

DISCUSSION

Catch Composition

The detailed catch composition data obtained during this study, from five reefs on five sampling occasions, provided the opportunity to examine the effect of reef and trip on the composition of the catch obtained from line fishing. The frequency of occurrence of the six dominant species was found to vary significantly among reefs and trips. The effect of trip was due to an increase in the proportion of *P. leopardus* in the catch during the September 1992 and October 1993 trips, which coincided with the peak of the spawning season of *P. leopardus*. It is suggested that this was the result of an increase in the catchability of *P. leopardus* when fish are aggregated to spawn, rather than a real increase in overall abundance. Catchability of *P. leopardus* is likely to increase as a result of the aggregated distribution of fish, in locations which can be efficiently exploited by anglers, and due to an increase in feeding activity of the fish associated with spawning (Johannes and Squire 1988; Samoilys and Squire 1994).

Species composition of the catch varied among reefs also. Potter and Taylor Reefs tended to have a higher proportion of *C. cyanostigma* and *L. bohar* than the other reefs, while Beaver, and to a lesser extent, Little Potter and Farquharson Reefs had a higher percentage of *L. miniatus*, *L. atkinsoni* and *L. carponotatus*. This could be interpreted as an increase in the proportion of by-catch (*C. cyanostigma* and *L. bohar*) at Taylor and Potter Reefs in response to higher fishing pressure on *P. leopardus* compared to Beaver Reef. However, it would be purely speculative in the absence of replication of the 'unfished' level. Furthermore, the overall percentage of *C. cyanostigma* appears to vary more due to the effect of trip than the effect of reef, with low percentages of *C. cyanostigma* associated with the trips done in the spawning season of *P. leopardus*. Thus, it is equally likely that the differences in the frequency of occurrence of *C. cyanostigma* and *P. leopardus* among reefs reflect differences in the catchability of *P. leopardus* rather than real differences in the abundance of the two species.

There are few published accounts on the species composition of catch of the Great Barrier Reef line fishery. With the exception of target species, several species are generally grouped into common retail categories, such as 'mixed reef a' which may include several species of lutjanid, lethrinid and serranid (Trainor 1991). This makes it difficult to estimate the relative contribution of each species to the total catch and the potential impact of the fishery on the broader reef fish community, a common problem in coral reef fisheries (Munro 1983). Beinssen (1989a) suggested that although a large number of species are caught in the Great Barrier Reef line fishery, a few species dominated the total catch, by number and weight, and that these species should be the focus of research and management. The results of this study, in which six species accounted for over eighty-five per cent of the catch, support this assertion.

However, the composition and frequency of species dominating the catch of the line fishery will vary among locations, particularly at cross-shelf and geographic scales. For example, *P. leopardus* (34%), *L. adetii* (24%), *L. miniatus* (12%) and *Epinephelus fasciatus* (13%) dominated the catch during the Boulton Reef opening (Beinssen 1989a). In contrast, at Heron Island, approximately 40 km to the north of Boulton Reef, although the dominant species were the same, their relative contribution to the total catch was different; *L. miniatus* (26%), *E. fasciatus* (22%), *P. leopardus* (16%) and *L. adetii* (13%) (Beinssen 1989b). The pattern among reefs in this study was similar, with six species dominating the catch at each reef, although the relative proportions of dominant species differed among reefs and trips. The catch at each reef was dominated by *P. leopardus* (57%), followed by *C. cyanostigma* (12%), *L. carponotatus* (6%), *L. atkinsoni* (4%), *L. miniatus* (3%) and *L. bohar* (3%), with the rank of the latter two species differing among reefs. This suggests that dominant species and their relative contribution to the catch of the Great Barrier Reef line fishery will vary widely among regions within the Great Barrier Reef.

