Otoliths	American Samoa (Deepwater)	Ralston and Williams (1988b)
L. lutjanus	25.1(TL)	0.497	-0.089	-	-	-	-	Length Frequency	Peninsula Malaysia	Ambak et al. (1985)
L. lutjanus	[Paper not sighted]		-	-	-	-	-	-	Red Sea	Sanders et al. (1984)

Table 10 cont.

Species	Growth Parameters L (cm)	K	t_0 (yr.)	Mortality Parameters Z	M	F	Maximum Longevity (yrs)	Method of Growth Determination	Locality	Reference
L. malabaricus	70.7(SL)	0.168	0.418	-	-	-	-	Vertebrae	N.W. Australia	Edwards (1985)
L. malabaricus	>90(FL)	0.132	-	-	-	-	-	Scales	Andaman Sea	Druzhinin (1970)
L. malabaricus	96.4(FL)	0.12	-1.29	-	-	-	10-11	Vertebrae	Arafura Sea	Lai and Lui (1979)
L. malabaricus	93.7(FL)	0.126	-1.34	-	-	-	>9	Vertebrae	N.W. Australia	Lai and Lui (1974), (1979)
L. malabaricus	86.1(FL)	0.252	-0.085	-	-	-	>10	Otoliths	N.W. Australia	Chen et al. (1984)
L. malabaricus	-	-	-	0.499 (Range: .37-.69)	-	-	10	Length Frequency	N.W. Australia	Yeh and Chen (1986)
L. malabaricus	-	-	-	-	0.34+	-	-	Plot of Z vs. F	N.W. Australia	Yeh (1988)
L. malabaricus	52.0(FL)	0.37	-	-	0.82	-	-	Petersen	Kavieng, PNG	Wright et al. unpubl.
L. malabaricus	60.0(SL)	0.31	-	0.447 0.441	0.545	-	-	Otoliths	Vanuatu	Brouard and Grandperrin (1985)
L. monostigma	55.0(FL)	0.22	-	-	0.60	-	-	Petersen	Kavieng, PNG	Wright et al. unpubl.
L. monostigma	47.9(FL)	0.23	-	-	0.64	-	-	Elefan	Kavieng, PNG	Wright et al. unpubl.
L. quinquelineatus	17.3(SL)	0.37	-	-	1.02	-	22	Otoliths	New Caledonia	Loubens (1980b)
L. rivulatus	70.0(FL)	0.22	-	-	0.73	-	-	Petersen	Kavieng, PNG	Wright et al. unpubl.
L. rivulatus	67.4(FL)	0.33	-	-	0.55	-	-	Elefan	Kavieng, PNG	Wright et al. unpubl.
L. sebae	85.1(FL)	0.16	-1.02	-	-	-	-	Scales	Gulf of Aden	Druzhinin and Filatova (1980)
L. sebae	81.7(FL)	0.13	-1.09	-	-	-	>10	Vertebrae	N.W. Australia	Yeh et al. unpubl.
L. sebae	-	-	-	-	-	-	35	Otoliths	New Caledonia	Loubens (1980a) in Pauly (1984)
L. vitta(m)	28.2(SL)	0.32	-	-	0.81	-	12	Otoliths	New Caledonia	Loubens (1980b)
L. vitta(f)	23.8(SL)	0.30	-	-	0.81	-	12	Otoliths	New Caledonia	Loubens (1980b)
L. vitta	42.5(TL)	0.256	-0.0001	-	-	-	-	Length Frequency	Peninsula Malaysia	Ambak et al. (1985)

6 CATCH AND EFFORT

6.1 Overview of Current Situation

Line fishing is allowed in approximately 95% of the Great Barrier Reef Marine Park (Craik 1989a). The reef line fishery on the Great Barrier Reef is divided into commercial and non-commercial (recreational) sectors. The recreational sector can be divided further into a small-boat fleet and a charter-boat fleet (Hundloe 1985; Hundloe et al. 1986). A small recreational spear fishery exists also (Steven 1988).

In 1989, there were 1963 commercial fishing vessels in Queensland which held line endorsements entitling them to operate in the `Reef Line Fishery' (Gwynne 1990). One hundred and seventy six of these vessels nominated line fishing as their principal activity. These 176 vessels operated 321 tender vessels. Of the 176 vessels, 69 held `line-only' entitlement, permitting them to operate four tender vessels per entitlement. The 69 vessels operated 153 tender vessels, indicating some potential for expansion of effort (Gwynne 1990). Total catch of reef fish (non-pelagics) by this fleet was 1815 mt in 1988, 2265 mt in 1989 and 2791 mt in 1990 (Qld Fisherman, June 1991). Coral trout was the dominant component of this catch (1016 mt, 1188 mt and 1490 mt in 1988, 1989, 1990 respectively). A total of 95 vessels caught 67% of this catch and 158 vessels caught 81% of the overall catch.

The small-boat recreational fleet fishing in the Great Barrier Reef region in 1990 was estimated to be 24, 300 boats (Blamey and Hundloe 1991). This fleet was estimated to catch approximately 3500-4300 mt of fishes (including pelagics) from the GBR region. This catch figure contrasts with that estimated by (Hundloe 1985 and Driml et al. 1982) of 6600 mt caught by 14887 small boats fishing the GBR region in 1980. It contrasts also with predicted catches of 12000 mt for 1990 by the small-boat fleet (Craik 1989a). The phone/mail and boat-ramp surveys carried out by the Institute of Applied Environmental Research (IAER) (Driml et al. 1982; Hundloe 1985; Blamey and Hundloe 1991) suggest that between 1980 and 1990 the small-boat fleet increased in size by 40% whilst total catch declined by 40%. They attribute these findings to falling numbers of fish caught per trip, falling average size of fish caught and lower estimates of the mean number of fishing trips per year made by small-boat recreational fishermen. These perceived changes in the catch-effort characteristics of the small-boat recreational fishery should be treated with caution because of the very low sampling fractions used in the 1980 and 1990 surveys. It is quite possible that the 1980 estimate of catch of 6500 mt (used subsequently in the predictions of Craik 1989a) was an overestimate, rather than the catch having almost halved while effort almost doubled over the period 1980-1990.

The size of the charter-boat fleet was estimated to be around 201 vessels by (Hundloe et al. 1986). A total of 90 of these vessels were classified as having fishing as a principal or significant activity. This fleet was estimated to catch 450 mt of fish per year (Hundloe et al. 1986).

One general aspect of catch-effort information that is often not stressed is the difference in spatial distribution of effort (and subsequent catch) of the commercial and small-boat recreational fleets. The report by Blamey and Hundloe (1991) indicates that a remarkably small percentage (1-2%) of recreational small-boat trips actually fish on the main clusters of mid to outershelf reefs (ie. the dark blue areas on most GBRMPA zoning maps), with the possible exception of the Cairns region (about 25% of trips in this region fish such reefs). This suggests that the small-boat recreational fleet and the commercial fleet tend to be separated spatially, particularly considering the high percentage of time spent by commercial fishermen in such areas as the northern section of the marine park, the Swains, Pompeys, Hardline reefs etc.

The catch of the recreational spear fishery is probably insignificant compared to the catch of other sectors. The limited amount of catch-effort data available has been reviewed by Steven (1988).

6.2 The Commercial Fishery

6.2.1 Catch Information

The commercial handline fishery on the Great Barrier Reef began before World War II (McPherson et al. 1988) but official catch records collected by the Queensland Fish Board appear to date only between 1957 and 1981. Attempts at reviewing and summarising these early official catch figures have been made by (Pownall 1971), (examining figures for 1968/69) Australian Bureau of Statistics (ABS 1977-1981) (summarising fisheries statistics in Queensland from 1970-71 to 1980-81 before being discontinued), (Bandaranaike and Hampton 1979) (summarising data from 1967-1977), Matilda and Hill (1981) (summarising data from 1966-67 to 1980-81), (Hundloe 1985) (summarising data from 1972-73 to 1980-1981, with detailed figures for 1979-81 and (Steven 1988) (summarising data from 1957 to 1981). A summary of the official Queensland Fish Board catch records for 1957-1981 (take from Steven 1988) is provided in Table 11 and a compilation of data from several reviews of catch records from 1966/67 to 1980/81 is provided in Table 12.

It is acknowledged widely that the catch records of the Queensland Fish Board (used as the basis of catch records submitted to ABS and as the basis of the review by Matilda and Hill) provided underestimates of true commercial catch of reef fish. An unknown (but possibly large) percentage of the catch was not sold through the Fish Board. The records summarised by Steven (1988) show an official annual catch of reef fish in the order of 100-200 mt in the 1950's and 1960's and 300-500 mt in the 1970's and early 1980's (Table 11). The figures summarised by Matilda and Hill (1981) are slightly higher, with total reef fish catches of 400-600 mt in the 1970's and early 1980's (Table 12). The pre-1972 catch figures for areas north of Rockhampton were collected by the north Queensland Fish Board. The Queensland Fish Board (established under the Fish Supply Management Act of 1972) collected the catch data from 1972-1981.

In March 1982, the Queensland Fishing Industry Organisation and Marketing (FIOM) Act included provision for a new authority, The Queensland Fish Management Authority (QFMA). The FIOM Act required that commercial fishing activity (e.g. catch, effort) be recorded and submitted to QFMA.

Since January 1 1988, commercial fishermen have been providing a summary of their fishing activity by location, effort, and landed weight by species. This program is known as CFISH, the Queensland Commercial Fisheries Database (Qld Fisherman, December 1989, p. 20). Mr Lew Williams of Queensland Fisheries Branch Headquarters, Brisbane, is in charge of the database. The latest information available (Qld Fisherman June 1991, p. 27) is summarised in Table 12.

Catch records for the commercial line fishery on the GBR are not available between 1980/81 and 1988, the period during which responsibility for the marketing of fish in Queensland transferred from QFB to QFMA. Total commercial catch of reef fish has varied from 1815 mt in 1988 to 2791 mt in 1990 although it may take some years before complete and fairly reliable catch and effort records are produced by the logbook system. Nevertheless, it is clear that CFISH has established that total commercial catch of reef fish is substantially higher (by a factor of 4 to 6) than the last QFB estimates in 1980/81. This is liable to reflect the severe inadequacies of the pre-1988 catch data, since nominal effort (numbers of licensed fishermen) does not appear substantially different between 1979 and 1989 (see Table 12 and next section).

Coral trout clearly dominate the current commercial catch of reef fish (54%), with Sweetlip emperor and Red emperor (24%) and other reef fish (22%) the other major components. The latest review of the CFISH data for the reef line fishery appeared in Queensland Fisherman in March 1991 (Trainor 1991).

6.2.2 Effort Information

Information on fishing effort in the commercial line fishery on the GBR is limited, with detailed information available only since January 1 1988 (Trainor 1991). The Fisheries Research Branch, Queensland Department of Primary Industries carried out questionnaire surveys of licensed master fishermen in Queensland in 1979, 1980 and 1981 to determine baseline information on numbers of fishermen in various fishing categories (Williams 1981, 1986; Hundloe 1985). The Queensland coast was divided into 7 regions. Williams (1981) reported 256 primary fisherman in the line fishery in 1979 (156 were reef fishermen of which 89 fished in the GBR region). In 1980, there were 215 primary fishermen in the line fishery (112 were reef fishermen of which 69 fished in the GBR region) (Table 12). Hundloe (1985) reported 279 primary fishermen in the line fishery in 1981. Of the 69 primary fishermen in the line fishery in the GBR region in 1980, 13 were based between Hervey Bay and Rockhampton (Area 2) 22 between St. Lawrence and Mackay (Area 3), 34 between Bowen and Cooktown (Area 4) and none in far north Queensland (Area 5). The figures gave no indication of mobility of the fleet and exactly where effort was expended. Williams (1981) commented on the substantial drop in the category `reef fishermen' from 156 in 1979 to 112 in 1980. However, the actual number of primary fishermen concentrating their efforts in the GBR region appears reasonably consistent, from the limited data for 1979, 1980, 1986 and 1989 (Table 12). Two surveys identical to those reported by Williams (1981) were carried out by QDPI in 1982 and 1983 (R. Quinn pers comm). These produced two reports which were not released. Gwynne (1990) provided data on numbers of fishermen in the line fishery in 1986 (Table 12) but did not indicate the source of this information. Some very general information about commercial (and recreational) fishing effort has been reported in the GBRMPA zoning plans for the Far Northern Section in 1984, the Capricorn and Capricornia Sections in 1987, and the Cairns and Central Sections in 1988 (see Craik 1989b). The only true effort data available for the fishery became available from January 1 1988 (CFISH database; Trainor 1991). In 1989, 176 primary fishermen recorded the line fishery as their principal activity with 69 holding a line-only endorsement.

Under the CFISH database system, Queensland has been divided up into bands each of 30 nautical miles latitude (see Fig. 4 of Trainor 1991). In 1988, the total line fishery data came from 911 boats which fished for 27771 boat-days with an average catch per boat of 3602 kg/yr or 118 kgs/boat/day. In 1989, 964 boats fished for 39202 boat-days for an average catch per boat of 4223 kg/yr or 104 kgs/boat/day (Trainor 1991). The line fishery displayed substantial variations in catch, effort and catch-per-unit-effort (CPUE) over time (seasonality) and in space (regional differences). The line fishery is seasonal with strong peaks in catch, effort and CPUE during the period August-October (monthly catch around 500 mt). Substantial increases in the catch of coral trout, red-throat emperor, mixed reef fish (`other') and mackerel occur at this time. Catch, effort and CPUE decline sharply during December to March (monthly catch about 150 mt). Effort peaks at 450 boats fishing per month and 5000 boat days fished per month in the August-October period and drops to around 200 boats fishing per month and 2000 boat days fished per month in March-May (Trainor 1991). CPUE peaks at around 150 kgs/boat/day or 1200 kgs/boat/month in the August-October period and drops to 70 kgs/boat/day or 600 kgs/boat/month in February-March (Trainor 1991). The majority of the catch is taken between Cardwell and Mackay. The two 30 nautical mile bands off Cardwell and Mackay account for 20% of the total line fish catch (800 mt). CPUE peaks between Cardwell and Mackay (3000-3500 kg/boat/band or 150 kg/boat/day/band) with another strong peak in the

Torres Strait (4000 kg/boat/year/band, 200 kg/boat/day/band). Over most of the other areas of the reef the CPUE averages around 1000 kg/boat/year/band or 50 kg/boat/day/band (Trainor 1991). Effort peaks between Cardwell and Mackay (100 boats fishing per band, 2500 boat days per band). Catches of coral trout, red-throat emperor and mixed reef fish (`other'), show peaks in catch between Cardwell and Mackay within the GBR region.

6.3 The Recreational Fishery

6.3.1 Catch and Effort of the Small-Boat Recreational Fleet

The major studies of catch and effort for the small-boat recreational fleet on the GBR were those of GBRMPA in 1979 and 1980 (Craik 1981a, b; Fallows and Craik 1980; Craik and Fallows 1981) the IAER of Griffith University in 1979-80 (Driml et al. 1982; Hundloe 1985) and the IAER in 1990 (Blamey and Hundloe 1991). These studies used three methods of data collection: surveys at boat-ramps, phone recall surveys and mail recall questionnaires. A summary of some of the major findings of these studies is provided in Table 13.

There is no doubt that the size of the small-boat fleet fishing in the GBR region is expanding rapidly. In 1979-80 there were 75,000 small boats registered in Queensland, with an estimated 14,887 fishing in the GBR region. In 1990 there were 94,369 small boats registered in Queensland, with an estimated 24,300 fishing in the GBR region. (The increase from 14,887 to 24,300 appears to be a 63% increase for the decade but is quoted as a 40% increase in Blamey and Hundloe (1991). The latter % increase is roughly 10 times the annual average growth). The small-boat fleet has an average annual growth rate of 2.6% for Queensland as a whole, and 3.3% for the areas adjacent to the GBR (Gwynne 1990). Annual growth rates for Cairns, Townsville, Mackay and Rockhampton are respectively 7.8%, 3.7%, 0.4% and 0.5%, reflecting a rapid growth of population in the north of the state.

The initial estimates of both total catch and effort of the small-boat recreational fleet (1979-80 by GBRMPA and IAER) were substantial. Craik (1981a) estimated that 4,357 small-boats in Cairns and Capricornia made 58,100 trips/year and caught 1,750 to 2,300 mt of fish (from 14% of the GBR region) (Table 13). Driml et al. (1982) and Hundloe (1985) estimated that 14,887 small boats in four regions of the GBR (excluding the northern section of the marine park) made 196,600 trips/year and captured 6600 mt of fish (Table 13). Comparisons between the initial GBRMPA and IAER Surveys are biased because a reasonable component of the GBRMPA survey was based in Capricornia (rather than the Rockhampton region as for the IAER survey). Catch rates appear to be substantially higher and average sizes of fish much lower in Capricornia. However, there is reasonable agreement between the studies that catch rates (fish caught and kept), averaged around 1 fish/person/hour (Table 13) in 1979-80.

