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Inter-reef Movement of the Common Coral Trout, *Plectropomus leopardus*

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SUMMARY

Movement of the Common Coral Trout, *Plectropomus leopardus*

i. Five tagging exercises have been completed over a period of 22 months from April 1992 to February 1994 on the cluster of reefs south of Innisfail (Beaver, Taylor, Farquharson, Little Potter (17 060 and 17 061) and Potter Reefs) in the Cairns Section of the Great Barrier Reef Marine Park which have been zoned for the Effects of Fishing Program Reef Experiment.

ii. A total of 4627 *P. leopardus* have been tagged and released on the five reefs with a total of 443 returns to date from the public (300) and the four tag-recovery exercises (143).

iii. Ninety-nine per cent of the research returns of *P. leopardus* were returned from their reef of release. One inter-reef movement was recorded from Taylor to Beaver Reef. The results of the research recovery exercises indicate movement of *P. leopardus* among reefs is negligible and unlikely to confound treatment effects in the proposed Effects of Line Fishing Experiment.

iv. Thirty-six per cent of the public returns were returned from reefs other than the one on which they were released. The majority of inter-reef movement from the public returns was from Beaver (Closed) to Taylor Reefs and from Potter Reef to other reefs in the cluster. On the basis of the public returns, frequency of inter-reef movement of *P. leopardus* varies significantly among reefs within the cluster and ranges from 12% at Farquharson Reef to 40% at Potter Reef.

v. It is suggested that the disparity in the extent of inter-reef movement of *P. leopardus* from Beaver Reef between the public and research returns is largely due to infringements, rather than a high level of movement from Beaver Reef. If this is the case, it is suggested that the level of fishing effort on Beaver Reef, in the form of infrequent pulse-fishing, may be enough to negate the potential effects of protection from fishing (i.e. higher abundance and protection of larger size classes of major target species). The catch per unit effort (CPUE) and length frequency data for *P. leopardus* tend to support this.

vi. Such a level of infringement on reefs zoned Marine Park 'B', which are theoretically closed to fishing, questions the validity of using these reefs as 'unfished' or 'control' treatments for large-scale manipulative experiments designed to investigate the effects of fishing, as the treatment effect size is likely to be small.

vii. Infringements do not explain the difference between estimates of inter-reef movement from research and public returns for the other reefs, and Potter Reef in particular. Furthermore, the research returns demonstrated a significant level of movement of *P. leopardus* among blocks within reefs which may represent movement of *P. leopardus* to spawning aggregations. Consequently, it is recommended that the movement study be continued as an integral part of the proposed manipulative experiment in order to: i) resolve the disparity between the estimates of inter-reef movement from the public and research returns, and ii) quantify the effect of a known change in abundance on the patterns of movement of *P. leopardus*.

Comparison of T-bar Anchor Tags and Standard Dart Tags

i. The frequency of tag loss of dart and t-bar tags differed significantly for returns from the research recovery exercises but not for the public returns, with the frequency of loss of

t-bar anchor tags being significantly lower for returns from the research exercise. This suggests that although the rate of shedding of dart tags is higher than t-bars, the dart tags are more likely to be detected and returned by the public.

ii. There was no difference in the frequency of loss of the different coloured t-bar tags used. Therefore, given the lower frequency of shedding, greater ease of application and lower cost of the t-bar anchor tags, it is recommended the t-bar anchor tags be used in future tagging programs of demersal reef fish on the Great Barrier Reef.