The percentage of *P. leopardus* in this study was considerably higher than that reported by Beinssen (1989a, b) from the Capricorn Bunker Group of the Great Barrier Reef and by Trainor (1991) for the Great Barrier Reef commercial line fishery (39%, after excluding Spanish mackerel). This highlights the importance of *P. leopardus* in the line fishery, particularly in the northern sectors of the Great Barrier Reef where it is the primary target species of both the commercial and recreational reef fisheries. In contrast, *L. miniatus* which is the second most common species in the Great Barrier Reef commercial line fishery (Trainor 1991), formed only a small percentage of the total catch from the five reefs. This is probably due to the restricted distribution of *L. miniatus* on the Great Barrier Reef, being found in greatest abundance between Cardwell and Shoalwater Bay (Trainor 1991; Williams and Russ 1994), and the study area being located at the northern extreme of that range.

The results of this study and those conducted by Beinssen (1989a, b), demonstrate that although a large number of species are caught in the Great Barrier Reef line fishery, the majority of the catch is comprised of a few dominant species, and that the composition of these dominant species will vary among reefs and regions of the Great Barrier Reef. Of these dominant species, the common coral trout, *P. leopardus*, is the most ubiquitous and abundant and, as such, should be the primary focus of studies on the effects of fishing on reef fish on the Great Barrier Reef. Furthermore, the fact that the dominant species in the line fishery vary among reefs and regions of the Great Barrier Reef, highlights the need for species level identification of catch composition by region so that the species most commonly caught in the fishery may be identified for future research.

Catch Per Unit Effort of *Plectropomus leopardus*

Studies of the relative abundance of *P. leopardus* and other species of large reef fish commonly targeted by the Great Barrier Reef line fishery have generally been performed using underwater visual census (UVC) (Ayling and Ayling 1983a, b; 1984a, b). These studies have provided invaluable information on the distribution and relative abundance of *P. leopardus* across the large range of spatial scales which occur on the Great Barrier Reef as well as providing evidence of effects of fishing on target species such as *P. leopardus* (Craik 1981; Ayling and Ayling 1992). However, the effectiveness of UVC techniques for assessing the effects of fishing on large reef fish has recently been questioned. The major disadvantages of UVC techniques are: i) it is not possible to routinely survey habitats deeper than 15 m, ii) the total area surveyed is often small in comparison to the total area occupied by the resource, and iii) total sample sizes are often small in comparison to estimated population size. Accordingly, Walters and Sainsbury (1990) recommended that alternative methods for estimating relative abundance of target species be compared prior to the commencement of the main experimental program.

Line fishing is an alternative sampling method to UVC for obtaining an index of relative abundance (CPUE) and for measuring the response of reef fish populations to different levels of fishing pressure. As with all sampling techniques it has disadvantages, the most serious being temporal and spatial variation in catchability and the fact that CPUE may not be related to stock size (Beinssen 1989a; Hilborn and Walters 1992). However, it has several advantages over UVC techniques, in that it is possible to sample over the entire depth range of the resource, a large proportion of the reef area may be sampled and, with the use of skilled commercial fishermen, total sample sizes per reef are usually large.

Although it was not a major aim of this study, CPUE data for *P. leopardus* from the tagging study provided some valuable information on the relative abundance of *P. leopardus* among trips and reefs. Catch per unit effort of *P. leopardus* varied significantly among trips and blocks within reefs but not among reefs. The significant effect of trip appears to be related to an

increase in CPUE of *P. leopardus* during the spawning season with the peaks in mean CPUE corresponding with trips done during the *P. leopardus* spawning season. This may reflect an increase in the abundance of *P. leopardus* on the reefs during the spawning season and/or an increase in the catchability of *P. leopardus* when the fish are aggregated to spawn. This is supported by the results of the movement study which suggest that the distribution of *P. leopardus* within reefs may change during the spawning season, with fish moving to specific sites within reefs to spawn (e.g. block 2 Farquharson Reef and Potter Reef).