Comparison of the results of the IAER surveys in 1980 and 1990 suggest some very substantial changes in the catch-effort characteristics of the small-boat fishery over the decade (Table 13). Total catch declined by 40% between 1980 and 1990 (as measured by the two IAER surveys) whilst the number of boats fishing in the GBR region increased by about 40%. This represents a reduction in catch from 6,600 mt (1980) to 3,500 to 4300 mt (1990) (or 2,600 to 3,200 mt in 1990, if one sums the individual area yields in Table 13). Blamey and Hundloe (1991) attribute these changes as `a consequence of falling numbers of fish caught per trip, falling average sizes of fish caught and kept, and lower estimates of the mean number of fishing trips made by fishermen'. Average catch rates in some regions were estimated to have almost halved (Table 13), number of trips per boat had declined substantially (e.g. Rockhampton, Townsville: Table 13) and average weight of fish caught and kept was down overall by about 40% (Table 13). If these are reasonable estimates of the true condition of this fishery then they have quite serious management implications and action may be required to limit the effective effort of the small-boat recreational fleet (see Section 12).

Some comment on the methodologies of these surveys is warranted. The original GBRMPA boat ramp surveys (e.g. Craik 1981a) were carried out only in August 1979 (Capricornia) and August 1980 (Cairns-300 questionnaires). The sampling fractions for the mean number of trips/year determined by phone/mail recall surveys in the two IAER surveys were 424 respondents who fished the GBR out of 14,887 in 1980 (2.8%) and 406/24,300 = 1.7% in 1990. These are possibly reasonable sampling fractions. However, Thompson and Hubert (1990) demonstrated that phone/mail recall surveys of recreational fishermen in Wyoming for 3 separate years gave estimates of number of days fished/year 3 to 4 times higher than those estimated by actual records kept by fisherman in a fourth year. Thus, phone/mail recall surveys can give biased estimates of real effort.

Furthermore, the estimates of numbers of fish caught (and their identity) from boat ramp surveys in the two IAER surveys were based on very small sampling fractions. The sampling fraction (number of people interviewed who had just completed a trip to the GBR expressed as a percentage of total number of trips per year) for 1980 was about 0.2% (424/196, 600) and for 1990 0.2% (444/270,000). Given the large variability one might expect from trip to trip and from boat to boat for variates such as species composition, number and size of fish etc., these sampling fractions are very low.

Some of the substantial changes suggested to have occurred (in terms of number of fish caught, average size of fish) on a regional scale should be treated with some caution (Table 13). For example, in the Mackay region catch was estimated to be down from 1,100 to 1,600 mt (1980) to 340 to 750 mt (1990) whilst number of boats were up 89% (Blamey and Hundloe 1991). The 1990 boat ramp figures were based on 46 interviews (of people that caught fish) for the whole region. In Townsville catch was estimated to be down from 1,880 to 2,350 mt (1980) to 470 to 760 mt (1990) whilst number of boats was up 47%. The 1990 boat ramp figures were based on 158 interviews (of people that caught fish) for the whole region.

The comparisons of the two IAER surveys should be treated with caution, particularly when the figures are used to extrapolate to `total reef' figures. The 1980 IAER survey data (Driml et al. 1982; Hundloe 1985) suggested a total annual catch of the small-boat fleet of 6600 mt. This led people to speculate (e.g. Craik 1989a) that the recreational catch of fish on the GBR may reach 10,000 to 12,000 mt by 1990 (3 to 4 times the commercial catch based on commercial logbooks). Blamey and Hundloe (1991) suggest that the bulk of the recreational catch (ie. by the small-boat fleet) is only about one third of the extrapolations used in the GBRMPA television advertisements on reef fishing. Furthermore, the 1990 estimate of catch of the small-boat recreational fleet (3500-4300 mt including pelagics; Blamey and Hundloe 1991) is very similar in magnitude to the official catch of the commercial line fishery (4070 mt including pelagics: Trainor 1991). Clearly, far more research on the catch-effort characteristics of the small-boat recreational fleet (with regular and extensive boat-ramp surveys being preferable to phone/mail recall surveys) is required before we can really judge the relative magnitude of the recreational and commercial catch of reef fish on the GBR.

It is important to note that the spatial extent of fishing effort by the small-boat recreational fleet is likely not to overlap greatly with the effort expended by the commercial fleet. To fish the main clusters of mid to outershelf reefs (ie. the dark blue areas on most GBRMPA zoning maps) one needs to travel from the cities of Cairns, Townsville, Mackay and Rockhampton 40, 80, 120 and 80 km respectively. These distances are considerably greater than the average `as the crow flies' distances fished by the small-boat recreational fleet (Blamey and Hundloe 1991). The percentage of small-boat trips travelling such distances in each region, respectively, are 24.6%, 2.1%, 2.1%, 1.3% (Blamey and Hundloe 1991). Thus, the impact of the small-boat recreational fleet is concentrated very close to the coast, away from the majority of the GBR coral reefs (where commercial effort is concentrated), with the possible exception of the Cairns region.

Aerial surveys are an underutilised technique for estimating effort in the recreational small-boat fishery. Walker (1989) gives a good example of the type of data that can be obtained from an area such as the Capricorn-Bunkers. Given good `ground truthing' information such as hours fished per boat, number of people per boat, etc. Such aerial surveys could produce estimates of effort in terms of hours fished per hectare of reef. Such estimates of effort, if combined with estimates of catchability for the particular region (e.g. Beinssen 1989a) could provide direct estimates of fishing mortality imposed upon stocks. Use of remote-sensing from satellites to estimate effort, although technically possible, is currently prohibitive in cost.

Relative Success of Anglers in the Small-Boat Recreational Fishery
Craik (1981a) reported that the distribution of catch amongst recreational fishermen was uneven. The top 10% of anglers took 25 to 30% of the catch (reported as 30 to 40% of the catch in Craik 1989a). An estimated 80% of the catch was taken by 50% of anglers. The top 10% of fishermen in Cairns caught a mean of 13 fish/day compared with 2.5 or fewer/day for the bottom 50% of anglers. This pattern was confirmed by Blamey and Hundloe (1991). They reported that in Cairns the top 8.6% of boats caught 30.7% of the total catch. Equivalent figures for Townsville, Mackay and Rockhampton were, respectively, 8.2% of boats catching 38.3% of fish, 6.6% of boats catching 27.1% of fish and 9.2% of boats catching 52.9% of fish.

6.3.2 Catch and Effort of the Charter Boat Fleet

The major studies of catch and effort for the charter boat recreational fleet on the GBR were those of GBRMPA in 1979 (Craik 1979a, b, 1981a, b), the IAER of Griffith University in 1981 (Driml et al. 1982) and 1985 (Hundloe et al. 1986; and see Stephen 1988) and GBRMPA in 1989 in the Cairns region (Zann-Schuster 1990). The studies of both Craik and Zann-Schuster involved analysis of back-records of catch-effort data from various fishing clubs which use charter boats to fish the GBR. A study is currently in progress (J. Higgs, Department of Marine Biology, James Cook University) to analyse these catch records for all GBR regions (except the northern section) over the period 1961 to 1989. A summary of the major findings of the studies available are provided in Tables 14 and 15.

Hundloe et al. (1986) estimated that 90 of 201 charter boats in the GBR region classified fishing as a principal or significant activity. A fleet of 83 of these charter vessels was estimated to have caught 450 mt of reef fish in 1985. Thus, the total catch of the charter boat fleet is substantially less than that of the small-boat recreational fleet.

Both Craik (1979a, b; 1981a, b) and Zann-Schuster (1990) provided detailed estimates of long-term trends in catch per unit effort of fishing clubs using charter boats or club boats. Data on average sizes of reef fish captured over long periods of time were derived. The data were derived from club competitions. Although factors such as changes in gear technology (e.g. echo-sounders), fishing practices (e.g. varying emphasis on daytime or night-time fishing leading to variations in catch composition, see Zann-Schuster 1990) and spatial extent of effort (e.g. more reefs or more distant reefs fished through time) are not taken into account, some interesting general patterns can be derived from this data (Table 15). Craik (1979b) could not detect any significant change in number of fish caught/person/day for Townsville (1961-1977), Mackay (1976-1979) and the Capricorn-Bunkers (1957-1978) (Table 15). A trend of declining catch rate (fish/person/day) was observed off Innisfail (1971-1976) but this was not significant either. Craik (1979b) could detect no significant decline in the average individual size of fish captured off Innisfail (1971-76), Mackay (1976-1979) nor the Capricorn-Bunkers (1957-1978).

A strong negative trend in average size of fish captured off Townsville overtime (from 2.6 kg in 1961 to 1.4 kg in 1977) was detected. When these average figures are plotted with confidence limits, the major influence on the downward trend is the high average size of fish captured in the early 1960's. The data on average size of fish captured off Townsville from the late 1960's to the late 1970's does not suggest a significant decline. Data analysed recently for the 1980's suggests that both average size of reef fish captured and catch rates by clubs off Townsville may not have changed significantly through the 1970's and 1980's (J. Higgs, pers. comm).

Zann-Schuster (1990) examined catch-records of clubs from the Cairns area in great detail. She detected a significant reduction in catch rate between 1963 and 1989 (Table 11). This trend was caused largely by very high catch rates in the 1960's. Catch rates from 1977-1989 have remained stable (see Table 4, Zann-Schuster 1990). Furthermore, the average size of reef fish captured has not changed significantly off Cairns since 1963 (Table 15). These results of Zann-Schuster (1990) for Cairns are consistent with preliminary analyses of similar data made by J. Higgs for the Townsville area. The relative consistency of catch rates and average size of fish captured off Cairns since 1963 (Zann-Schuster 1990) and off Townsville since the mid-1970s (J. Higgs, pers comm) contrast with the declines in these variates reported for the small-boat recreational fleet by Driml et al. (1982) and Blamey and Hundloe (1991) between 1980 and 1990 (see Table 13). However, it should be noted that charter boats are likely to be fishing on reefs further off the coast, on average, than small boats.

Craik (1979b) detected a trend of increasing catch rate (kg/person/day) with distance from both Cairns (1977-78) and Innisfail (1971-76) but could not detect such a trend in the Capricorn-Bunkers (1957-78). Zann-Schuster (1990) suggested that CPUE (kg/person/day) showed little trend with distance from Cairns for 1978 and the periods 1980-84 and 1985-89.

Craik (1979b) detected some marked differences in CPUE (both in terms of fish/person/day and kg/person/day) and average size of fish captured with geographic location (see Fig. 12 of Craik 1979b and Table 14). CPUE tended to increase as one moved south, with a distinct peak in the Capricorn Bunkers. Average size of fish declined as one moved south. These trends most likely represent natural changes in density and average size of fishes, rather than any patterns induced by fishing pressure (e.g. see visual census data for coral trout of A.M. Ayling - Fig. 3 in Munro and Williams 1985).

Catch composition of the charter-boat fleet is dominated by coral trout and sweetlip emperor, as for the commercial and small-boat recreational fleets (Table 16). Red emperor is caught relatively more commonly in the Cairns region and sweetlip emperor relatively more commonly in the Townsville and Mackay regions. Craik (1979b) showed that coral trout and sweetlip dominated the recreational charter-boat catch off Townsville from 1961-1976. This pattern is consistent also through the 1970s and 1980s (J. Higgs pers comm). Zann-Schuster (1990) showed that coral trout dominated catches but commented on the variations in relative contributions of major groups to catch from year to year and from reef to reef off Cairns. For example, she attributed a relative decline in percentage coral trout in the catch of the mid 1980s to a trend of clubs to fish at night (and thus catch more lutjanids). This trend was reversed in the late 1980s when large, fast catamarans could fish the outer reefs on day trips, so that coral trout again dominated catches.

The distribution of the catch amongst recreational fishermen on charter boats is very uneven, similar to the findings for the small-boat recreational fleet. Craik (1981a) reported that the top 10% of charter boat fishermen in Capricornia caught 33 fish/person/day.

6.3.3 Catch and Effort in the Recreational Spear fishery

Steven (1988) has provided the only recent review of catch-effort characteristics of the recreational spear fishery on the GBR. He supplemented data from the earlier review of Saenger (1976) with data collected by clubs in 4 regions during competitions. The regions were Cairns, Ayr, Mackay and Bundaberg. The total annual catch in club competitions for all 4 regions appears to be in the order of 1.4 mt (see Stephen 1988). Steven (1988) listed average catch rates varying from 1.8 fish/man (Bundaberg) to 5.6 fish/man (Cairns), with average size of fish varying from 2.3 kg (Bundaberg) to 2.9 kg (Ayr).

6.4 Summary

6.4.1 Commercial Line Fishery

Records of reef fish processed by the north Queensland Fish Board and the Queensland Fish Board between 1957-1981 provided substantial underestimates of commercial catch for this period. Reliable catch records did not become available until the introduction of the QFMA-QDPI CFISH database system on January 1 1988. Commercial catch of demersal reef fish from the GBR region for the years 1988, 1989 and 1990 were 1,815 mt, 2,265 mt and 2,791 mt. The apparent increase in catch over the 3 years may reflect fishermens' attitudes to the new logbook system as much as any real increase in catch.

Reliable effort data for the commercial fishery became available on January 1 1988, through the CFISH database system. Before this, estimates of numbers of commercial fishermen in the line fishery and the GBR demersal line fishery were available from surveys carried out by the Queensland Fisheries Service in 1979, 1980, 1981 and 1986. The numbers of fishermen in the line fishery, and the number of `line only' endorsements does not appear to have increased over the period 1978/79 to 1989. The major increase in effective effort in this fishery would have occurred with the introduction of `tinny fishing' by Sonny Butterworth (Mackay) in the late 1970's-early 1980's. Substantial latent effort exists in the current fleet, with 1963 line endorsements. Of these, 176 vessels (operating 321 tender vessels) form the core of the line fishery fleet. Sixty-nine `line only' entitlements operate 153 tender vessels but are legally permitted to run 276 such tender vessels. A total of 95 vessels caught 67% of the total catch.

6.4.2 Recreational Fishery

6.4.2.1 Small-Boat Fishery

The numbers of small-boats fishing in the GBR region has expanded greatly in the past 10 years (14,887 --1980; 24,300 --1990). The rate of annual growth of small-boat registrations is 3.3% per year for the GBR region and in some places within the region the rate is extremely high (e.g. Cairns, 7.8%). This fleet was estimated to catch 6,600 mt in 1980, a figure which was predicted to be 2 to 3 times the commercial catch. Predictions were made that the small-boat recreational catch could reach 10,000 to 12,000 mt by 1990. However, 1990 figures suggest that although boat numbers fishing the GBR have increased by 40%, number of trips/year, number of fish caught per trip and average sizes of fish caught have all declined, resulting in a 40% decline in total annual catch to 3,500 to 4,300 mt. This estimate is almost identical to the estimated commercial catch. The small-boat catch-effort figures, collected from boat-ramp and phone/mail recall surveys, are based on very small sample sizes and far more extensive data is required before the true status of this sector of the fishery is known. One aspect that is apparent is that the small-boat fleet concentrates its effort close to the coast and close to centres of human population and thus is not likely to overlap substantially with the commercial sector.

6.4.2.2 Charter Boat Fishery

In 1984/85 it was estimated that 90 charter boats had fishing as a principal or significant activity in the GBR region. Of these, 83 were estimated to catch 450 mt in 1985. Some very useful long-term sets of catch-effort data exist from fishing club records of competitions held on charter or club boats. Catch rates have not declined significantly in 3 regions: Townsville (1961-1977), Mackay (1976-79) and the Capricorn-Bunkers (1957-1978). Some evidence of decline in catch rates was observed off Innisfail between 1971-1976 but average size of fish caught appeared to increase there during this period. The only region displaying a substantial decline in catch rates was Cairns (1963-1989), and this was due almost entirely to very high catch rates recorded in the 1960s. Catch rates have been stable off Cairns through the 1970s and 1980s. Average size of fish caught has not declined in 4 of 5 regions (Cairns, Innisfail, Mackay and Capricorn-Bunkers). Average size of fish caught declined substantially off Townsville during the 1960s but appears to have been stable through the 1970s and 1980s.

6.4.2.3 Spear fishery

The catch of the recreational spear fishery appears to be insignificant compared with all other recreational and commercial sectors.

6.5 Studies in Progress

(i) The CFISH database system set up by QFMA-QDPI is ongoing and will provide the necessary detailed information on catch and effort characteristics of the commercial line fishery in the GBR region.

(ii) N. Trainor (QFMA) plans to collect past catch records (pre-1988) of commercial line fishermen in Queensland.

(iii) J. Higgs (Department of Marine Biology, James Cook University) is currently analysing catch records of fishing clubs from all GBR regions collected by the GBRMPA. Many of the records span the 1960s to the 1990s. This will provide valuable historical data on the recreational charter-boat fishery.

(iv) Shorthouse/Jones are currently carrying out a survey of the reef line fishery for GBRMPA.

(v) J. Alder (QNPWS) is carrying out a boat-ramp survey of the small-boat recreational fleet in the Cairns region.