Catch Composition, Catch Per Unit Effort and Size Structure of Catch from Line Fishing

i. A total of 8043 fish were caught from the five reefs over five trips. Catch was dominated by Serranidae, Lutjanidae and Lethrinidae which comprised greater than 97% of the total catch. Sampling by line-fishing was found to be very selective, with six species, *P. leopardus* (57%), *Cephalopholis cyanostigma* (12%), *Lutjanus carponotatus* (6%), *Lutjanus bohar* (3%), *Lethrinus miniatus* (3%) and *Lethrinus atkinsoni* (4%) dominating the catch.

ii. Catch composition varied significantly among trips and reefs. *P. leopardus* comprised a greater proportion of the catch on the trips done during the spawning season (September 1992 and October 1993). This may be indicative of an increase in the catchability of *P. leopardus* during the spawning season and warrants further investigation.

iii. The difference among reefs was mainly due to the higher proportion of *C. cyanostigma* and *L. bohar* and the lower proportion of *L. miniatus* and *L. carponotatus* at Taylor and Potter Reefs compared to the other reefs in the cluster. Catch per unit effort of *P. leopardus* varied significantly among trips and within reefs. However, there was no significant difference in CPUE among reefs. The pattern of CPUE among trips and within reefs indicates that the increase in CPUE occurs during the spawning season and is likely to be the result of an increase in the catchability of *P. leopardus* when the fish are aggregated to spawn.

iv. It is strongly recommended that the temporal and spatial variation in catchability of *P. leopardus* by line fishing be investigated over a range of abundances of *P. leopardus*. Such information is essential for an accurate interpretation of changes in relative abundance from commercial line-fishing log book data and research surveys.

v. The average size (mean length to caudal fork) of *P. leopardus* decreased significantly over the five trips, with a monotonic reduction in average size from April 1992 to February 1994. Mean size of *P. leopardus* varied significantly among reefs and blocks (block = within reef strata, 2-2.5 km stretch of reef perimeter) also, with Taylor Reef having a significantly greater average size than the other reefs and Beaver Reef having a significantly smaller average size than all other reefs.

vi. Although the overall reduction in mean size of *P. leopardus* across all reefs is indicative of growth overfishing and cause for concern, in the absence of size-at-age information it is not possible to accurately interpret these effects in terms of differences in the population dynamics of *P. leopardus*. The significant effect of block on mean length of *P. leopardus* suggests that there may be significant differences in age-structure within reefs also. These results highlight the need for rigorous and powerful sampling programs, which include within reef strata, for monitoring changes in age-structure of target species.

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INTRODUCTION

The use of permanent spatial closures, or fisheries refugia, as a management technique for coral reef fisheries has recently received substantial attention (Russ 1991; Plan Development Team (PDT) 1990; Russ et al. 1994, DeMartini 1993). Marine refugia have often been invoked when more conventional techniques, such as effort or gear restrictions, have failed to achieve the desired management objectives, particularly in regions where the fisheries are subject to intense and unmanageable fishing pressure (e.g. Russ 1991; PDT 1990). In other cases, such as the Great Barrier Reef Marine Park, fisheries refugia have been used to separate potentially conflicting uses of the coral reef environment and its limited resources (e.g. extractive and nonextractive activities, such as fishing and SCUBA diving, respectively). The relative ease with which spatial boundaries may be defined in coral reef systems and their apparent isolation from each other, has prompted several authors to suggest that individual coral reefs may be ideal experimental units for manipulative experiments to investigate the effects of fishing on coral reef fish communities (Hilborn and Walters 1992; Walters 1986; Sainsbury 1988; Russ 1991).

A fundamental assumption underlying much of the theory of fisheries refugia is that there is limited exchange among individual spatial strata (reefs) (Hilborn and Walters 1992; Walters and Sainsbury 1990; Caddy 1993). In the light of the common perception of coral reef fish as sedentary, territorial animals, whose movements may be measured in the order of 10s to 100s of metres (Sale 1991), this assumption appears well justified. However, there is relatively little quantitative information available on the degree to which species of large reef fish commonly targeted by fisheries move within or among individual coral reefs (see appendix B of PDT 1990). A general feature of these studies is that the recapture effort is often unknown and the majority of the returns are recaptured shortly after release in close proximity to the release site. However, there are many examples of large scale movements of individual fish (10-100 km) and the existence of spawning migrations, particularly by large epinephiline groupers, has been widely documented (Manooch 1987; Johannes and Squire 1988; PDT 1990; Colin 1992).