There was no significant variation in CPUE of *P. leopardus* among reefs. Although CPUE was generally higher on Beaver Reef, the difference was not significant and the proportion of variation explained by reef was small (0.05%) in comparison to variation due to trip (8.42%) and block (1.22%). This suggests there is little difference in the relative abundance of *P. leopardus* among the five reefs. This is supported by estimates of relative abundance from visual census for Beaver and Potter Reefs, made just prior to the first tagging exercise (trip a), which found no significant difference in the mean density of *P. leopardus* between the two reefs (Ayling and Ayling 1992).

The significant effect of block and the interaction between trip and block indicates that CPUE of *P. leopardus* varies significantly within reefs and this effect varies over time. This highlights the need to stratify sampling programs among the various temporal scales which are likely to influence CPUE (e.g. tidal state, lunar cycle and season) as well as spatial scales within reefs (e.g. front/back, deep/shallow). For example, experience gained from the commercial fishermen over the course of this project suggests that fishing the different sides of a reef when the tide is running on to the reef may result in a significantly higher CPUE relative to the 'run off' tide in the same location. Such an effect is likely to be the result of temporal variation in the catchability of *P. leopardus*, possibly related to feeding behaviour, rather than variation in actual abundance. However, the important point is that by stratifying the sampling temporally, as well as spatially, it may be possible to remove a large part of the variation from estimates of relative abundance. This will apply equally to alternative sampling methods such as traps and UVC techniques.

The results of the CPUE analysis demonstrate that CPUE of *P. leopardus* varied significantly among trips and blocks within reefs. How accurately CPUE from line fishing reflects actual abundance of *P. leopardus* is not clear. The results of the Boulton Reef opening suggest that CPUE is not proportional to total population size (Beinssen 1989a). Beinssen (1989a) suggested that CPUE was more related to the fraction of the *P. leopardus* population which was in 'feeding phase', and therefore available to be caught, rather than the total population of Boulton Reef. In a separate study at Heron Island, using encounter rates from a UVC technique and CPUE data from commercial line fishermen, Beinssen (1989b) demonstrated that catchability of *P. leopardus* was considerably higher in an area protected from fishing compared to the adjacent area in which fishing was permitted, and that this difference increased with fishing effort. Thus, there is evidence that catchability of *P. leopardus* varies over space and time and with exposure to fishing effort. Therefore it seems unlikely that CPUE from line fishing will be directly proportional to abundance of *P. leopardus*. A more thorough understanding of the relationship between CPUE and abundance of *P. leopardus* and its power to detect changes in abundance due to fishing pressure is required if it is to be used to monitor changes in abundance as part of the proposed manipulative experiment. This would best be achieved through a comparative study in which the power of available sampling techniques (UVC, traps, line fishing, drop lines) to detect a known change in abundance is compared over a range of abundances.

Size Structure of *Plectropomus leopardus*

The mean length of *P. leopardus* decreased monotonically over the course of this study. This decline was particularly evident at Farquharson Reef on the final trip, with large reductions in the proportion of fish in the larger size classes resulting in a 40 mm decrease in mean length. In the absence of size-at-age data and replicated unfished reefs, it is not possible to determine whether this effect is the result of growth overfishing or the passing influence of a strong cohort.

The situation is further complicated by the fact that the effect is equally evident for Beaver Reef, which is theoretically unfished, as it is for the other open reefs and that the mean length of *P. leopardus* on Beaver Reef was significantly lower than the other reefs. A higher level of recruitment at Beaver Reef would explain the higher proportion of *P. leopardus* in the smaller size classes and a high level of infringement may explain the low proportion of fish in the larger size classes. However, the causes of the observed patterns in size structure of *P. leopardus* will only be resolved with the availability of age-structure information at each reef over time and replication of 'unfished' reefs.

The significant effect of block and the interaction between trip and block for the mean length of *P. leopardus* demonstrates that mean size differs among blocks within reefs and that these differences may not be constant over time. This implies that samples taken from different locations within a reef at different times may provide significantly different estimates of mean size and size structure, even when there has been no change in the overall size structure of the population on the reef. This emphasises the need for sampling programs to include within reef stratification in order to obtain representative estimates of age/size parameters from individual reefs.