Table 11 Estimated landings of reef fish (metric tons, whole fish) at Queensland Fish Board depots between 1957 and 1981 (after Stephen 1987). Categories of reef fish included in these figures are coral trout, cod, emperor, mixed, nanygai, parrot and sweetlip. The category `coral trout' was not used in statistics until 1962. The pre-1962 figures for `coral trout' shown here are actually the category `cod'. Post-1962 `cod' figures were not included in figures for coral trout. The Northern Section depots were Port Douglas (1980, 81 only), Cairns and Innisfail. The Central Section depots were Ingham, Townsville, Home Hill, Bowen, Proserpine and Mackay. The Capricornia Section depots were Yeppoon, Rockhampton, Gladstone, Rosslyn Bay, Bundaberg and Maryborough. Note that all fish received at a local depot incurred a 10% handling levy so these official figures are certainly below true commercial landings.

Year	North		Central		Capricornia		TOTAL	
	Coral Trout	Total Reef Fish	Coral Trout	Total Reef Fish	Coral Trout	Total Reef Fish	Coral Trout	Total Reef Fish
1957	7.3	27.5	7.6	41.8	7.8	50.2	22.7	119.5
1958	8.6	29.9	7.1	44.8	9.6	86.1	25.3	160.8
1959	3.7	12.4	4.9	25.0	8.0	84.2	16.6	121.6
1960	3.3	15.3	2.9	17.8	8.4	87.4	14.6	120.5
1961	2.5	15.7	1.8	36.4	5.3	48.8	9.6	100.9
1962	1.8	15.1	4.5	43.8	9.7	89.7	16.0	148.6
1963	14.7	38.4	19.6	58.2	11.4	81.7	45.7	178.3
1964	13.6	36.9	14.1	45.8	11.8	106.2	39.5	188.9
1965	17.6	43.3	10.2	45.6	22.1	119.1	49.9	208.0
1966	7.7	35.9	11.3	48.7	21.3	123.9	40.3	208.5
1967	32.9	75.1	23.4	70.1	15.9	105.4	72.2	250.6
1968	28.7	66.9	21.0	67.1	9.5	71.8	59.2	205.8
1969	21.8	57.0	23.0	86.4	9.9	72.8	54.7	216.2
1970	34.8	93.8	86.1	169.6	32.9	123.2	153.8	386.6
1971	15.4	71.3	16.1	117.9	39.7	145.4	71.2	334.6
1972	27.4	84.4	90.3	199.3	45.2	126.1	162.9	409.8
1973	7.8	49.0	84.2	200.0	46.7	137.5	138.7	386.5
1974	13.6	69.3	104.3	274.4	37.2	132.6	155.1	476.3
1975	11.7	76.6	84.7	263.2	29.4	126.4	125.8	466.2
1976	18.8	81.6	74.1	196.4	38.5	124.0	131.4	402.0
1977	29.5	69.6	59.2	217.8	32.4	136.9	121.1	424.3
1978	30.9	79.4	10.4	150.2	22.3	102.7	63.6	332.3
1979	22.6	63.0	93.9	228.9	21.3	118.1	137.8	410.0
1980	19.3	56.2	123.9	270.0	33.3	145.3	176.5	471.5
1981	20.5	71.5	130.7	240.6	19.2	87.9	170.4	400.0

Table 12 Estimated landings of fish (mt) in Queensland from various sources from 1966/67 to 1990. Estimates of 'nominal' effort measured as the number of primary fishermen who specified the line fishery as their principal activity and those with a line-only endorsement.

	CATCH (mt)							NOMINAL EFFORT		
Year	Coral Trout + Cod	Emperor + Red Emperor	Other Reef Fish	ReefFish Total	Spanish Mackerel	Total Line Catch	Catch Reference	Line Fishery Principal Activity	Line Only Endorsement	Effort Reference
1966/67	~120	~125	~126	371	~780	~1151	a			
1967/68	~100	~100	~130	345	~810	~1155	a			
1968/69	~100	~105	~126	331	~615	~961	a			
1969/70	~200	~150	~124	474	~615	~1089	a			
1970/71	218	218	151	587	734	1321	a, b			
1971/72	229	185	86	500	668	1168	"			
1972/73	269	263	104	636	1111	1747	"			
1973/74	252	327	111	690	986	1676	"			
1974/75	165	289	128	582	1096	1678	"			
1975/76	247	288	67	602	964	1566	"			
1976/77	174	223	83	480	924	1404	"			
1977/78	174	163	74	411	1029	1440	"			
1978/79	174	205	67	446	734	1180	"	256	89*	d, e
1979/80	206	222	108	536	772	1308	"	215	69*	d, e
1980/81	201	38	165	404	800	1120	"	279	-	e
1986	-	-	-	-	-			160	41	f
1988	1016	455	344	1815	550	2365	c	-	-	
1989	1188	506	571	2265	640	2905	c	176	69	f
1990	1490	672	629	2791	-	-	c	-	-	

* Reef demersal fishermen on GBR

References:
a = Matilda and Hill (1981)
b = ABS Fisheries Statistics, Queensland, 1977- 1981
c = CFISH database
d = M. Williams (1981)
e = Hundloe (1985)
f= Gwynne (1990)

Table 13 Summary of some catch and effort data collected for the small-boat recreational fleet, GBR Region. Consult original references for estimates of variability around means

Year	Region	No. Small boats fishing GBR	Average No. trips /boat/year	Average Boat Length (m)	Total No. Fishing trips/year	Annual Catch fish (Numbers)	Annual Catch (mt x 10^3)	Average No. Persons per trip	Fish /Person /trip	Fish /Person /hour	Average Wt. of each fish (kg)
1979-1980	Cairns	3530		5.2	5900	770000	1.5-2.0	3.5	4-6	0.5-0.75	2
*	Capricornia	827		6.4	6200	300000	0.25-0.3	2.5	11-15	1.4-1.9	1
	14% of Total GBR	4357		5.9	58100	$1.07x10^6$	1.75-2.3	3	7.5-10.5	0.95-1.3	1.5
1979-80	Cairns	3530	14.58	5.1	49400	854000	2.3	-	6.7	1.02	2.7
**	Townsville	4320	14.47	5.2	62200	817000	1.9	-	5.1	0.89	2.3
	Mackay	2597	10.55	4.8	27300	501000	1.1	-	7.1	0.99	2.2
	Rockhampton	4440	13.20	4.5	57700	982000	1.3	-	6.6	0.97	1.3
	Four GBR Regions (excluding northern)	14887	13.20	4.9	196600	$3.16x10^6$	6.6	2.6	6.3	0.97	2.3
1990	Cairns	6122	12.85	5.6	75000		1.5	3.03	3.84	0.59	1.7
***	Townsville	6370	10.95	5.5	54-86000	900000	.48-.78	2.86	1.81	0.32	1.9
	Mackay	4898	8.65	5.4	26-58000	250-410000	.35-.78	3.00	3.13	0.44	1.4
	Rockhampton	6911	7.10	5.5	44-54000	250-560000	1.1-1.3	2.87	5.93	0.88	0.96
	Four GBR Regions (excluding northern)	24300	9.88	5.5	210-270000	$2.5-3.17x10^6$	2.6-3.2 (3.5-4.3)	2.94	3.67	0.54	1.49

Sources:

* Fallows & Craik (1980)
** Drim et al.
*** Blamey & Hundloe (1991)

Table 14 Summary of some catch and effort data collected for recreational fishing from charter boat fishing in the GBR region. Consult original references for estimates of variability around means.

Year	Region	No. of Charter boats fishing	Average Boat length (m)	No. Anglers per boat	Total No. Fishing trips/year	Annual Catch (fish numbers)	Annual Catch (mt x 10^3)	Fish /person /day	Wt. (kg) /person /day	Trip Duration (days)	Average Wt. of each fish (kg)
1979	Cairns	-	10-15	15	-	-	-	1.5	5.3	1-2	3
*	Innisfail	-	10-15	7	-	-	-	2.3	5.6	1-2	2
	Townsville	-	-	-	-	-	-	5.0	9.2	-	1.3
	Mackay	-	-	-	-	-	-	6.5	10	-	1.6
	Capricornia	9	-	8	210	70-110000	0.07-.11	17	15	4	1
1981	Townsville	10	-	-	-	-	0.09			-	-
**	Mackay	60	-	-	-	-	0.34	-		-	-
	Rockhampton	10	-	-	-	-	0.13	-		-	-
						-					
1984	Northern Section	20	-	-	-	-	0.02	7.1	3.9(?)	-	1.8
***	Central Section	31	-	-	-	-	0.13	6.7	13.8	-	1.9
	Capricornia	21	-	-	-	-	0.05	6.9	8.97	-	1.3
1985	Four GBR Regions (excluding northern)	83	-	-	-	-	0.45	-		-	-

Sources:

* Fallows & Craik (1980)
** Drim et al.
*** Blamey & Hundloe (1991)

Table 15 Summary of catch-effort data collected from fishing club competition records where clubs have used charter boats or club boats to fish the Great Barrier Reef. Craik (1979b) figures have been estimated from graphical presentations and are approximate. Consult original references for estimates of variability around means.

Study	Region	Year or Period	Fish/Person /Day	Kg/Person /Day	Average Wt. (kg) of Individual Fish
Craik (1979b)	Innisfail	1971	7.5	10.5	1.4
		1972	8	11.2	1.4
		1973	5.5	9.4	1.7
		1974	4.5	6.3	1.4
		1975	5.0	10.2	2.1
		1976	2.5	5.3	2.1
	Townsville	1961-62	6.5	16.3	2.5
		1963-64	6.0	12.0	2.0
		1965-66	7.8	14.8	1.9
		1967-68	9.0	16.2	1.8
		1973-74	7.0	11.2	1.6
		1975-76	8.0	12.0	1.5
		1977	5.0	7.0	1.4
	Mackay	1976	5.5	8.3	1.5
		1977	8.0	12.0	1.5
		1978	6.0	9.6	1.6
		1979	5.5	9.4	1.7
	Capricorn-Bunkers	1957-58	6.5	8.1	1.25
		1959-60	-	-	1.4
		1961-62	-	-	0.75
		1966	11	12.1	1.1
		1967	16	15.2	0.95
		1968	17	17.0	1.0
		1973-74	12	12.0	1.0
		1975-76	9.5	10.5	1.1
		1977-78	13.0	13.0	1.0
Zann-Schuster (1990)	Cairns	1960-64	7.17	14.74	2.10
		1965-69	5.97	12.26	2.03
		1975-79	1.26	3.48	2.94
		1980-84	2.15	6.14	2.96
		1985-89	2.20	5.92	2.81

Table 16 Catch composition of Recreational and Commercial reef-demersal line fisheries by region, 1980-81 (various sources).

	% Catch Composition 1980-81					
	Cairns		**Townsville**		**Mackay**	
	Comm.	**Rec.**	**Comm.**	**Rec.**	**Comm.**	**Rec.**
Coral Trout	44%	37%	29%	34%	50%	36%
Sweetlip	12%	9%	22%	54%	34%	50%
Red Emperor	17%	17%	4%	1.6%	5%	-
Total	**73%**	**63%**	**55%**	**90%**	**89%**	**86%**

7 STOCK STRUCTURE

Nothing is known of the stock structure of fish species of major commercial and recreational interest on the GBR. Larval studies suggest that extensive dispersal of larvae of these species is likely and genetic studies suggest that relatively little genetic differentiation is likely for these species. This does not mean, however, that significant stock differentiation does not occur.

Leis and Goldman (ms) hypothesised that species whose (larval) distribution on a local scale was non-random might actively maintain this pattern rather than drift passively and could be expected to have relatively restricted population units. Species which, on the other hand, have apparently random larval distributions on a local scale might, however, be more influenced by passive drift and could be expected to have relatively wide-spread population units. With this hypothesis in mind, Leis and Goldman examined the distributions of reef fish larvae in the GBR lagoon in the vicinity of Carter Reef. They found that '1. about 60% of reef fish larvae have random distributions, and we predict these taxa will have large population units; 2. about 40% of reef fish larvae have non-random distributions and these should have restricted population units; and 3. most of the fishes of sport and commercial importance are in the first category' (Leis and Goldman MS). Leis and Goldman stressed a number of caveats to their third conclusion. The results of this and other studies of larval fish distributions on the GBR lead to the conclusion, however, that to the extent that distributions of larvae of GBR species suggest a spectrum of dispersal ranging from relatively restricted to more widespread, species of recreational and commercial importance tend to the more widespread end of the spectrum.

The length of larval duration of GBR reef fish species varies from nothing to several months (see e.g Brothers et al. 1983). Larval duration of species of recreational and commercial importance on the GBR is reviewed in Section 3 of this report. Doherty and Mather (unpublished data) have explored the hypothesis that the degree of genetic variation within a species on the GBR is inversely related to the length of its larval duration. These authors found major genetic variation within *Acanthochromis polyacanthus* even over relatively short distances. This species does not have a larval stage but broods its young. The results were expected given earlier unpublished results of electrophoretic studies by Soule (cited in Ehrlich 1975) and the observation of large colour variation in the species throughout the GBR (Allen 1975). Whereas ten of the 11 polymorphic alleles found in Acanthochromis showed very significant differences among the geographic regions examined, none of the alleles of a surgeonfish (estimated larval life = 60 days) showed any significant departures over the same area. A damselfish with a larval life of approximately 25 days showed significant variations for five out of the nine polymorphic alleles.

Doherty and Mather concluded on the basis of their preliminary results that the five species studied in detail did show patterns of variation consistent with their hypothesis i.e. there is a correlation between the genetic similarity of distant populations and the known duration of larval stages. However, all species with pelagic larvae (all the species of concern to this report) have shown low levels of variation relative to the one species in which larvae do not leave the adult habitat.

We stress again that the lack of evidence for stock structure within major recreational and commercial species on the GBR may simply reflect the lack of relevant studies, in particular studies of comparative life histories and of morphometrics within species over different regions of the GBR. Are there any pointers as to regions where differentiation is most likely or are there species that are more likely than others to differentiate?

On the basis of geographic and potential physical oceanographic isolation, the GBR might be divided into three from the perspective of larval connectivity: waters north of Cape Melville;

waters from Cape Melville to the Swains; and the Capricorn-Bunker group. The continental shelf is particularly narrow at Cape Melville and two reefs (South and North Warden) run across almost the entire width of the shelf just south of the Cape. The potential relative isolation of the Far Northern GBR may also be enhanced by the northward movement of the extension of the South Equatorial Current (SEC) adjacent to this region. The SEC crosses the Coral Sea from East to West and then bifurcates between 14°S and 18°S on approaching the continental shelf. The northern branch follows the shelf edge northward to the Gulf of Papua, the southern branch flows south-eastward and is the beginning of the East Australian Current. The relative geographical isolation of the Capricorn-Bunkers from the rest of the GBR is clear on a map or chart. It is also interesting that *P. leopardus* appears to grow much larger here than elsewhere on the GBR. This is not the result of the Capricorn-Bunkers being on the southern end of a cline in growth because the same species in the Swains, the closest region of the GBR, is relatively small (A.M. Ayling pers. comm., see Distributions and Habitats section above).

Are any of the species of particular interest more likely to show stock structure than others? Early life histories (Section 3) give us no clues. *Lutjanus argentimaculatus* and *L. johnii* are possible candidates because preferred habitats of these species as presently understood (rivers and rocky headlands, respectively) are much more patchily distributed along the GBR region than the preferred habitats of the other species.

7.1 Studies in Progress

None of which we are aware.

8 MOVEMENTS, MIGRATION AND SEASONALITY OF FISHERY

8.1 Seasonality of Fisheries

Reef fishing activity is at a minimum during the peak of the cyclone season from January to March. Bandaranaike and Hampton (1979) examined seasonality of reef fisheries through catch statistics of the Queensland Fisheries Board in Cairns, Innisfail, Townsville and Bowen. They concluded that sweetlip showed a distinct peak in production in September to November in Cairns, Townsville and Bowen but that no seasonal pattern was obvious at the Innisfail market. Similarly, a pronounced peak was observed in production of coral trout in all four markets during October to November. Unfortunately these two months generally provide the best weather of the year, complicating the interpretation of these peaks in production.

In a more recent analysis using data from newly introduced log-book system, Trainor (1991) examined seasonal trends in the commercial line fishery from January 1988 to August 1990. These data confirm the general trend observed by Bandaranike and Hampton, with peak catches during August to October and lowest catches in January-March (see Section 6).

8.2 Movements and Migration

Much of the available information on movement of the larger reef fish species is anecdotal and is summarised below. Tagging studies have been carried out as part of two GBRMPA consultancies (Beinssen 1989a, 1989b) and Melita Samoilys' MSc thesis in the Capricorn-Bunker Group. A report on an earlier tagging study carried out in the same area by GBRMPA was not available to us. A number of tagging studies which should considerably increase our understanding of movements and migrations are currently in progress (see below).

8.2.1 *Lethrinus* spp.

Very little is known of movements of *Lethrinus* spp.. Many fishermen, however, have inferred that *L. miniatus* is a very site-attached species that does not move between reefs or major areas of shoal. Some fishermen even claim to be able to identify individuals as coming from certain areas of reef. Beinssen (1989b) carried out studies of movements of a number of species along 4km of the northern reef slope of Heron Reef in September to October of 1989. This section of reef slope was divided into 8 contiguous blocks 500m long and fish caught in each block tagged in a characteristic pattern. Movement of fish among the blocks was studied over an average period (for each fish) of 3 weeks. Movements of the three major species derived from this study are given in Table 11. These data tend to confirm the particularly site-attached behaviour of *L. miniatus* even in comparison to *P. leopardus* and *L. adettii*.