In 1989 the Great Barrier Reef Marine Park Authority (GBRMPA) commissioned Professor Carl Walters and Dr Keith Sainsbury to develop and compare alternative experimental designs for a large scale manipulative experiment to investigate the effects of line and trawl fishing on the fish communities of the Great Barrier Reef. The design proposed by Walters and Sainsbury (1990), which incorporated line fishing treatments applied at a level of reef, assumes that the fish communities of individual reefs are independent. Walters and Sainsbury (1990) suggested that movement of adult fishes among individual reefs in excess of 25% yr^{-1} would be sufficient to confound the effects of the proposed manipulation of fishing effort. Given the equivocal nature of the present information on the extent of inter-reef movement by large reef fish, they recommended that a tagging study, designed to estimate the rate of movement of target species among individual reefs within the experimental clusters, be performed as part of a pilot study preceding the main experimental program. This report presents the results, conclusions and recommendations of such a tagging study.

The main objective of this study was to determine the extent to which large reef fish, principally the common coral trout, *Plectropomus leopardus*, move among individual reefs. This was achieved through a large scale tagging study done on five reefs south of Innisfail, in the Cairns Section of the Great Barrier Reef Marine Park, from April 1992 to February 1994. The main aims of the study were to determine:

i) what was the extent of movement among individual reefs;
ii) what proportion of the population moved among reefs;
iii) whether movement among reefs was related to the spawning season of *P. leopardus*.

Additional aims of the study included a comparison of two types of tag commonly used for reef fish on the Great Barrier Reef and the collection of catch composition, catch per unit effort and length frequency data for the dominant species in the Great Barrier Reef line fishery.

This study differed from previous studies of movement of large reef fish in two ways. Where logistically feasible, the tagging effort was spread across the entire area of each of the five reefs sampled, so that tagged fish were relatively evenly distributed through the population. Secondly, returns were obtained from the recreational and commercial fishing communities and from subsequent research tag-recovery exercises. This meant that, at least for the research returns, the recapture effort was known and, secondly, it also provided two independent data sources for estimates of rates of inter-reef movement which could be used to interpret potential biases in the tag return data.

METHODS

Study Site

The study was done on a cluster of five reefs (Beaver, Taylor, Farquharson, 17 060/17 061 (Little Potter) and Potter Reefs) adjacent to the southern boundary of the Cairns Section of the Great Barrier Reef Marine Park (figure 1). The estimated shortest distances between adjacent reefs within the cluster ranges from 200 m, between Beaver and Taylor Reefs, to 1500 m, between Farquharson and Little Potter Reefs (figure 2). These reefs have been zoned Fisheries Experimental reefs for the purposes of the Great Barrier Reef Marine Park Authority's Effects of Fishing Program following the revision of the Cairns Section Zoning Plan in 1993, with Beaver Reef closed to fishing and the other reefs open to line and spear-fishing.