Tag Loss and Comparison of Tag Types

T-bar anchor (TBA) tags and dart tags are the two types of tag most commonly used for demersal reef fish on the Great Barrier Reef. However, opinions of individual researchers on the merits of the two tag types and effect of different colours on their rate of loss have differed (G. MacPhearson, pers. comm.; L. Squire pers. comm.; M. Sheaves pers. comm.). Therefore, in order to determine the 'best' tag for use in future research the two tag types were compared as part of this study. The 'best' tag was defined as that having the higher rate of retention and lower overall cost.

The estimates of p (0.8927) and L (0.00101) from the Bayliff and Morbran (1972) tag loss model for TBA, predict that 38% of the TBA tags will be lost in the first year following release. This is considerably less than the 48% first year loss reported by Davis and Reid (1982) for *Lates calcarifer* using a similar TBA tag (Floy® FD67) and slightly higher than the 34% estimated by Sheaves (1993) for a range of estuary species using identical Hallprint® TBA tags. In contrast to these two studies, Type I tag loss was significant in the tag loss process. This may have been the result of a greater proportion of the tags being shed immediately following tagging or a higher rate of post-release mortality in this study. Unfortunately, it is effectively impossible to separate these two processes. There was no difference in the frequency of returns of the six different coloured TBA anchor tags used in the study indicating that tag colour does not have a significant effect on the frequency of tag loss.

It was not possible to estimate parameters for the dart tags as the model fit was not significant due to the low and variable number of returns for each time interval. However, the diagnostic plot suggests that Type I tag loss is likely to be significant and considerably higher than that for the TBA tags. This may reflect a higher rate of tag loss immediately following release as a

result of the head of the dart not being firmly secured behind the pterygiophore. However, care was taken to test that each tag was secure prior to release. It is considered more likely that this may reflect a higher level of tagging mortality associated with the dart tagging procedure and, in particular, with the potential for damage to the pterygiophores. Such injuries to the pterygiophores have been shown to be a major source of mortality in *L. carponotatus* (Whitelaw and Sainsbury 1986).

The frequency of return of TBA tags was significantly higher than the dart tags for the research returns. However there was no difference in the frequency of return of the two tag types from the public returns. The lack of a significant effect from the public returns suggests that the larger dart tags are more likely to be observed and reported by the public than the smaller t-bar tags and that this compensates for their higher frequency of shedding. However, given the lower frequency of shedding, greater ease of application, ability to be effectively used on small, medium and large fish and the lower cost of the TBA anchor tags, it is recommended the TBA anchor tags be used in future tagging programs of demersal reef fish on the Great Barrier Reef. Furthermore, this study has demonstrated that the different colour tags may be used to colour-code releases without significant differences in the frequency of tag loss.

Movement of *Plectropomus leopardus*

Individual coral reefs potentially represent the ideal unit for manipulative experiments investigating the effects of fishing on multi-species fish stocks (Walters and Hilborn 1978; Sainsbury 1988; Walters 1986; Russ 1991). The use of individual coral reefs as experimental replicates assumes that stock size on one reef is independent of another, and therefore, that the rate of movement of adult fish among replicated reefs is low in comparison to the treatment effects. The results of the research recovery exercises in this study suggest that, under the present conditions, the level of inter-reef movement by *P. leopardus* is low (< 1% of the tagged population) and is unlikely to confound treatment effects of the proposed Effects of Fishing Experiment (Walters and Sainsbury 1990). However, it should be noted that the difference in relative abundance (CPUE) and size structure among reefs within the cluster was low and variable. Thus, it is possible that with greater contrast in abundance of *P. leopardus* among reefs the rate of inter-reef movement may increase. The proposed large-scale manipulative experiment to examine the effects of line and spear fishing on coral reefs will involve deliberate depletion of replicate reefs. It is strongly recommended that the tagging study be continued as an integral part of the proposed experiment. Future estimates of patterns of movement during the depletion and recovery phases of the experiment will be valuable for interpreting the response of *P. leopardus* populations to varying levels of fishing effort.