Tidal movements of *L. miniatus* and *L. nebulosus* from outside of reefs into lagoons to feed at night have been reported to us (A. Schneider pers. comm.). Notable catches of *L. nebulosus* are often made in shallow water in winter (McPherson et al. 1988) but it is not known whether this represents movement of the fishes or simply changes in catchability. As indicated under **Distributions and Habitats**, *L. nebulosus* may undergo significant inshore-offshore developmental movements but clarification of this will depend on a better understanding of the distribution of juvenile fish.

Davies (pers. comm.) has recorded movement of *L. laticaudis* over a distance of 1.5 to 2km between Orpheus and Pelorus Islands.

8.2.2 *Lutjanus* spp.

Commercial fishermen in the Cairns region maintain that the larger *L. malabaricus* and *L. sebae* are present in deeper waters (>60m) during the summer, then move into shallower waters during the winter (McPherson et al. 1988). Other fishermen have indicated to us that *L. sebae* in more southern areas also move into relatively shallow areas in the coldest months of the year.

The recreational fishery for fingermark, *L. johnii*, is seasonal with large fish being caught primarily from December through the summer months. Fishermen have linked these catches to inshore spawning migrations and to seasonal occurrence of squid concentrations. Our preliminary underwater observations suggest, however, that fingermark are on the fishing grounds for most, if not all, the year and that the seasonality in the fishery may reflect changes in catchability rather than migrations or other movements.

Developmental migrations as fish grow older appear to occur in a number of *Lutjanus* spp. (see section on **Distributions and Habitats**). *L. argentimaculatus* is believed to move from estuaries to nearshore and midshelf reefs as it matures. Studies in progress (by Sheaves, Newman and Williams) suggest that similar movements may occur in *L. russelli*, *L. malabaricus* and *L. erythropterus* appear to use shallow nearshore areas as nursery grounds and move further offshore and deeper as they increase in size.

Davies (pers. comm.) has recorded movements of 1.5 to 2km for *Lutjanus carponotatus* between Orpheus and Pelorus Islands.

8.2.3 *Plectropomus* spp.

Fishermen from the Swains and off Townsville report that trout (of smaller size) tend to be most abundant in the shallows ((October to May) and in the deeper waters (larger fish) in the cooler months of June to September (G. Clarke, A. Schneider pers. comm.). On the basis of direct observations, Ayling (1989) reported that the number of trout in shallow waters of Davies Reef (off Townsville) in June to- September of 1989 was significantly down on counts earlier in the year. The fish remaining in the shallows were mostly small. 'Some of the large fish remaining on the reef were observed courting during the September trip and it was thought that many of the trout recorded on the reef in June and August had moved elsewhere for spawning activities'. Conversations with a commercial fisherman encountered on Bowden Reef on 28 September 1989 revealed that they had been having good catches of coral trout in deep (40m) reef associated with shoal areas around a number of reefs in the previous few weeks. They reported that the roe of the trout were all ripe and running. 'This suggests that the trout 'missing' from Davies in late September had moved out to deeper waters to spawn' (Ayling 1989). Mathew (1988) indicates a strong consensus among fishermen that trout spawn primarily in August to September but that some believe that spawning times vary with latitude.

Johannes and Squire (1988) report on apparent spawning aggregations of *Plectropomus laevis*, *P. leopardus* and *P. areolatus*. These observations infer movement of fishes to join spawning aggregations but the distances from which these fish are drawn is unknown. *P. laevis* aggregations occur in 6-20m of water on the reef slope, near to, but not on, the bottom. Aggregations form off Cairns around late September or October and progressively later northwards. *P. leopardus* and *P. areolatus* are also reported to aggregate, often in multi-species groups, for several months around the end of the year (Johannes and Squire (1988). The depth of these aggregations is not given. A detailed study of spawning aggregations at Scott Reef (Samoilys, Squires, Bib - Northern Fisheries Centre) forms part of a QDPI-AIMS-JCU FIRDC project.

A tagging study of trout during the Boult Reef Experiment where fish were at liberty for up to 90 days confirm Beinssen's (1989b) Heron Reef study (Table 17) that movement of *P. leopardus* around a reef is very limited, albeit these studies do not include data on spawning aggregations.

Samoilys (1987) also carried out studies of movements of *P. leopardus* on Heron Reef. She found that short term movements of coral trout, measured by underwater tracking over a 15 minute period, revealed no patterning by time of day or tidal state. In general, size of area of movements increased with the size of fish but this was not consistent over two observation periods. In December/January a reduced area of movement in the larger sizes (>60cm TL) was measured compared to September/October ($26m^2$ vs $134m^2$). Samoilys suggested this change was due to pre-spawning behaviour.

Longer term movements were examined by Samoilys (1987) by capturing trout on lines, freeze branding them and resighting branded fish in underwater surveys. Of 101 fish branded, 59 were resighted. Of these 59 fish, 47 were resighted in the same (300m x 60m) site in which they were branded over a mean period of 142 days and up to a maximum of 289 days. [The maximum time periods reflected the durability of the tags rather than the total period of residency]. The other 12 fish were located at maximum distances of 0.4 to- 7.5km from where they were branded (up to 271 days after branding). Despite each individual being resighted up to six times, 7 of the 12 fish had moved a maximum distance of 0.8km or less. Three of the remaining five had moved maximum distances of 1.3km or less. The two fish that had moved the largest distances were resighted 7.0 and 7.5km away from where they were branded (on the same reef). There was no clear relationship between the maximum distance moved and the time between branding and resighting. Samoilys concluded that the large numbers of resightings in the same, approximately $2,000m^2$, sites was indicative of individuals returning repeatedly to one small area within a larger home range, rather than a home range of such small size. She believed, however, that the range of movements of coral trout are relatively confined and that individuals were ranging over approximate distances of 2km along the reef slope [sic].

Davies (pers. comm.) using tagging studies, has recorded movement of a *P. leopardus* over a distance of approximately 4km along the inside of Orpheus Is. The vast majority of recaptures indicate restricted movements over distances of 50 to 200m.

8.3 Movement Between Reefs

Beinssen (1989a) noted that during the Boult Reef Experiment, no tagged fish of any demersal species were returned from reefs other than that at which they were tagged and it was felt that inter-reef migration is 'unlikely to be significant'.

Davies (pers. comm.) reported movement of a *P. leopardus* 1.5 to 2km from Orpheus to Pelorus Islands.

Given that the GBRMPA's management strategy is based primarily on zoning of individual reefs, the extent of movement between reefs is a critical question for management. In the first successful (GBRMPA sponsored) tagging study of reef fish movements on the GBR 343 coral trout were tagged on reef slopes in the Capricorn-Bunkers. After eight months, 27 had been recaptured close to, or at the site of tagging. The remaining 4 were recaptured at other reefs, 12-28km away (W. Craik cited in Samoilys 1987). This study was based out of Heron Island and it is possible that many, if not all, movements between reefs were between Heron and Wistari Reefs which are only separated by a relatively shallow channel hundreds of metres across or between Heron and Sykes Reef which are joined by an extensive area of relatively shallow coral bottom (the original data are not available to us).

This raises the possibility of differential movement between groups of reefs depending on the 'inter-reefal' habitat type. This has implications for both appropriate management strategies and the design of large-scale experiments to examine the effects of management strategies (see for example Walters and Sainsbury 1990). We see an improved understanding of 'inter-reef' habitats, the dependence of reef fish upon them in general, and the significance and nature of inter-reef 'stepping stones' between reefs as a priority area for future research.

8.4 Studies in Progress

(i) Mark-release-recapture programs using fish traps are being carried out on Orpheus and Lizard Islands by JCU and on a number of reefs across the shelf in the central GBR by AIMS. These ongoing studies should greatly improve our knowledge of within-reef movements of the relevant species.

(ii) QDPI (NFRC) is carrying out intensive tagging, particularly of *P. leopardus*, around Sudbury Reef off Cairns, using line fishermen to sample rather than trapping. This program too should improve our knowledge of within-reef movements of fish.

No studies are specifically aiming to evaluate inter-reefal movements however this is likely to be a priority in the GBRMPA 'Effects of Fishing' program to begin in 1992.

Table 17 Distances moved by three species along northern reef slope of Heron Reef. Fish were caught by line and tagged, then observed in underwater surveys. Average time between release and observation was approximately 3 weeks. (From Beinssen 1989b).

	Distance Moved			
	0m	**>0-500 m**	**>500-1000 m**	**>1000-1500 m**
Plectromus leopardus	71%	17%	8%	4%
Lethrinus miniatus	93%	7%	0%	0%
Lutjanus adettii	78%	16%	6%	0%

9 DESCRIPTION OF COMMERCIAL FISHERIES

This section gives a very brief description of the commercial line fishery to help put biological studies in a context. It is not intended as an exhaustive description of the fisheries.

9.1 Bottom Fishing

Bottom fishing can be simply divided into two fisheries: a deepwater, night-time fishery aimed primarily at 'reds' and a shallow, night-time fishery in lagoons aimed at sweetlip, spangled and red emperor.

9.1.1 Deep-water, Night-time

Techniques used in the deep-water reef fishery in north Queensland have changed little since the fishery commenced prior to the Second World War (McPherson et al. 1988). The commercial fishery is very similar to that carried out by 'recreational' anglers on charter boats in the same areas. They are both essentially 'hand-line' fisheries although large, deck-mounted, hand-operated reels are now often used. The most widely used terminal gear is the 'red' rig which is very similar to that used commonly for snapper (*Chrysophrys auratus*) in waters of southern Australia. It usually comprises two or more hooks (6/0 to 10/0) on short snoods above a sinker. A wide range of fish and squid bait is used.

Localities fished by those in this fishery are often determined by vessel size and prevailing weather conditions (McPherson et al. 1988). When moderate to strong south-east winds are blowing, fishing areas are usually selected in deep water adjacent to, and in the lee of reefs. The targeted species are primarily the 'reds', in particular *L. malabaricus* and *L. sebae*, and the preferred fishing areas are in deeper water away from the reefs over shoals or small pinnacles or around wrecks. Locations with suitable substratum and evidence of fish are generally found using an echo-sounder and the anchor dropped as close as possible (McPherson et al. 1988). Alternatively boats drift until fish are caught or show on the sounder and then the anchor is dropped. Coral trout are very rarely caught in this fishery and the capture of a sweetlip (*L. miniatus*) or trout is considered a certain sign that the boat is drifting onto a coral reef (J.Sikora pers. comm.).

Until recently, considerable skill has been required to find the isolated shoals, pinnacles and wrecks that are prime 'red' fishing grounds. The introduction of GPS systems to many boats will change this situation considerably and may lead to a marked increase in effective effort in this fishery.

In the northern GBR boats in this fishery generally fish in less than 80m. Occasionally larger boats conduct fishing operations in 100 to 160m. However, 100m is usually considered to be the deepest limit for handline fishing operations 'apparently because of low catch rates below 100m' (McPherson et al. 1988). The fishing time lost in retrieving lines and the tangling of lines becomes more of a problem in deeper depths (McPherson et al. 1988). A Townsville fishermen noted for exceptional commercial catches of 'reds' told D.McB. Williams that it was not profitable to fish in depths approaching 180 feet or more. This was not because the fish were not there but that they were too large and brought significantly lower prices than the smaller fish.

9.1.2 Shallow-water Night-time

This fishery targets *L. nebulosus*, *L. miniatus* and *L. sebae* in the sandy lagoons of the larger reefs at night. Perhaps because the main catch is *L. nebulosus*, generally regarded as a fish of lesser market value, it does not appear to be widely pursued at this point in time. There are claims that it was once possible to catch large numbers of the more valuable *L. sebae* in this manner, even during the daytime (Mathew 1988).

9.2 Trout Fishing

This is a day-time, primarily shallow-water, fishery targeting coral trout and to a lesser extent, *L. miniatus*. This fishery has been revolutionised by the introduction in the last decade of 'tinny' fishing which will be discussed separately below.

9.2.1 Wogging

Traditionally the fishery was based primarily on 'wogging' from dories used in the mackerel fishery. A wog is a large fly or jig made of coloured feathers, polypropylene or plastic fibres. The wog is attached to a long wire trace and towed behind a dory at 3 to 4 knots. The wog is 'worked' or jerked as it is dragged through the water about 100 feet behind the dory. The dory works closely around coral bommies or along the hard wall of the reef (Mathew 1988). Trolling baits behind a dory, as carried out in the mackerel fishery, has also at times been used to catch coral trout (Mathew 1988).

9.2.2 Tinny Fishing

Mathew (1988) attributes the introduction of this form of fishing to north Queensland to Sonny Butterworth from Mackay. 'Essentially it involves the use of light, aluminium open boats powered by outboard motors of 10 to 40hp. [Mackerel dories are generally heavy displacement vessels, powered by small diesel engines]. The areas fished are shallow spots sometimes only 20 feet deep. The anchoring is precise and depends on current, wind and tide. The fishing rig involves light nylon (30-70lb) using the lightest possible running sinker and a size 8/0 to 10/0 hook, baited with a whole Western Australian pilchard (*Sardinops neopilchardus*). These pilchards readily break up underwater and make an ideal 'chumming' bait. Due to their oily nature, fish are attracted from a wide area' (Mathew 1988). Mathew is not explicit as to the timing of the introduction of tinnies but infers that it occurred sometime between the late 1970's and the early 1980's.

Tinny fishing is a far more efficient means of catching trout than wogging or trolling. Fishermen believe it to be far more selective for trout than the latter techniques (more than 80% of fish taken are trout). A large number of fast dinghies can also cover much more ground than mackerel dories and they are much more efficient at targeting trout concentrations around a reef. Light-line fishing with pilchards also results in many smaller fish being taken than with previous methods. In some markets these plate-size fish, very close to the minimum legal size, have brought premium prices.

Trout fishermen often distinguish between fishing 'shallow' water (where they can see the bottom, generally are often used to find fish and bait in shallow waters and depth-sounders in deeper water. Fish caught in the shallower waters tend to be darker coloured and are sometimes called 'greenies'. Those from deeper water are much redder in colour and called 'strawberries'. Many fishermen believe in the principle of 'creaming the top off the reef' and then moving to another reef, often within a day. They believe that the fish taken are replaced by fish moving up from deeper water. The 'creamed-off' fish are often believed to be the largest but presumably reflect the most catchable.

10 INTERACTION BETWEEN FISHERIES

As with the previous section this is only a brief overview of major likely interactions between fisheries to help give some context for biological studies.

10.1 Line fishing: Commercial and Recreational

The overlap between commercial and recreational fisheries both on coral reefs and in inter-reefal areas would appear at first glance to be substantial. They fish for the same species, in similar areas and with very similar gear. However, a recent study of the location of fishing of the small-boat recreational fleet (Blamey and Hundloe 1991) indicates that the effort of this fleet is concentrated heavily near the coast in most regions of the GBR (with the exception of Cairns) (see Section 6). The commercial fishermen are perhaps more likely to fish the more remote areas.

10.2 Line fishing: Reefs and Inter-Reefs

There appears a considerable differentiation among both recreational and commercial fishermen between those targeting trout and sweetlip (*L. miniatus*) around reefs and those targeting 'reds' in deeper, 'inter-reefal' waters. Of the reds, only juvenile red emperor seem to be taken with any regularity in close proximity to reefs, although some locations have reputations for regular catches of adult red emperor in relatively shallow water and sometimes even in daylight. The degree of spatial overlap between 'reef' and 'inter-reefal' species and the nature of their interaction remains to be quantified. An experienced 'inter-reefal' fisherman (J. Sikora) has indicated to us that if the boat is drifting for reds and a trout or sweetlip (*L. miniatus*) is caught, a 'reef' will be found in the immediate vicinity. *L. nebulosus* is, however, one species caught regularly by fishermen in both habitats. The significance of 'inter-reefal' waters as habitat for juvenile 'reef' species and as a migration route between reefs is unknown.

10.3 Trawling and Line fishing

The interaction between commercial and recreational line-fisheries on reefs is obvious. The interactions between the trawl fisheries for prawns and the line-fisheries are no less contentious but more difficult to determine. The issues were discussed at some length at a recent workshop sponsored by GBRMPA (Craik et al., Poiner and Gliester 1989). Studies carried out by QDPI (Jones and Goeden 1985, Watson 1989) conclude that the only species of major significance in the linefisheries that are also caught regularly as by-catch in the prawn trawls are juvenile 'reds' (*Lutjanus* spp.). Catches of juveniles, particularly of *L. erythropterus* and *L. malabaricus* are often considerable.

The major impediment to understanding the effects of trawling is a lack of knowledge of the distributions and life histories of the species involved. In particular the major nursery grounds of the important fin-fish species have not been determined. Trawlers certainly work heavily in areas known to contain both adult and juvenile reds but the degree of overlap between the habitats of these fishes and areas of intensive trawling is unknown, as are the indirect effects of trawling via bottom disturbance and modification.