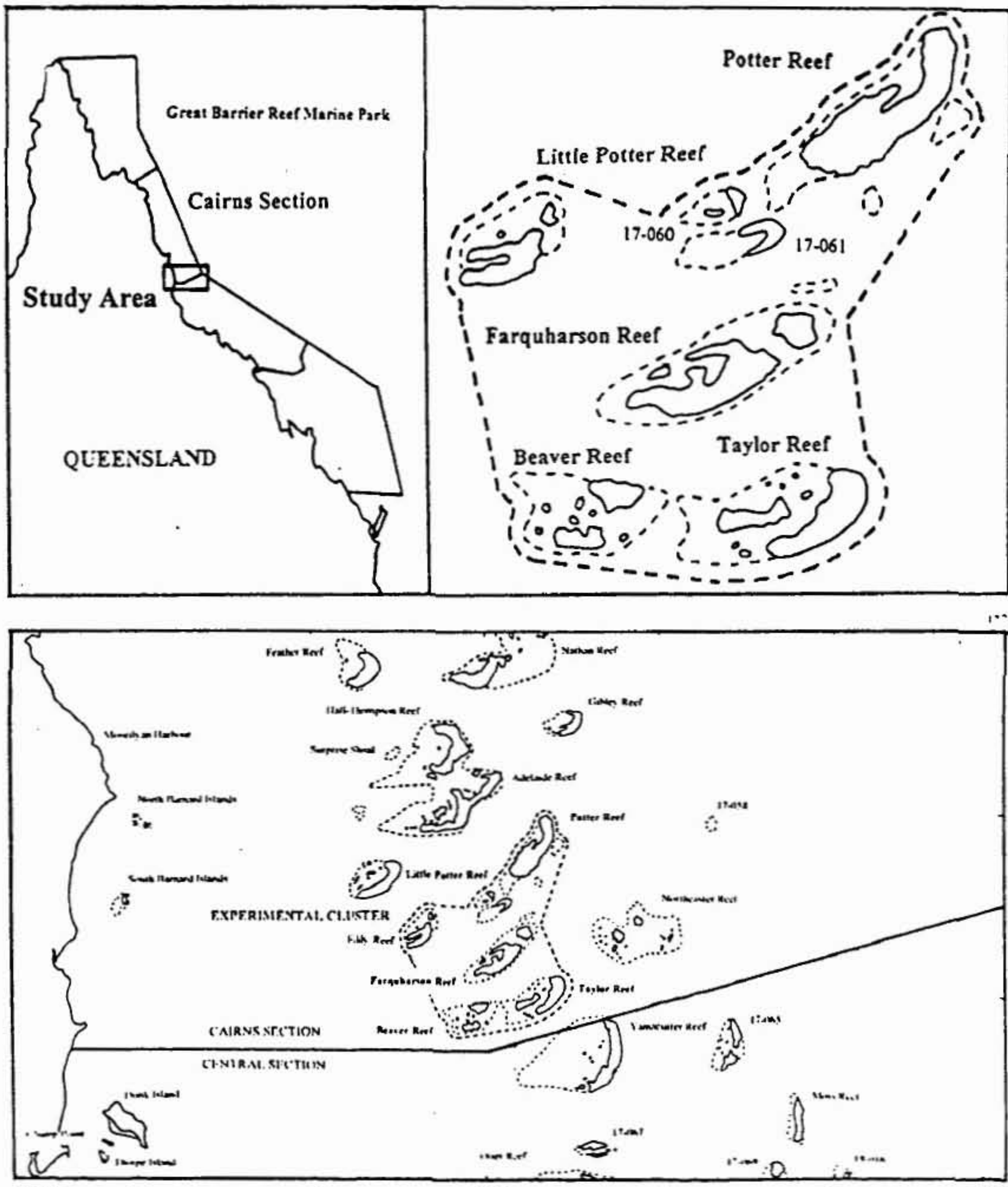

Figure 1. Location of study area and study reefs for the large-scale movement study on the Great Barrier Reef