A major result of the study was the marked contrast in the estimates of inter-reef movement of *P. leopardus* from the research recovery exercises and the public returns. A large part of this disparity appears to be the result of some anglers fishing at Beaver Reef and subsequently reporting the capture from another location. This suggestion is supported by the results of the final research recovery exercise which deliberately targeted areas within the cluster where the majority of the reported movements had occurred (i.e. the channel between Beaver and Taylor Reefs). Of the 13 *P. leopardus* returned from the blocks between Beaver and Taylor Reef, 100% were returned from their reef of release. If *P. leopardus* was moving from Beaver to Taylor Reef at the rate indicated by the public returns, approximately two (1.89) of the research returns from Taylor Reef should have been released at Beaver Reef, based on the proportion of movements from Beaver to Taylor Reef in the public returns. This suggests that the disparity among sources of returns is a result of misreporting of location of capture for the public returns, rather than inadequate sample size on behalf of the research returns.

At least two scenarios may explain the misreporting of capture location for fish actually caught on Beaver Reef: incidental and deliberate infringement. The channel separating Beaver and Taylor Reef is no more than 200 m wide at the closest point of each reef and both reefs are characterised by long, tapered shoals which extend for over a kilometre from the main reef complex (figure 2). This makes it difficult to determine where one reef finishes and the other begins. Consequently, incidental infringements may occur as a result of the proximity of the two reefs to each other and the public being unsure of where the exact boundary lies. Although this type of infringement is unlikely to have a major impact on the stock, it may be more effective to select isolated reefs for Marine National Park zoning to avoid confusion about the location of zoning boundaries. This scenario applies equally to individual reefs which include split zoning (e.g. Marine National Park/General Use 'B').

The results of the public returns indicate that certain fishers may deliberately and intensively fish Beaver Reef. This is likely to have a significant impact on the stock and should be of considerable concern not only to managers, but scientists wanting to use reefs zoned Marine National Park as controls for manipulative experiments examining the effects of fishing on reef fish stocks. If all the returns from source A (table 20a) from Beaver Reef were actually caught on Beaver, as suggested, and assuming the fishing effort was distributed in the same way as the research effort, approximately 844 *P. leopardus* would have been caught to obtain the 23 returns. If all the public returns of *P. leopardus* from Beaver Reef are included, this estimate increases to 1578 *P. leopardus*. This is likely to represent a significant proportion of the *P. leopardus* population on Beaver Reef. For example, Beinssen (1989a) estimated that the 136 *P. leopardus* caught in the first 14 days following the opening of Boulton Reef represented approximately 25% of the population on the reef. The estimated level of infringement at Beaver Reef is substantial and could possibly negate the positive effects of Marine National Park protection. As a consequence, in manipulative experiments investigating the effects of different levels of fishing effort on coral reefs, Marine National Parks should be considered as a low fishing pressure level rather than a control for no fishing.

Infringement does not explain the difference in the estimates of inter-reef movement between the research returns and the public returns for the other reefs, and Potter Reef in particular. Furthermore, the research returns demonstrated a significant level of movement among blocks within reefs, which may represent movement of *P. leopardus* to, or from, spawning aggregations. The majority of the inter-reef movement from Potter Reef to other reefs was from blocks 1 and 2 at the northern end of the reef, which reduces the possibility that the movements were the result of mistaken location of capture. Block 2 of Potter Reef has also been identified as a potential spawning site for *P. leopardus*. Therefore, it is not possible to exclude unequivocally the possibility that *P. leopardus* may move between reefs. It is recommended that the tagging study be continued as an integral part of the proposed manipulative experiment to: i) resolve the discrepancy in the estimates of inter-reef movement between the public and research returns, and ii) determine the effect of a known change in abundance on the patterns of movement of *P. leopardus*.