11 YIELD ESTIMATES AND SPAWNING POTENTIAL

11.1 Surplus Production Models

The review of catch and effort information (Section 6) indicated that no long-term time series of reliable catch and effort data exists for the commercial and recreational line fisheries that would be suitable for use in a surplus production model. The infrastructure is now in place for collecting such catch-effort data over a long period of time for the commercial fishery (CFISH database). No infrastructure is in place to collect such long-term data from the entire recreational fishery. In particular, no plans currently exist to collect regular (at least yearly) and reliable data from the small-boat recreational fleet by use of boat-ramp surveys.

Even when catch and effort data are available, experience from two reef fisheries (Gulf of Mexico/U.S. Southern Atlantic and Hawaii) suggests that their value in the development of management plans may have substantial limitations. Huntsman and Waters (1987) provide an enlightening history of the development of management plans for reef fisheries in the Gulf of Mexico and the U.S. Southern Atlantic since the mid-1970s. Although commercial catch records were available, they were found to be of limited value. Catches were recorded by location of landing rather than location of fishing. Separation of species in the catch records were either lacking, improper, or not applied consistently. For example, `grouper' referred to over twelve species in two genera. Also, information on recreational catches was either totally lacking or `so fragmented that it was useless'. Of even greater importance, little information on fishing effort was available and no information was available on the economic and social aspects of the reef fisheries in the two areas (Huntsman and Waters 1987). These limitations on the usefulness of catch and effort data for the fisheries remained as the management plans were implemented, with the managers eventually opting for a management strategy based on yield-per-recruit rather than surplus-production models (Huntsman and Waters 1987).

Ralston and Polovina (1982) examined catch and effort statistics for the deep-water line fishery in the Hawaiian Islands for the period 1959-1978. They examined statistics for 13 species from 4 banks and attempted to fit Schaefer surplus-production models to the data. No fits were statistically significant (Ralston and Polovina 1982; Polovina 1987). Fits were improved by combining species into three groups based on cluster analysis and a significant fit was obtained for all species combined for one of the banks. Overall, catches were maintained at high levels but catch per unit effort declined with increasing effort (Ralston and Polovina 1982).

These two examples stress that even if a long-term time series of catch and effort data existed for the entire GBR demersal line fishery (both commercial and recreational), good statistical fits of models such as the Schaefer or Fox surplus-production models are not necessarily assured. Yield estimates based upon catch-effort data alone are not recommended for the GBR demersal hand-line fishery. Such estimates should be combined with yield-per-recruit estimates.

11.2 Yield-Per-Recruit Models

The review of age, growth, mortality and longevity information (Section 5) indicated that reliable estimates of some of the necessary biological parameters for yield-per-recruit modelling are, or soon will be, available (ie. growth characteristics) whereas others are known only poorly (ie. mortality estimates - total (Z), natural (M) and fishing mortality (F) and thus exploitation rates). Reliable age determination should provide the key to good estimates of Z. Estimates of Z from length frequency distributions of relatively long-lived fishes such as coral trout (10 to 12 years) and sweetlip emperor (>14 years) should be treated with care. If sufficiently large samples of fish can be aged from populations that have not been fished for perhaps 10 to 15 years (e.g. preservation zones) a good estimate of M is possible for species such as coral trout and sweetlip emperor. Most estimates of M for reef fish have been derived from Pauly's (1980) empirical formula. Ralston (1987) provides another empirical formula to estimate M for lutjanids and serranids. Such estimates of M can be used to estimate the ratio M/K (natural rate of mortality/von Bertalanffy growth co-efficient) and to estimate F if Z is known. The ratios M/K and F/Z (exploitation rate) can be used to estimate relative yield per recruit values. The empirical formulae will provide only approximations of M and thus M/K and F/Z. Far more direct estimates of M (by determining age structure on unfished reefs) and F (by obtaining good estimates of catchability (q) and fishing effort (f) to get a direct estimate of F via F = qf e.g. Beinssen (1989a)) are recommended. Mark-release-recapture techniques also provide some promise for estimating mortality rates.

No yield-per-recruit assessments have been published for any species on the GBR. G. McPherson (QDPI --Northern Fisheries Laboratory) has made preliminary estimates for species such as coral trout and these are being refined as more information becomes available. Some of these preliminary estimates are likely to be useful in the current deliberations on legal minimum sizes of many fishes in Queensland (QFMA-QDPI Working Group on Legal Minimum lengths, 1991). Other research groups also are working towards collecting the necessary biological data for yield-per-recruit assessments (e.g. QDPI --Southern Fisheries Laboratory, JCU --Marine Biology, AIMS). Given the reasonably successful use of yield-per-recruit models in the line fisheries of the Gulf of Mexico and the US Southern Atlantic (e.g. Huntsman et al. 1982, 1983; Mahmoudi et al. 1984; Huntsman and Waters 1987), this form of yield assessment holds a great deal of promise for a wide variety of species taken by the demersal line fishery on the Great Barrier Reef.

11.3 Spawning Potential

Two measures related to equilibrium yield from a stock are the spawning stock biomass per recruit and egg per recruit (Goodyear 1989; Goodyear and Phares 1990). The spawning stock biomass per recruit (SSBR) is a measure of the expected lifetime reproductive potential of an average recruit and is obviously an important correlate of the potential for growth of a population. The ratio of the fished to unfished spawning stock biomass per recruit (SSBR fished/SSBR unfished = Spawning Potential Ratio (SPR)) provides a basis for evaluating the condition of the spawning stock and the establishment of criteria for managing the spawning potential of the stock (Goodyear 1989). Egg per recruit estimates require not only information on the spawning stock biomass per recruit but also the lifetime fecundity.

These measures have been proposed recently as a fisheries management objective for the reef fisheries in the U.S. Southern Atlantic (Goodyear 1989; Goodyear and Phares 1990). Given our relatively limited knowledge of spawning stock biomass and fecundity for the stocks of reef fish of commercial and recreational fishing interest on the GBR, such management objectives to produce an equilibrium yield of specified magnitude remains an objective for the future on the GBR.

12 MANAGEMENT MEASURES

12.1 The Commercial Line Fishery

12.1.1 Responsibility for Management

Management of the Commercial `Reef Line Fishery' is the responsibility of the Queensland State Government. The fishery is managed by the Queensland Fish Management Authority (established under the Fishing Industry Organisation and Marketing (FIOM) Act of 1982 - See Section 6). The current legislation comes under the FIOM Act 1982-89 and the Fisheries Act of 1989 (Gwynne 1990).

Discussions regarding jurisdiction over the fishery were held between the Commonwealth and Queensland State Governments in the various rounds of the Offshore Constitutional Settlement (OCS). On June 1 1987, the Commonwealth and Queensland State Governments agreed that under the OCS the Demersal Reef Fishery would be managed by the state.

The spatial boundaries under this agreement were amended under OCS on the 31 August 1988. A further found of OCS negotiations in May 1989 identified clearly that the state was responsible for managing the reef demersal stocks.

The other legislation which clearly affects management of the Reef Line Fishery is the Commonwealth's Great Barrier Reef Marine Act of 1975. This Act established the Great Barrier Reef Marine Park (GBRMP) and the GBRMP Authority. GBRMPA is responsible for the control, care and development of the Marine Park. Its main strategy of management is zoning of the GBR reefs. This zoning has the following objectives:

i. the conservation of the Great Barrier Reef;

ii. the regulation of use of the Marine Park so as to protect the Great Barrier Reef while allowing the reasonable use of the Great Barrier Reef region;

iii. the regulation of activities that exploit the resources of the Great Barrier Reef Region so as to minimise the effect of those activities on the Great Barrier Reef;

iv. the reservation of some areas of the Great Barrier Reef for its appreciation and enjoyment by the public;

v. the preservation of some areas of the Great Barrier Reef in its natural state undisturbed by man except for the purpose of scientific research.

The framework for the management of the Marine Park by GBRMPA has been provided by the GBRMPA Zoning plans. These Zoning regulations and their role in fisheries management are discussed later in this Section. Clearly the management by QFMA of the Reef Line Fishery within the Great Barrier Reef Marine Park exists within a framework of spatial closures to fishing setup by GBRMPA. A `Memorandum of Understanding' was signed by GBRMPA, QFMA and the Division of Fisheries and Wetland Management of the Queensland Department of Primary Industries (QDPI) in 1988. Within this memorandum of understanding GBRMPA recognises the responsibility of QFMA and QDPI to manage the reef fisheries. It is generally acknowledged by both State and Commonwealth representatives that in the case of any conflict of interest the Commonwealth Act would override the State Act. Such conflicts of interest have not arisen with respect to the Reef Line Fishery and the policy of both Commonwealth and State organisations has generally been one of consultation. Such consultation is likely to increase with the recent establishment of the `Effects of Fishing Program' set up by GBRMPA on the advice of the Advisory Committee on Research into the Effects of Fishing in the Great Barrier Reef Region. This program, beginning in 1991, will involve extensive consultation and co-operation between a wide variety of State and Commonwealth management and research institutions, aimed at investigating effects of fishing in the GBR region.

12.1.2 Management Measures

12.1.2.1 Controls on Fishing Effort

A freeze on commercial fishing licences in Queensland has existed since 1979 (Qld Fisherman, April 1991, p. 11). This has had the general effect of an overall reduction in the number of commercial fishermen in Queensland. However, the vast majority of fishermen in Queensland have a line-fishery endorsement (1963 line-fishery endorsements in 1989) despite the majority of the reef line catch being taken by about 100 commercial fisherman (see Section 6). Theoretically at least, great potential exists for many commercial fishermen to shift into the reef line-fishery in the future. Furthermore, a fair amount of latent effort exists amongst the 69 vessels with Line-Only endorsements. These Primary vessels have access to 4 Tender vessels per endorsement, permitting operation of 276 tender vessels. Currently (1989) these Primary endorsements operate only 153 tender vessels (Gwynne 1990).

In 1986 the Reef Line Fishing Advisory Committee of the Queensland Commercial Fishermens' Organisation (QCFO) proposed the introduction of an interim management plan for the reef line fishery based on limited-entry licensing for line fishing and trolling operations conducted in a defined area of the Great Barrier Reef (Qld Fisherman July 1986, p. 19). Many of the supporters of this proposal were reef line fishermen based in Mackay. This proposal was rejected by the QCFO State Line Committee (see Qld Fisherman August 1991 Supplement on Line Review). The recent review of the Reef Line Fishery (Gwynne 1990) has also proposed that a commercial Reef Line Fishery (RLF) endorsement be established. It proposes that those Primary vessels which contribute the majority of the commercial reef line catch (about 100) be endorsed to utilise up to 4 tender vessels (except those currently licensed to use more than 4 tenders). It recommends steps be taken (over a 5 year period) to limit all RLF endorsed vessels to no more than 4 tender vessels. The recommendation stops short of attempting to reduce the number of line fishery endorsements, opting to simply prevent an increase in effort in the fishery by proposing that all other Primary vessels holding a line fishery entitlement be authorised to operate in the fishery using only one tender vessel (ie. the current situation) (Gwynne 1990). The recommendation of Gwynne regarding an RLF has again been rejected by QCFO (Qld. Fisherman, August 1991 Supplement in Line Review). The only QCFO Branch (of which there are 13) to support a `separate endorsement' was the Mackay Branch. QCFO rejected the proposal based largely on its objection to the use of `performance criteria' and `historical involvement' in selection of RLF endorsements. However, QCFO did recommend that a total freeze on tender vessels for use in the Line Fishery be implemented immediately, until at least the outcome of the Reef Line Fishery Review (Qld Fisherman, August 1991 Supplement on Line Review).

12.1.2.2 Gear Restrictions

Descriptions of fishing gear used in the fishery were given in Section 9. The fishery for demersal reef fish is a line fishery. Legislation provides for the use of up to 6 hooks (maximum of 1 hook in Marine National Park `A' Zone) on a hand line or rod. Most commercial operators use only one hook per line (Gwynne 1990).

A multiple-hook fishery has been proposed recently in waters > 100 fathoms off the Queensland Coast by the QFMA. (Qld Fisherman, May 1991, p. 19). The apparatus proposed are drop lines (maximum 6), trot lines and bottom-set longlines (maximum 300 hooks per line).

It will be a condition of permit that coral trout, emperor and snapper will not be allowed on board at the same time as the multiple-hook apparatus. However, a similar and directly adjacent multiple-hook fishery has been proposed recently by the Australian Fisheries Service (AFS) in which there appear to be no restrictions in taking coral trout, emperor or snapper.

12.1.2.3 Restrictions on Catch

No restrictions on catch such as catch quotas or individual transferable quotas exist for the commercial Reef Line Fishery. Restrictions on catch in the form of minimum legal sizes do exist e.g. Coral Trout, 35cm TL; Sweetlip Emperor, 30cm TL; Red Emperor, 35cm TL. Gwynne (1990) gives a list of all legal minimum and maximum sizes of fish allowed to be captured in Queensland waters (see his Appendix 2). The current minimum legal sizes have been a source of concern, particularly with market pressure for `pan-sized' reef fish. The demand for coral trout below its minimum legal size of 35 cm TL has apparently been substantial in some areas. A recommendation of the recent review of the Reef Line Fishery (Gwynne 1990) was that the minimum size limit on coral trout be reviewed immediately, and that further research be conducted to determine if a greater length would be more appropriate (see Sections 5 and 11). This was supported by the QCFO (Qld Fisherman, August 1991, Supplement on Line Review). Beinssen (1989a) suggested that the legal minimum size of coral trout be raised to 45cm TL in Capricornia. A QFMA Working Group has been formed recently to review all minimum legal sizes of fish in Queensland. The recommendations of this Working Group have now been made (as of October 1991) and these recommendations are being reviewed by the QFMA Board. If approved by QFMA the recommendations will then pass to the Minister for Primary Industries for approval. The legal minimum sizes of both coral trout and sweetlip emperor are likely to increase, perhaps as early as 1992.

12.1.2.4 The Recent Review of the Reef Line Fishery

The main recommendations of this review (Gwynne 1990) regarding the commercial reef line fishery were the establishment of a Reef Line Fishery (RLF) endorsement, a limit of 4 tenders per RLF endorsement and 1 tender per line-fishing endorsement, a review of the legal minimum size of coral trout, extra emphasis on enforcement (ie. an additional Boating and Fisheries Patrol office be established at Innisfail and a mobile task force of the Boating and Fisheries Patrol be established), and that the Reef Line Fishery be reviewed again in two years (from 1990). Other recommendations regarding the commercial reef line fishery related to amendments to FIOM to provide for sales of product by Master Fishermen only where that product is taken by the use of a licensed commercial fishing vessel endorsed appropriately, consideration be given to greater account of prior fishing experience in applications for Master Fisherman's Licences and a recommendation to maintain the current boat replacement policy should an RLF be accepted. Comments on the Reef Line Fishery Review are currently being assessed by QFMA. A detailed response to all of these recommendations has been provided by the QCFO (Qld Fisherman, August 1991, Supplement on Line Review).

Closures of reefs to commercial fishing under the GBRMPA zoning plans are dealt with later in this Section.

12.2 The Recreational Line Fishery

12.2.1 Responsibility for Management

Responsibility for the management of the recreational line fishery on the GBR falls under similar arrangements to those described for the commercial line fishery. The QFMA (and QDPI) are responsible for managing the fishery within the framework set by the GBRMPA zoning scheme.

12.2.2 Management Measures

12.2.2.1 Controls on Fishing Effort

No controls currently exist on the size of the small-boat recreational fleet nor the charter boat fleet. The small-boat recreational fleet is growing very rapidly (at 3.3% per year for the GBR region - see Section 6) and is very likely to continue growing rapidly over the next few decades. The greatest `controls' over effort by this small-boat recreational fleet are natural ones - distance of the reef from shore (40 to 50 km minimum for most mid-shelf reefs along many parts of the coast) and weather (strong SE winds throughout most of the winter). There are essentially no controls on the expansion of the charter boat fleet. The QCFO has recently rejected the idea of dual endorsed commercial fishing and charter vessels (Qld Fisherman, August 1991, Supplement on Line Review).

12.2.2.2 Gear Restrictions

Essentially the same as for the commercial fishery. Efficiency of the recreational fleet has no doubt increased over the past few decades with improved quality of lines and hooks, availability of depth-sounders and electronic fish-detector devices.