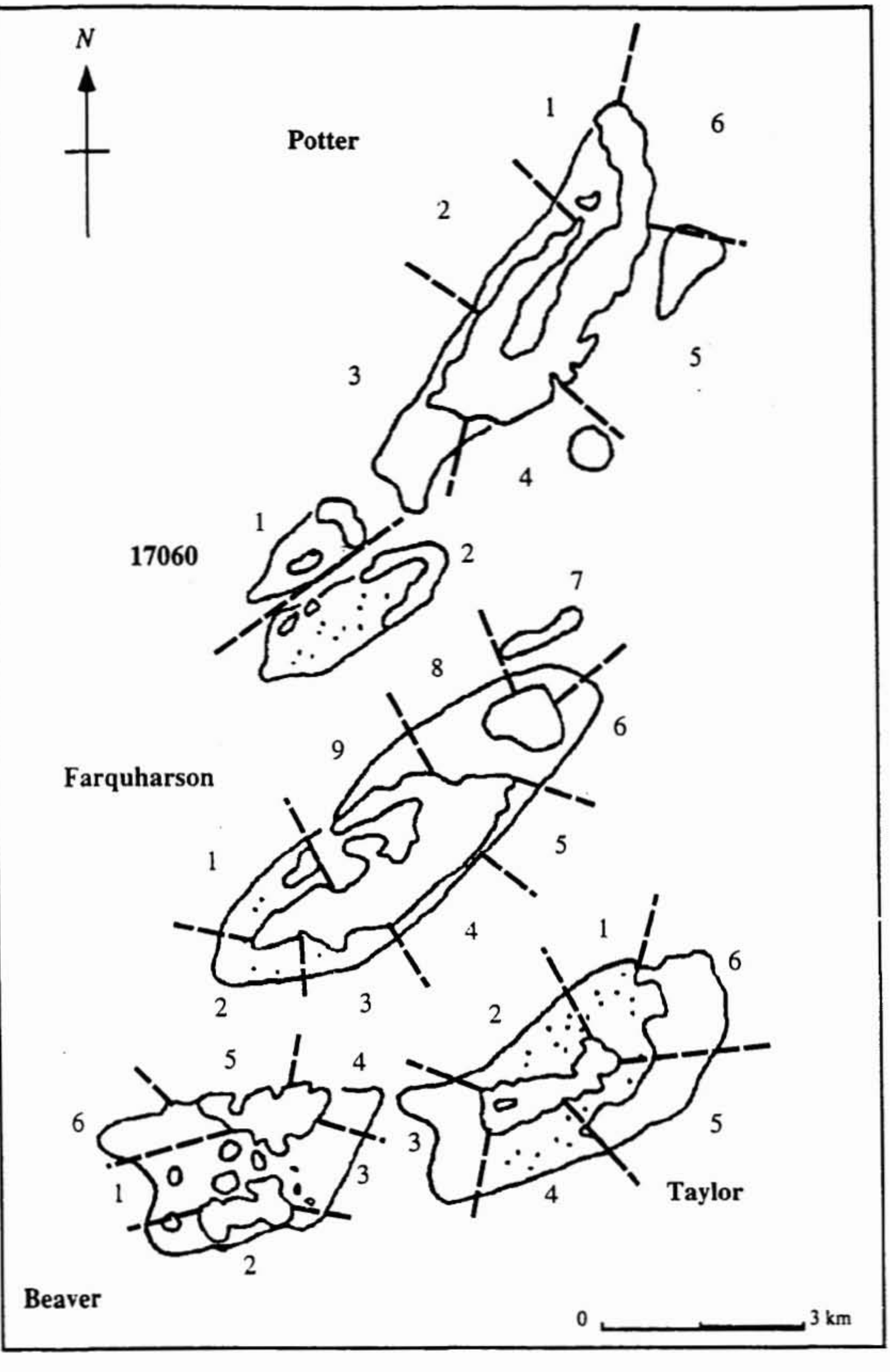

Figure 2. Location of sampling blocks within each reef of the cluster

Sampling by Line-fishing

Fish were caught by commercial line-fishers using 80 lb (36 kg) handlines rigged with a running sinker, and a single 8/0 or 9/0 hook, baited with a whole Western Australian pilchard (*Sardinops neopilchardus*). Fishing was done from 4.1 m aluminium dories, with one fisher and one tagger per dory, and from one commercial mother vessel, with two fishers and one or two taggers. For convenience, any combination of vessel, fishers and taggers will hereafter be referred to as 'dory' and the process of a dory anchoring and fishing will be defined as a 'hang'. In order to distribute the effort of each dory more evenly within defined spatial strata, minimum (10 min) and maximum (30 min) hang times were set. The location, depth and start and finish times of each hang were recorded onto prepared data sheets and maps.