12.2.2.3 Restrictions on Catch

The same minimum size limits apply to the recreational line fishery as the commercial line fishery. To this point no other restrictions have been placed on the catch of recreational fishermen. In the recent review of the Reef Line Fishery (Gwynne 1990) it was recommended that a bag-limit of 30 reef or pelagic fish in possession at any time, including not more than 10 of any one species, be introduced in the recreational fishery throughout Queensland. This recommendation has been supported recently by the QCFO, with the additional suggestion that there be a limit of not more that 5 Narrowed Barred Spanish Mackerel in possession (Qld Fisherman, August 1991, Supplement on Line Review). Gwynne (1990) provides reasonably sound arguments as to why bag limits should be introduced to the recreational sector of the Reef Line Fishery. The essence of the arguments are that there is `.......... extensive public opinion that the reef fish resources are under extreme pressure, .......', that `......... the only broad based control available on recreational fishing effort, bag limits, be introduced', and that the `........ true recreational fisherman will not be affected by the proposed bag limits as 30 reef fish in total or 10 reef fish of any one species is more than adequate for domestic purposes'. Gwynne points out that bag limits are used as a management tool for one of both of two reasons: resource protection and equitable distribution of the resource. Gwynne (1990) provides a list of all recreational bag limits that exist in the various states of Australia (see his Appendix 1). Bag limits occur in Western Australia (for 27 species as species groups), NSW (for 23 species or species groups, many introduced on 1 July 1990), South Australia (for 11 species or species groups), Victoria (for 10 species or species groups), Tasmania (for 7 species or species groups), Queensland (for 5 species or species groups) and NT (for 1 species). Part of the recommendation for introduction of a bag limit to the recreational line fishery on the GBR is that all fish landed by unlicensed (recreational) fishermen be landed in a whole (head-on) form. Gwynne (1990) argues that a large impetus for introduction of bag limits would be to limit the amount of fish illegally offered in the market. If up to 30-40% of the recreational catch is taken by 10% of recreational fishermen (see Section 6) and if these fishermen are more likely to sell their catch illegally than other recreational fishermen, bag limits could have considerable impact in both reducing recreational catch and ensuring a far more equitable allocation of the resource both within the recreational sector and between the recreational and commercial sectors.

Craik (1989a) provided an extensive review of management options for the recreational fishery on the GBR. These included making sales of fish illegal (this became law in Queensland in May 1990 with the abolition of Section 35 - see below), educating recreational fishermen that fishing should be a non-profit recreation, limiting entry, closing areas, increasing lower size limits, imposing upper size limits, reducing the number of fishing trips, use of barbless hooks and bag limits.

The management options listed above were considered with respect to their likely success in achieving four management objectives of GBRMPA with respect to the reef fishery:

i. sustain a viable commercial fishery;

ii. allow recreational fishermen to catch one or two fishes if they wish without great difficulty;

iii. ensure that recreational divers are able to see a reasonable number and variety of fish when diving;

iv. ensure that some areas are set aside to provide unfished `reference areas' (Craik 1989a).

Each of the management options for the recreational fishery on the GBR listed by Craik (1989a) are dealt with briefly below.

The legal sale of fish by amateurs under Section 35 of the Fishing Industry Organisation and Marketing Act has been a highly contentious issue in Queensland for some time (Craik 1989a; Gwynne 1990). No other state of Australia allows unlicensed persons to sell fish. Prior to 1988, under Section 35 an amateur fisherman could sell fish which was in excess of their personal needs. In March 1988, Section 35 was amended such that recreational fishermen were restricted to selling 50 kg of whole fish per permit with a maximum of 12 permits to be issued to each individual annually. Each permit cost $15. On May 22 1990, Section 35 was removed and it is now illegal for amateurs to sell fish. The situation where some amateur fishermen were in essence fishing commercially and developing substantial businesses around sale of fish under Section 35 (or illegally) has been of great concern to QFMA/QDPI, QCFO and GBRMPA. These so called `pro-ams' were able to recover costs of fishing and in some cases make a profit from what was portrayed as a `recreational' activity. The abolition of Section 35 has been supported strongly by commercial and the vast majority of recreational fishermen (Craik 1989a; Gwynne 1990). Gwynne (1990) provides a history of Section 35 of the FIOM Act.

Instigation of programs to educate recreational fishermen that fishing should be a non-profit recreation are seen as highly desirable management options by GBRMPA (Craik 1989a), QFMA (Gwynne 1990) and the QCFO (Qld Fisherman, August 1991, Supplement on Line Review). As Craik points out, voluntary acceptance of responsible fishing attitudes will in the long-term be more successful than regulation.

The option of limited entry in recreational fisheries e.g. resident and non-resident recreational fishermen being treated differently under regulations, is generally seen as being largely impractical on the grounds of difficulty of enforcement, and for both political and logistic reasons (Craik 1989a).

Up to the present time, the zoning plans of GBRMPA have not included closures of reefs specifically to recreational fishermen. Generally, closures apply equally to both commercial and recreational fishermen although some reefs were specifically closed to commercial fishing in the Capricornia Section Zoning Plan (Craik 1989a). Commercial fishermen have suggested closing the Hardline Reef complex to recreational fishermen (Craik 1989a).

Changing minimum and maximum size limits of fish has been discussed previously as a management option within the commercial line fishery. Legal minimum and maximum sizes of reef fishes in Queensland are currently under review by QFMA and minimum sizes of some important species (e.g. coral trout) are likely to increase in the near future.

Although Craik (1989a) listed reducing the number of trips made by recreational fishermen as a potential management option, she concedes that means of achieving this would be difficult. Similarly, Craik (1989a) concludes that use of barbless hooks would be of very doubtful acceptability to recreational fishermen, despite putting more `sport' back into fishing and reducing mortality rates of released fishes.

Craik (1989a) provides a detailed review of the potential effectiveness of recreational bag limits as a management option (see her Appendices I to IV). Craik reported that a proposal to include a mechanism for the introduction of a recreational bag limit in the first draft (1979-80) zoning for Capricornia was generally not favoured by recreational anglers. However, surveys in Capricornia by Walker (1986) indicated a greater acceptance of the idea (Craik 1989a). The major factors in favour of recreational bag-limits are that they reduce amateur catches, they affect a small percentage of anglers and they legislatively reinforce the notion of `recreational fishing' being desirable behaviour. The major factors against bag limits are that they are difficult to enforce, they require fish to be landed whole, the bag limit becomes a target in itself, anglers may replace fish caught initially with more desirable fish caught later in the trip, anglers may take additional passengers on board to maximise catch and their introduction may adversely affect the charter boat industry. Craik (1989a) considered these and made a number of recommendations regarding the potential introduction of bag limits. The most important of these were that a bag limit should apply to `all reef fish', a bag limit for each marine park section should not be the same, both a daily and a maximum possession limit would be necessary, that a bag limit should apply equally to spear and line fishing, that retention of whole fish was necessary and that bag limits could not be applied easily to particular reefs. She suggests bag limits for Capricornia of 20 (Daily limit) and 40 (Maximum possession limit) and for Cairns of 10 (Daily limit) and 20 (Maximum possession limit). Craik (1989a) suggests that introduction of such bag limits may reduce total recreational catch by 12% in each region. Craik (1989a) concludes that bag limits may have some attraction in catch reduction if they can be enforced in the marine situation at an acceptable cost. She points out that it is almost impossible to determine their cost-effectiveness and that this has not been evaluated formally elsewhere.

It should be noted that the bag limit proposed for recreational line fishing on the GBR by QFMA (Gwynne 1990) did not include both a daily limit and a maximum possession limit. This is a point of concern to recreational fishermen. Charter boats and fishing clubs frequently make trips to the reef in excess of one day and a maximum possession limit should reflect this (Craik 1989a).

The final recommendation by Gwynne (1990) with respect to the recreational line fishery on the GBR was that a review be conducted of recreational catch monitoring programs with a view to implementation of an adequate monitoring scheme prior to the next review of the reef line fishery (see Section 6). The response of the QCFO to this recommendation was one of support, with a recommendation of their own that a recreational fishing levy by introduced throughout the state to help fund such monitoring and management of the recreational fishery.

12.3 GBRMPA Zoning: The Role of Reef Closures in Fisheries Management

The five objectives of the Great Barrier Reef Marine Park Authority Zoning strategy of management were given earlier in this section (see Management Measures in the Commercial

Line Fishery). The GBR Marine Park and GBRMPA were established under the Commonwealth Great Barrier Reef Marine Park Act 1975. The major management strategy of GBRMPA has been its Zoning Plans. The first zoning plan came into operation in July 1981 in the Capricornia Section of the Marine Park. Table 18 summarises information relevant to zoning of the GBR Marine Park and relevant to the reef line fishery on the GBR.

The zones and the type of fishing they permit are as follows:

General Use `A' Zone (Light Blue on Zoning Maps): permits trolling, line fishing (maximum 6 hooks per line), spear fishing, limited collecting, oyster gathering, crabbing, bait gathering, bait netting, commercial netting and trawling. A range of other activities are permissible with written permission from GBRMPA (e.g. traditional fishing and hunting).

**General Use `B' Zone** (Dark Blue on Zoning Maps): as for General Use `A' Zone but trawling not allowed.

**Marine National Park `A' Zone** (Yellow on Zoning Maps): as for General Use `B' Zone except spear fishing, commercial netting and limited collected not allowed. Also, line fishing allowed only with no more than one hook per line.

Marine National Park `B' Zone (Green on Zoning Maps): no fishing of any kind allowed.

Scientific Research Zone (Orange on Zoning Maps): no fishing of any kind allowed.

Preservation Zone (Pink on Zoning Maps): no fishing of any kind allowed.

In addition, certain provisions relating to `Designated Areas' exist. The two of relevance to fishing are the `Replenishment Areas' where fishing is not permitted, other than trolling for pelagic species during the period May 1 to January 31 of any year and `Seasonal Closure Areas' where fishing is not permitted in certain seasons.

In the recent review of the Cairns Zoning Plan (October 1989) the zones have been renamed. They will now be called General Use Zone (= old General Use `A' Zone), General Use (No Trawling) Zone (= old General Use `B' Zone), Marine Park Recreation Zone (= old Marine Park `A' Zone) and Marine National Park Zone (= old Marine Park `B' Zone). Scientific Research Zones and Preservation Zones will be retained as in previous zoning plans. A new zone (No Structures Subzone) will be introduced, free from fixed structures and permanently moored facilities (other than approved moorings and markers). Replenishment Areas and Seasonal Closure Areas will be retained as for previous zoning plans.

Zoning Plans have been formulated and put into action in the various Sections of the Marine Park (see Table 18). These Zoning Plans were intended to have a duration of 5 years. At present the only revisions of existing zoning have occurred for the Capricornia Section in 1987-88 (which involved a review of the initial Capricornia Section and its incorporation into the Mackay/Capricorn Section) and the Cairns Section (October 1989 to present).

The general strategy with respect to line fishing has been to implement zoning on an individual reef scale. The **approximate** number of reefs per marine park section and the **approximate** numbers closed to line fishing per section are given in Table 18. These figures are approximate because they were calculated by eye from the existing zoning maps. The total number of coral reefs in the Marine Park shown in Table 18 (1,471) is considerably less than that on the

GBRMPA computer records (> 2,900, S. Hillman pers. comm). This is due mainly to the criteria used in counting reefs. Coral reefs that were _1 km maximum dimension only were counted and shoals, patches and banks were not included in counts. The reason for the exclusion of small reefs and shoals, patches and banks was that such `reefs' are likely to be too small to attract separate zoning in their own right in most situations. Their exclusion in counts in no way diminishes their potentially great biological significance as `stepping stones' in potential movements of adult reef fish between reefs.

The percentage of reefs actually closed to line fishing in the Marine Park is 23.3% (342 out of 1471 - See Table 18). This figure is affected greatly by the existence of the green `cross-shelf transect' in the Far Northern Section. There are 94 `green' reefs and 4 `pink' reefs in this transect. If these are omitted, the percentage of reefs closed to line fishing in the whole park is 16.6%. The percentage of closed reefs varies from section to section, being lowest in the Mackay/Capricorn Section (14.9%) and highest in the Far Northern Section (32.0% - but only 9.9% excluding the `cross-shelf transect') (Table 18). The percentage of the area of the marine park actually closed to fishing is considerably smaller, and in approximately 2 to 5% (2% in the Mackay/Capricorn section, for example).

The maximum duration of closures to line fishing in each section as of late 1991 are Capricornia - 10 years (17 years for certain sites on Heron Island), Cairns Section - 8 years, Far Northern Section - 6 years, Central Section - 4 years and Mackay/Capricorn Section - 3 years (Table 18).

12.4 Fisheries Management and Spatial Closures to Fishing

The use of long-term (> 1 year) spatial closures to fishing is a relatively common management strategy in the conservation of reefs. The first marine protected area in modern times was apparently established in the 1930s in Florida (Plan Development Term = PDT 1990). Since that time marine parks aimed at reef conservation have been established all over the world (see reviews by Kenchington 1988; UNEP/IUCN 1988; Dartnall 1989; PDT 1990). It has long been recognised that establishment of marine parks (areas closed to fishing) affect existing reef fisheries. These effects have been viewed as both negative (most often as a reduction in the stock available for exploitation and a concentration of fishing effort on the areas remaining open to fishing) and positive. Any positive benefits of marine parks depend on the nature and degree of interchange of fish between areas closed and open to fishing. The most commonly cited potential benefit is a build-up of fish biomass in closed areas and a subsequent dispersal of larvae from closed to open areas. Given the length of larval life and extent of potential larval dispersal (Doherty and Williams 1988), such interchange could occur over considerable geographic areas. The greater the area over which fish are dispersed, the greater any positive effect will be diluted and any benefits will be influenced strongly by year to year variations in survivorship of larvae in the planktonic phase. Another potential positive benefit on reef fisheries is movement of adult fish between closed and open areas. Benefits to reef fisheries can potentially be gained by emigration of adults from unfished to fished areas (e.g. Alcala and Russ 1990) or, given high fishing mortality in the fished areas, by random fluxes across boundaries between open and closed area (Beverton and Holt 1957).

Despite the potential effects of marine parks on existing fisheries, the establishment of long-term spatial closures has not been used commonly as part of management strategies for reef fisheries. The recent proposal for establishment of Marine Fishery Reserves on 20% of the continental shelf in the US Southern Atlantic (PDT 1990) to conserve and manage stocks of reef fishes is one of the first reef fishery management plans to have long-term spatial closures as a central theme of the plan. In contrast, the zoning plans of the Great Barrier Reef Marine Park were not set up explicitly to manage the GBR reef fishery. Nevertheless, any advantages and disadvantages of long-term spatial closures in the GBR Marine Park will affect the GBR reef line fishery.

The potential advantages and disadvantages of the use of long-term spatial closures to fishing in management of reef fisheries are summarised in Table 19. There is ample evidence that long-term spatial closures to fishing increase the density, biomass, average size (and probably age) and fecundity of reef fishes (see PDT 1990 and Russ 1991 for recent reviews). The evidence that such effects influence reef fisheries in areas outside the closed areas, in either a positive or negative manner, is extremely limited. However, there is no doubt that the protection of part of a stock of reef fish from fishing is going to increase the probability of conservation of the stock in the long-term, provided that the area closed to fishing is of sufficient size.

Based upon detailed biological and fisheries knowledge of *Lutjanus campechanus* (the red snapper) and other reef fishes in the US Southern Atlantic Bight, a team of fisheries biologists from the US National Marine Fisheries Service has proposed a reef fish management plan which has long-term, large scale spatial closures to fishing as its central theme (PDT 1990). Very high levels of fishing mortality in this reef fishery through the 1960s, 1970s and 1980s has reduced the spawning stock biomass of many species to dangerously low levels. For example, the spawning stock biomass per recruit of the red snapper was estimated to be between 1.5% and 1.8% of the unfished level. It was estimated that under high fishing pressure total fecundity was only 5% of that at low fishing pressure (PDT 1990). However, by protecting 20% of the stock, it was estimated that total fecundity would increase 5-fold over that under heavy fishing pressure. The team has proposed creating Marine Fishery Reserves on 20% of the continental shelf in the US Southern Atlantic. In terms of basic demographic information on target species, such as growth, mortality and recruitment, this is probably the best studied (in a fisheries context) reef fishery in the world. Relatively sophisticated analyses such as yield-per-recruit and egg-per-recruit have been carried out for many of the important species (e.g. Huntsman et al. 1982, 1983; Mahmoudi et al. 1984; Huntsman and Waters 1987; Goodyear 1989). However, fishing effort and fishing mortality have been unable to be controlled by conventional fisheries management strategies and this team has opted for long-term, large-scale spatial closures as the best means to conserve stocks. If such a situation can arise in a developed country such as the United States, the message has even greater gravity for developing countries where rates of human population increase and pressure on reefs is generally much greater. A recent World Bank funded fisheries management plan for the Philippines has establishment of marine reserves as a major management strategy (White and Lopez 1990).

To increase the knowledge of the effects of long-term spatial closures to fishing on reef fisheries, very detailed studies of fish movements (both larval and adult) are required. Only through detailed knowledge of the nature and rates of interchange between fished and unfished areas can the degree of any effects be gauged.

12.5 Effects of Reef Closures on the Great Barrier Reef

No direct assessment has been made of the overall impact of the zoning strategy of closing whole reefs on either the commercial or recreational reef fisheries on the Great Barrier Reef. However, reef closures have been shown to have some effects on such things as density and size structure of target populations and such effects potentially may influence fisheries outside the closed areas. Some evidence exists that recruitment rates of coral trout may be lower into high density populations on closed reefs, for example. Much of this evidence relating to effect of closures comes from underwater visual census studies. Limited evidence exists that catch rates are higher on less heavily fished reefs and on closed reefs (determined by experimental fishing). The evidence of effects of closures (or reductions in fishing pressure) on density, size structure, recruitment and catch rates is summarised in Table 20.

The evidence that closures of reefs to fishing increases average size of individuals of target species such as coral trout is good. This pattern has been observed consistently since the mid-seventies. It has not been demonstrated yet that closures of reefs increase the average age of populations of reef fishes but this is obviously likely. Evidence that closures of reefs increases the density of target species is reasonably good but is not as unequivocal as perhaps many expected. For example, no significant differences in density of coral trout were detected between closed and open reefs in the Capricorn and Capricornia Sections (Ayling and Ayling 1984a, 1986). No significant differences in density of coral trout, lethrinids or lutjanids were detected between closed and open reefs in the Cairns Section (Ayling and Mapstone 1991). It is difficult to argue, particularly in the case of the Cairns surveys, that closures have been of insufficient duration to affect density of coral trout. The lack of significant differences in density between closed and open reefs in these cases is unlikely to be due to high variability between replicate censuses and use of techniques not sensitive enough to detect reasonably large changes in density. In the recent Cairns surveys the mean densities of coral trout on closed and open reefs were virtually identical (Table 20). A.M. Ayling (pers. comm) suggests that the fishing pressure may simply not be great enough to cause a significant change in density. Another factor which may contribute to the result could be frequent violations of reef closures by fishermen although evidence for this is anecdotal at best. The evidence that reef closures of the order of 3-4 years increase catch rates is reasonably good. Beinssen (1989a, b) has stressed that catch rates may drop very quickly after intense fishing. Catch rates are not necessarily a good index of density because catchability appears to alter quite rapidly. Finally, evidence that recruitment rates of coral trout are higher on open reefs than closed reefs is limited but worth examining more closely. Summarising the evidence in Table 20, it is clear that closures of reefs do increase average size of individuals in target populations. A good deal of evidence suggests that closures increase density of target species but some extensive and fairly rigorous studies have not demonstrated this. The evidence for the effect of reef closures on density of target species remains equivocal.

Some very clear gaps in our knowledge arise from examination of the evidence in Table 20. We need far more reliable information on the nature and extent of violations of reef closures by fishermen (both commercial and recreational). Research that to this point has not been carried out includes:

i. Long-term, regular (e.g. yearly) monitoring (by visual census, catch rates, perhaps traps) of fished and unfished sites, which includes some provision for actually monitoring fishing effort at the study reefs;

ii. More rigorous monitoring of `fish down' experiments on previously protected reefs such as at Boult reef (Beinssen 1989a);

iii. Very importantly, the regular (e.g. yearly) monitoring of how long it takes for a reef to `recover' after being fished (either at natural levels or pulse fished). Data on long-term dynamics of recovery of fish stocks on reefs closed to fishing is almost non-existent on GBR reefs.

12.6 Potential Target Species of the Line Fishery in the Future

The species which currently constitute the bulk of those targeted by the reef line fishery are ***Plectropomus*** leopardus, *P. maculatus*, *P. laevis*, *Lethrinus miniatus*, *L. nebulosus*, *Lutjanus sebae*, *L. malabaricus*, *L. erythropterus*, *L. johnii* and *L. argentimaculatus*. Species which may become increasingly targeted if catches of the larger, most desirable species, decline or if markets for smaller fish are developed, include: *Lutjanus adetii, L. carponotatus, L. russelli, L. fulviflamma, L. kasmira, L. quinquelineata, Lethrinus atkinsoni, L. harak, L. laticaudis, L. lentjan, L. obsoletus, L. olivaceus* and *L. ornatus*.

12.7 Summary

1. Management of the commercial reef line fishery is the responsibility of the Queensland State Government through the Queensland Fish Management Authority/Queensland Department of Primary Industries. Management of the reef line fishery on the GBR is carried out in unison with the zoning plans set up by the GBRMPA. Effort is controlled by a ceiling on new commercial licences but considerable clatent effort exists within the existing industry. Some gear restrictions apply but no catch quotas. Minimum size limits apply and these are currently under review by QFMA. A management plan has recently been proposed for the reef line fishery (Gwynne 1990) and this is under review.

2. Management of the recreational reef line fishery is the responsibility of QFMA/QDPI also. Again, management of the fishery on the GBR is carried out within the framework of the GBRMPA Zoning Plans. No controls on effort in the recreational fishery currently exist. There are some gear restrictions but no catch quotas. Bag limits have recently been proposed for the recreational fishery (Gwynne 1990) and this is currently under review.

3. The Zoning Plans of the Great Barrier Reef Marine Park Authority were first introduced in the Capricornia Section of the park in July 1981, with the entire GBR under Zoning Plans by July 1988. No direct assessment of the effect of zoning on the reef line fishery has been made but many potential advantages and disadvantages are recognised. Reasonable evidence exists that closing reefs to fishing increases average size and perhaps density of target species. Whether such effects influence fishery yields outside the closed areas awaits research on the extent of interchange of fishes (both larvae and adults) between closed and open areas. The zoning does provide a very good basis for conservation of stocks of reef fish. Experience from the reef fishery in the US Southern Atlantic supports this contention. This fishery has a history of about 15 years of fisheries research on target species, and in terms of reef fish demography is probably the best studied reef fishery in the world. However, lack of success in controlling effort has reduced spawning stock biomass of target species to dangerously low levels. The management plan proposed to address this problem had as its central focus the permanent closure to fishing of 20% of the continental shelf of the US Southern Atlantic. This was proposed as the best strategy to conserve spawning stock biomass. Such experience suggests that the original strategy of Zoning Plans for the Great Barrier Reef by GBRMPA was a good one in terms of long-term conservation of stocks of reef fish of commercial and recreational fishing interest.

12.8 Studies in Progress

(i) Consideration of the management plan for the reef line fishery formulated by QFMA (Gwynne 1990).

(ii) Review of minimum size limits by QFMA/QDPI.

(iii) The GBRMPA Effects of Fishing Program. This was funded initially in 1991 and a coordinator was appointed at GBRMPA in 1991 (Dr. Bruce Mapstone). The program could potentially run for 10 years. The objectives of this program are:

a. to determine the effects of line fishing on reefs, of trawl fishing in inter-reef areas and of the combination of trawl and line fishing on the abundance of particular species, such as coral trout, that are directly impacted by fishing;

b. to describe the effects of line fishing and trawl fishing and the combination of both on species that are not directly affected by fishing but may be indirectly affected through ecological processes;

c. to determine how populations of particular reef organisms recover when reefs are closed to fishing; and

d. to determine the effects of inter-reef trawling in the timing of such recovery.

Part of the Effects of Fishing Program will involve a multi-institutional study based around the general, large-scale experimental concepts defined by Walters and Sainsbury (1990) that arose from an initial workshop on the `Effects of Fishing in the Great Barrier Reef Region' (Craik et al. 1989). The general experimental concepts proposed involved some direct tests of the effects of reef closures on stocks of reef fishes and upon reef fisheries.

(iv) The GBRMPA Reef Monitoring Program. The objectives of the program as stated for 1991-92 are:

a. to determine the effects of zoning provisions and uses during the life of Zoning Plans;

b. to determine the abundance of representative reef organisms and magnitudes of variability in population density and distribution;

c. to determine the effects of permitted uses of the Marine Park on the Marine Park and adjacent areas e.g. tourist developments.

Results from this program will have direct relevance to the effectiveness of the zoning strategy of management.

Table 18 Summary of information relevant to zoning of the Great Barrier Reef Marine Park and relevant to the reef line fishery on the GBR, 1991. Green = Marine National Park B Zone; Orange = Scientific Research Zone; Pink = Preservation Zone.

Marine Park Section	Marine Park Area (km^2)	Start of Operational Zoning	Max. Duration of Reef Closures (years)	Approx. No. of Reefs*	**Approx. No. of Reefs Closed To Line Fishing***				Total Closed To Line Fishing	% Closed To Line Fishing
					Green	Orange	Pink	Replenishment		
Capricornia	12,000	July 1981	10**	**21**	2	1	1	2	**6**	28.6%
Mackay/ Capricorn (minus Capricornia)	125,000	July 1988	3	**578**	78	0	6	2	**86**	14.9%
Central	77,000	July 1987	4	**279**	44	1	7	15	**67**	24.0%
Cairns	35,000	Nov 1983	8	**150**	20	3	4	14	**41**	27.3%
Far Northern	83,000	Aug 1985	6	**443**	127#	1	8	6	**142#**	32.0%
TOTALS	344,000			**1471+**	271	6	26	39	**342**	
% of TOTAL REEFS					18.4%	0.4%	1.8%	2.7%	**23.3%**	

* True Reefs ≥ 1 km maximum dimension (i.e. excluding shoals, patches, banks): determined from GBRMPA zoning maps.

** Some sites on Heron Island protected since 1974 (1.e. 17 years protection).

\+ GBRMPA computer records list > 2900 (S.Hillman pers. comm) but many would be too small to attract separate zoning in their own right in most situations.

\# Includes 94 Green reefs on Cockburn Map BRAQ102 in the Far Northern cross-shelf transect.

Table 19 Potential advantages and disadvantages of the use of long-term spatial closures to fishing in management of reef fisheries (adapted and modified from Plan Development Team 1990)

ADVANTAGES

1. **Reduces chance of recruitment overfishing by maintaining a critical spawning stock biomass.** A core of spawning stock in areas closed to fishing potentially can supply fished areas with recruits because of the great dispersal capability of larvae of reef fishes. Ensures recruitment supply even if fished areas are exploited heavily, and especially under environmental uncertainty.

2. **Potential long-term maintenance or even enhancement of fisheries yield to broad regional areas by larval dispersal.** Areas closed to fishing allow individuals to live longer, grow larger and thus become more fecund. Such increases in fecundity may enhance recruitment in fished areas and thus compensate for the reduced area available for fishing. Closed areas should provide a ready source of supply of larvae to fished areas downstream.

3. **Provision of undisturbed spawning/breeding grounds for fishes.** For example, protection of sites of spawning aggregations of species of commercial and recreational fishing significance.

4. **Maintenance of intra-specific genetic diversity.** Long-term genetic benefits accrue with fish populations inside closed areas retaining at least some long-lived individuals. Allows maintenance of longer generation times within the gene pool.

5. **Provides unfished populations for scientific research.** Allows estimation of such things as natural rates of mortality and growth, natural longevity, natural age and size structures, natural fecundity, size and age at first reproduction and sex change, and (if the areas were of a scale equivalent to that of larval dispersal) natural rates of recruitment. Other information such as natural standing stock and densities could be determined and experimental catch rates in unfished populations could be measured.

6. **Maintenance or possible enhancement of fisheries yield to areas adjacent to the closed areas via adult emigration.** Closed areas may provide a 'growth refuge' where fish under $F = 0$, survive grow and perhaps later move into fished areas. Movement to fished areas can be either directed (emigration to fished areas) or random across boundaries of closed /open areas. Both can enhance yield-per-recruit and total yield to unfished areas under high levels of F in fished areas (Beverton and Holt 1957). Requires detailed knowledge of movements of adult fish.

7. **Protection of community/ecosystem structure and thus maintenance of interspecific genetic diversity.**

8. **Data collection needs for management are reduced and management occurs without complete information and understanding of population parameters of every species, nor of interactions between species.** Under single-species fisheries management, detailed information of population dynamics is required. Management can proceed without such details.

DISADVANTAGES

1. **Concentrate fishing effort on a smaller portion of the stock.** The same total effort that would have been applied in the absence of spatial closures is applied to a smaller area, increasing fishing mortality in open areas.

2. **Less of the stock is available to fishermen, possibly reducing short-term fisheries yield.** Spatial closures will have immediate impacts on existing fishing. Catch may decline and patterns of distribution of effort and catch will change in response to spatial patterns of closures.

3. **Any benefits to the fisheries may manifest themselves only in the long-term.** Maintenance or enhancement of yield through maintenance of recruitment or migration of adult fishes from closed to open areas are likely only to occur over years to decades.

4. **Closed areas created an increased incentive for deliberate poaching.** Areas closed to fishing are likely to eventually sustain larger populations of larger fishes, often with high catchability. If surveillance is not adequate, the temptation to poach is enchanced.

5. **Increased need for intense surveillance and enforcement.** Closed areas will require intense surveillance to prevent poaching is too frequent, any benefits predicted by management may not arise, creating problems of management credibility. At sea surveillance and enforcement is expensive. Costs are greater than dockside enforcement but less than those required to enforce bag limits, size limits etc.

6. **Strong local resistance is likely in those specific areas where closures are proposed.** Many fishermen support spatial closures to fishing but most would prefer them to be anywhere else except where they normally fish.

7. **Uncertainty concerning the size, location and number of spatial closures to ensure persistence of reef fisheries.** Areas closed to fishing must be sufficiently large to support a breeding population with a stable age structure. Detailed information on current patterns may be required for optimal location of closures.

8. **Long-term and detailed research required to justify spatial closures.** In addition to details of current patterns, research on minimum spawning stock biomass to maintain a reef fishery may be required to determine the extent of closures. In the US Southern Atlantic, researchers calculated that a minimum of 20% of the reef fish spawning was required to maintain the fishery.

9. **Direct economic benefits through tourism.** Areas closed to fishing such as marine parks generate secondary economic benefits such as tourism, diving, snorkelling, underwater photography, educational group visits, etc.

10. **The concept is easily understandable by the general public and more easily acceptable than some other management strategies.** Public awareness and support will assist in the success of closed areas.

11. **Surveillance and enforcement are simplified.** Areas closed to fishing are easy to target in public education programs. Violations can be detected by surface or aerial surveillance, often with public participation. Enforcement avoids problems associated with measuring fish sizes, species identification, determining if appropriate gear has been used and determining if quotes have been exceeded.

12. **Protection of fish habitat.** If some types of fishing or other activities are destructive to fish habitats closed areas may protect such habitats, perhaps enhancing recruitment. Protection of estuaries which act as nursery areas for offshore fisheries is a common example.

13. **Provide some insurance against management and recruitment failures.** Having areas closed to fishing is a 'bet-hedging' strategy. Conventional fisheries management strategies are implemented outside the closed areas and if these fail to control effort and catch, the populations in closed areas act as insurance to management failure.

14. **Have equitable impact among fishery users.** Under most circumstances, closed areas do not allow fishing by either commercial or recreational fishermen.

15. **Large resident fishes that stray outside reserves may help maintain certain trophy fisheries.**

16. **Provide areas for educational use.** Such areas provide examples of 'undisturbed' habitats and communities.

17. **Reduction of inadvertent fishing mortality.** Mortality caused by embolisms, hook wounds, infections, etc, occurring during the processes of capture and subsequent release are eliminated. This applies equally to both target species and bycatch. Capture of bycatch for bait is eliminated also.

18. **Reduces temptation of fishermen to violate laws.** In normal situations, fishermen are often tempted to keep undersized or oversized fish or to exceed catch quotas. In closed areas where fishing is prohibited, such temptations for 'incidental poaching' are reduced.

19. **Can be used as sources of broodstock for aquaculture.**

20. **Can be used as sources of juveniles/sub-adults for supplemental restocking of depleted areas.**

9. **Unlikely to be useful for highly migratory species.** Most reef fishes are relatively sedentary as adults although our knowledge of movement patterns of reef fish of commercial and recreational fishing significance is very limited.

10. **Resistance of fisheries managers to 'new approaches'.** Long-term spatial closures to fishing have not often been used as a common part of a fisheries management policy. More intensive application of traditional approaches is likely rather than adoption of 'new' approaches.

11. **Conflicts with other fishery management plans.** Co-ordination with other fishery management plans would be required. For example, spatial closures for a reef demersal fishery may impinge on management of a troll or trawl fishery. The fisheries may interact directly or indirectly and this will have to be taken into account in designing a management plan which includes spatial closures.

12. **Closed areas should include all habitats necessary for maintenance of all life-history stages of fish.** For example, a closed area may have to include reef adjacent estuaries, mangrove forests, seagrass beds, etc. This is likely to require large areas.

13. **Large areas as in 12. will span coastal offshore areas, and thus mean that both state and federal jurisdiction apply.** Co-operation between State and Federal organisations will be required.

Table 20 Summary of evidence for effects of spatial closures to fishing or reduced fishing pressure on stocks of reef fishes on the Great Barrier Reef.

Year	Reference	Nature of Study and Evidence
1976-1980	Goeden (1979, 1982, 1986)	Scuba manta-towing of 76 reefs from Melville Passage to Heron Island. Population density indexes of coral trout suggesting fishing was reducing coral trout densities significantly, particularly *Plectropomus leopardus*. Showed a significant correlation between coral trout density and distance from centres of human population (Cairns). Proposed that *Plectropomus* was a keystone species and that fishing, in reducing its density, affected `community flux' of other predatory species of reef fish.
1977	Goeden (1977, 1978)	Used visual census at Heron Island to show that coral trout density was 68 per hectare on unfished area compared with 35 per hectare at fished area (densities down to 3 per hectare in fished areas).
1977	Goeden and Blackford (1977)	Scuba manta-towing of Wheeler Reef. Suggested fishing pressure moderate because of low numbers of coral trout perceived to be in the 3-5 year range.
1979	Craik (1979a, 1979b 1981a, 1986)	Analysis of catch rates of recreational fishermen. Catch rates increased with distance from Cairns.
1979-1980	Craik (1981c)	Visual census of 13 Capricorn and 7 Bunker group reefs. Density of coral trout markedly higher at unfished sites on Heron Island (up to 98 per hectare) than fished sites at both Heron and a large number of other reefs (densities 6-52 per hectare). Mean length much greater at unfished sites (48.5 cm TL) than fished sites (38.9 cm TL). Sites on Heron Island protected for 5 years.
1983	Ayling and Ayling (1983a)	Visual census of coral trout on 44 reefs in Cairns Section of Marine Park. Compared reefs with relatively high and low fishing pressure. Reported a small but significant (p per ha on fished reefs, 29 per ha unfished reefs).
1983/84	Ayling and Ayling (1983, 1985)	Visual census of coral trout on 12 reefs off Townsville (1983) and 42 reefs in the proposed Central Section of Marine Park (Dec 1984). Mid-shelf reefs in the northern part of the Central Section grouped into high and low fishing pressure reefs. Density of coral trout significantly higher on low fishing pressure reefs (51 per ha) than high fishing pressure reefs (29 per ha) (p size structure not detected between high and low fishing pressure reefs.

Year	Reference	Nature of Study and Evidence
1984/85-86	Ayling and Ayling (1984a, 1986)	Visual census of coral trout on 10 reefs in the Swains (1984) and 30 reefs in the Capricornia (Dec 85-Jan 86). Reefs protected from fishing for 2.5 to 12 years. No significant difference in density of coral trout between 6 fished and 6 unfished sites. Mean length significantly greater at unfished sites (44.6 cm TL) than fished sites (35.7 cm TL). Noted that recruitment appeared higher at fished sites.
1984	Ayling and Ayling (1984b)	Visual census of coral trout on 29 reefs in proposed Far North Section of GBR Marine Park. No major inferences made about differences in density or size structure on reefs of different fishing pressure.
1984-85	Dinesen et al. (1985) Dinesen (1986), Osborne et al. (1986)	Queensland National Parks and Wildlife Service visual census of coral trout on 13 reefs in Capricornia (some more than once). Differences in densities demonstrated between fished and unfished reefs. Some evidence for larger sizes on unfished reefs.
1986	Beinssen (1989a)	Detailed study of pulse fishing of Boult Reef in December 1986. Reef had been protected from fishing (as a Replenishment Area) from 1 July 1983 (a period of $3^1/2$ years). Average size of coral trout at Boult Reef in September/November 1986 significantly greater than at a nearby fished reef (Fitzroy) and significantly different from that at Boult Reef in May 1988, after 18 months of fishing. Using tagging studies, intense pulse fishing shown to reduce standing stock of coral trout by 25% in 14 days. Fishing reduced stock to 75% of that in Nov 86 by May 1988. Catch rates in the first 3-4 days after the opening were generally much higher than those recorded on open reefs. Visual census before and after fishing estimated a decline of 30% in density over 14 days. This predicted a catch of 2583 fish from an estimated total 8613 (;873 SE) in 342 hectares. Actual catch was 2136, indicating that a relatively crude visual census technique detected fishing effect very well. Stock size estimated by 3 methods - Petersen mark recapture, Leslie Depletion method and visual census. Leslie method unreliable because of distinct reduction in catchability after 3-4 days of intensive fishing. First estimate of catchability (q) for coral trout (0.15). Clear demonstration that catch rates are not necessarily a good indication of coral trout density. Catch rates declined sharply after 3-4 days of intense fishing but visual census confirmed that up to 70-75% of initial stock remained. Clear demonstration that protection from fishing for 3-5 years increased density and average size and that such removal of protection eliminated such effects in 1.5 years.

Year	Reference	Nature of Study and Evidence
1989	Beinssen (1989b)	Detailed study of patterns of movement along a 4 km stretch of the northern slope of Heron Island. Designed to sample 4 500 m blocks in Marine Park B (closed to line fishing) and 4 500 m blocks in Marine Park A (open to line fishing). Size frequency distribution of coral trout in closed area with far more large fish than size frequency distribution in area open to fishing. No such pattern for sweetlip emperor. Catch rate of coral trout 3.6 times higher in closed area but visual census suggested ratio of trout density in closed to open area was 0.78. Catch rate of sweetlip emperor 3.6 times higher in closed area and visual census suggested ratio of density in closed to open area 5.6. Thus, in one case, CPUE did not reflect density as measured by visual census and for another species it did. Catch rate for all species 3.1 times higher in closed area. Catchability of both coral trout and sweetlip emperor declined with duration of fishing over 15 hours sequential fishing. Detailed movement patterns recorded (see Section 8). About 29% of coral trout moved from release block in 3 weeks. Concluded that `significant leakage' or coral trout occurred across closed/open boundary. Concluded that Marine Park B/A split zones at Tyron, Northwest, Masthead and Lady Elliot were such that closed areas were too small to be effective at maintaining stocks unaffected by fishing.
1990-1991	Russ Laycock, Ferreira (unpub. data)	Line fishing on 2 reefs open to fishing and 2 reefs closed to fishing off Townsville twice per year over 2 years (1990, 1991). Reefs closed since July 1987 (ie. 3-4 years of protection). Each reef fished for one day (approx. 6-7 hrs) by 4-5 fishermen on one charter boat on each occasion. Catch rates of coral trout and sweetlip emperor approximately 2-3 times higher on closed than open reefs. Length frequency distributions of coral trout not significantly different between fished and unfished reefs. Comparisons of age structure on fished and unfished reefs in progress (Ferreira).
1991	Ayling and Mapstone (1991)	Visual census of coral trout, lethrinid s and lutjanids on 50 reefs in the Cairns Section of the GBR Marine Park. On mid-shelf reefs 16 reefs open to fishing compared with 10 reefs closed to fishing. Closures for approximately 8 years (since Nov 1983). Density of coral trout not significantly different between closed (44.7 per ha) and open (45.7 per ha) reefs. Average length approx. 4 cm greater on closed reefs. Greater abundance of 0+ fish on open reefs. On outershelf reefs 13 reefs open to fishing compared with 8 reefs closed to fishing. No significant difference in density of coral trout between open and closed reefs. Mean length 3.3 cm greater on closed reefs (38.3 vs 35.0 cm TL). On both mid- and outershelf, no significant differences in density of either lethrinids nor lutjanids on closed and open reefs. Density actually slightly higher on open reefs.

13 RECOMMENDATIONS ON RESEARCH PRIORITIES

Below we describe areas we have identified as priority areas of research for species of fish of commercial and recreational importance on the GBR. They have been selected on the basis of research relevant to management of the GBR. The knowledge required is not necessarily sophisticated relative to that identified as priority requirements in better studied fisheries. This reflects our present understanding of the ecology and population dynamics of the relevant species on the GBR. Numbers and headings below refer to chapters of this review.

13.1 Distributions and Habitats

Basic knowledge of the distributions of fish species of recreational and commercial importance is remarkably lacking within the Great Barrier Reef Marine Park. For no species do we have a good understanding of its distribution throughout its complete life-cycle. We highlight two general areas requiring particular attention:

(i) **Distributions of Juvenile Fish.** Little is known of the distributions of juveniles of any species of commercial or recreational importance. Yet such information is critical to understanding, for example, the significance of nearshore habitats to reef fishes and interactions between the trawl fishery and the line fishery. Data is particularly required on the significance of nearshore habitats, especially sea-grass areas, but also estuaries, fringing reefs and shallow bay habitats as nursery areas for lethrinids and the snappers *Lutjanus malabaricus*, *L. erythropterus* and *L. johnii*. The habitat of juvenile *Lethrinus miniatus*, in particular, needs to be defined. This is the second most important species commercially and yet juveniles (<20cm) have rarely been found.

(ii) **Distribution and Abundance of Fish Below SCUBA Depths.** We have a good understanding of the distribution and abundance of the coral trouts through extensive visual surveys using SCUBA. We have little idea, however, of the proportion of the population or its distribution, below these depths. Most of the spawning population, for example, may occur in depths and habitats that cannot be surveyed using SCUBA. There is a general lack of understanding of species distributions and size distributions of species below about 20m. Is there a clear distinction between the 'reef' fauna and species found on the surrounding trawl grounds (as there appears to be in trawl by-catch)? Answers to these problems will require the development and refinement of sampling techniques other than visual surveys. Traps, droplines, surveys from submersibles and fish trawls appear to be good candidates.

13.2 Early Life Histories

(i) **Taxonomy.** Although lethrinids and lutjanids (*Lutjanus* spp.) are not uncommon in larval net tows, the value of net tow studies for examining significant problems of early life histories are very limited because of the inability to identify these taxa to species level. Significant advances in our knowledge of the early and middle stages of pre-settlement of these taxa (critical for understanding patterns of dispersal) is dependent on taxonomic studies that will allow species-specific identification, similar to studies carried out for coral trout by Leis.

(ii) **Recruitment and Light-traps.** An understanding of spatial and temporal variability in patterns of recruitment of species of recreational and commercial importance is critical for a number of reasons outlined in the text. Although underwater studies of newly-settled individuals of these species have to date been largely unsuccessful, light-traps are proving very useful in assessing recruitment variability of at least coral trout. Their use in this role should be extended.

13.3 Reproduction

(i) **Spawning Aggregations.** A number of species of commercial and recreational importance are known to form spawning aggregations. Such aggregations create unique opportunities to study many problems. Further work is required to better define spawning behaviour, specifically the timing and location of aggregations, for as many species as possible.

(ii) **Age and Size at Maturity.** Age and size at maturity are very important parameters in stock assessment but are poorly known for most species. More effort is required to determine these parameters for species on the GBR.

(iii) **Mechanisms of Sex-Change.** Most, if not all, coral trouts and emperors undergo sex-change during their lives. This greatly complicates the question of size and age at maturity and requires detailed study. An important problem for stock assessment and questions of the effects of fishing is the mechanism of sex change. Is it size-dependent, age-dependent, socially controlled, a mixture of these or perhaps controlled in other ways? The answers to these questions will have different management implications.

13.4 Age, Growth, Mortality and Longevity

(i) **Determination of Age and Longevity.** A more concentrated effort is required to identify annual and seasonal banding patterns in the hard parts of reef fish of commercial and recreational fishing significance. Section 5 established clearly that biologists working on reef fish on the GBR have been slow to address questions of basic demography, and age determination is the key to sound demography. We need to be able to age all species of commercial and recreational interest, including the smaller lethrinids and lutjanids and species in a range of genera which are likely to become more important in the reef fishery in the future e.g. *Epinephelus, Cephalopholis, Gymnocranius, Diagramma, Plectorhyncus, Aprion, Etelis, Cheilinus.*

(ii) **Validation.** An important aspect of age determination is validation of the temporal significance of checks in hard parts of fishes. The use of traps, tetracycline injection and mark-release-recapture techniques probably offers the best opportunity for such validation.

(iii) **Rates of Growth and Mortality.** Determination of age is the key to good estimates of both growth and mortality. Growth and mortality estimates are the key elements in yield-per-recruit estimates. We need estimates of both growth and mortality for a wide range of species. [More effort is required to sample the components of the stocks in deeper waters for inclusion in growth and mortality estimates.] Comparisons of rates of growth, mortality and longevity in different regions of the GBR are essential for management.

(iv) **Age-Structured Population Dynamics.** Our knowledge of the population dynamics of large reef fish must be age-based. Age-structure information from a number of reefs of known recruitment history exists for only one species of reef fish on the GBR - the pomacentrid *Pomacentrus moluccensis* in the Capricorn-Bunkers. The insights into population dynamics of this species gained through age-structured information (longevity, growth, mortality, factors affecting population size) are exemplary. It is this level of detail of population dynamics that is required for species of commercial and recreational fishing significance on the GBR.

13.5 Catch and Effort

(i) **Commercial Line Fishery.** Detailed information is now available (since January 1 1988) for catch-effort characteristics of the commercial line fishery (QFMA/QDPI CFISH database).

The value of this information will increase as the duration of the data collection increases. There is a strong need to contact as many commercial line fishermen as possible for historical records of catch/effort. Many fishermen keep such records as a means of paying employees.

(ii) Recreational Small-boat Fishery. A strong need exists for more extensive and regular boat-ramp surveys to improve our knowledge of the small-boat recreational fleet. Such studies seem to be far preferable to telephone or mail recall surveys.

(iii) Charter Boat Fishery. The best time-series of catch-effort data for the GBR Reef Line Fishery come from the competition records of fishing clubs using charter boats or their own boats. A strong need exists to document and analyse these data and to ensure that such information continues to be collected.

(iv) Aerial Surveillance. Within the constraints of limited budgets, it would be advantageous to make more use of aerial surveillance to estimate numbers of boats (from all fishery sectors) fishing on particular reefs. With good ground-truth information on numbers of fishermen per boat, hours fished per day etc., such data might potentially provide good estimates of effort.

13.6 Stock Structure

Basic studies of stock structures are required. These are important in determining the potential interdependence of different reef areas and to highlight populations that may have different population parameters (and hence different responses to disturbance). Coral trout and sweetlip emperor (*L. miniatus*) are the obvious species to emphasise, not only because they are the major taxa of commercial interest but also because of particular aspects of their distribution and ecology. Circumstantial evidence suggests that sweetlip may be particularly restricted in their movements, and hence may be more likely than other species to differentiate into different stocks. As discussed in the text, there is evidence that population parameters of *P. leopardus* in the Capricorn-Bunkers are different to those elsewhere on the GBR. Together with the relative geographic isolation of the Capricorn-Bunker Group from the rest of the reef, these observations suggest that *P. leopardus* in this Group may be a different stock to those elsewhere.

13.7 Movements and Migration

Little is known of the movements or migrations of species of recreational and commercial importance. A number of mark-release-and-recapture studies in progress will greatly increase our understanding of movements within reefs. The most important problem from a whole-reef management view and for the design of effects of fishing experiments is the extent and nature of movements of fish between reefs. Large, carefully thought out, tagging studies will be required to solve this problem.

13.8 Yield Estimates and Spawning Potential

(i) Surplus Production Models. Given the need for collection of catch-effort data from all sectors of the fishery over a long time period, and the need for a range of effort values over many years, it is unlikely that estimates of yield from a surplus-production model for the GBR reef line fishery will be available for some time, if at all. Nevertheless, collection of reliable catch-effort data from all sectors of the fishery over as long a period as possible is essential to detect major trends in the fishery.

(ii) Yield-Per-Recruit Models. The basic information on growth, and to a lesser extent mortality, will soon be available to make preliminary yield-per-recruit estimates for a few of the major species. We still need better estimates of rates of natural and fishing mortalities, however. The data required for yield-per-recruit estimates (growth, mortality estimates) for a wide range of species of fish of commercial and recreational fishing interest are simply not available (Section 5). Such information should become available over the next 5 years or so. Yield-per-recruit estimates will provide us with some of the most reliable yield estimates available for the GBR reef line fishery.

13.9 Management Measures

(i) Legal Minimum Sizes of Fish. Research to determine age and size at first reproduction and sex change for a wide range of reef fish of commercial and recreational fishing interest should be a high priority. Such information is essential for making decisions on appropriate legal minimum sizes at first capture. For example, the current minimum size of sweetlip emperor (30cm TL) would appear to be below the size at first reproduction. (Minimum legal sizes of reef species are under review by QDPI at the time of writing this report).

(ii) Cost-effectiveness of Bag Limits. Some research should be directed to determining if bag limits do provide a cost-effective method of reducing catch in the recreational fishery.

(iii) Assessment of the Effects of Zoning on the Reef Line Fishery. An assessment of whether zoning of reefs is having a beneficial, detrimental or neutral effect on the reef line fishery will require detailed studies of the nature and rates of movement of fish between fished and unfished areas. This includes detailed studies of movement and mortality rates of both adult and larval fish as they move between reefs. Studies of interreefal movements of adult and larval fish should be a priority.

(iv) Closures of Parts of Reefs. Zoning has generally been applied on a whole-reef scale. Some pilot studies should be made to determine the impact of closing parts of individual reefs on the fishing at that reef. Such studies will require detailed knowledge of within-reef movements of adult fish.

(v) Recruitment Rates of Coral Trout to Closed and Open Reefs. Detailed monitoring of this kind would provide insight into an important aspect affecting population size on an individual reef.

(iv) Nature and Extent of Fishing Violations on Closed Reefs. Information of this type is critical in interpreting the effects, if any, of zoning on the reef line fishery. If 'unfished' reefs are in fact receiving unmeasured but substantial amounts of fishing mortality, the real impact of zoning may be underestimated.

(vii) Surveys of Distribution and Abundance of Target Species. Surveys of the type carried out to date (e.g. visual surveys of coral trout) should be continued and, if possible, monitoring should be both regular and long-term, in both fished and unfished areas. The methods of monitoring could be expanded to include visual census, trap studies, monitoring of experimental catch rates, monitoring of age structures etc.. Such monitoring would provide some of the best estimates of stock abundance available.

(viii) Experimental Studies. Use of zoning provisions to set up well-designed, long-term experiments to investigate effects of fishing and protection from fishing should be a high priority. Studies comparing fished and unfished areas, depletion experiments (such as the Boult Reef experiment) and studies of the long-term dynamics of the recovery of stocks are recommended.

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