Tag Type

Standard t-bar Anchor (TBA) tags and standard dart tags, both manufactured by Hallprint® (Holden Hill, SA), were used in this study. Tags were labelled with an individual number, a toll-free telephone number and the words 'RESEARCH-REWARD'. The standard TBA tags were colour-coded for each reef in the study whilst the dart tags were yellow and were used with yellow TBA tags only.

Tagging Technique

All fish were double tagged. The first tag was applied between the third and fourth dorsal spine approximately 0.5-1.0 cm below the base of the dorsal fin. The second tag was applied approximately 1 cm posterior to the commencement of the soft dorsal fin, on the same side as the anterior tag. All tags were tested to ensure that they were secure and any tag which was not secure was removed and a new tag applied. During the first four tagging exercises all species of serranid, lutjanid and lethrinid were tagged. For the final recovery exercise only *P. leopardus*, *C. cyanostigma*, *L. bohar*, *L. carponotatus*, *L. atkinsoni* and *L. miniatus* were tagged.

A minor objective of this study was to compare the effectiveness of standard TBA tags and dart tags for use on large reef fish, as the opinions of researchers on the merits of the two types of tag differ (G. MacPhearson pers. comm.; L. Squire pers. comm.; C.R. Davies, pers. observ.). Approximately one-third of the total number of *P. leopardus* and *L. miniatus* greater than 35 cm fork length were tagged with one standard TBA tag and one dart tag. The locations of the tags were the same as described above and the relative positions of the two types of tag were alternated. All other fish were tagged with two standard TBA tags.

Captured fish were dehooked by the fisher and placed in either the kill bin, a self-draining bin permanently fixed to the centre of the dory, or a plastic bin (600 x 400 x 400 mm), filled with water. Fish were taken from the bin with a piece of foam rubber and placed on a 1 m wooden measuring board where they were measured, tagged and released. The following data were recorded for each fish: species, length to caudal fork (to the nearest mm) and standardised comments on the condition of the fish at release. The entire process generally took less than 45 seconds to complete.

Sampling Protocol

The perimeter of each reef was divided into a series of blocks, approximately 2-2.5 km long, which were used to distribute the sampling effort as evenly as possible around the reef. The number of blocks varied between reefs according to the area of the reef (figure 2). The boundaries of the blocks were buoyed on the initial tagging exercise and their location mapped and recorded with Global Positioning System (GPS). Following the second tag-recovery exercise, prominent reef features were used to delineate the blocks as the process of deploying the buoys required too much time which could otherwise be used sampling.

The number of dories and total sampling effort varied between trips, however the sampling protocol was the same. Teams of 2-3 dories were assigned to a block which they fished during a session (average duration = 4 h). In order to distribute the effort evenly within blocks, dories commenced fishing at opposite ends of the blocks and fished towards each other. Two or three blocks were sampled during each session, although this varied between reefs and according to the total number of dories on each trip.

Generally the blocks within each reef were fished sequentially as this minimised travelling time and therefore maximised sampling effort. However, following the initial tagging exercise and on the advice of the commercial fishermen, the order in which blocks were fished was timed to coincide with the 'run on' side. The 'run on' side of a reef is the side where the tide is pushing up onto the reef from the deeper off-reef water. Conversely, the 'run off' side of a reef is the side where the tide is flowing off the top of the reef into the deeper reef slope water. The 'run off' side of a reef becomes the 'run on' side when the tide reverses. The fishers believe that there is a substantial difference in catch rates between the 'run on' and 'run off' tides with catch per unit effort (CPUE) being higher on the 'run on' side. Therefore, it was decided to stratify the sampling effort with respect to tide in order to maximise CPUE.

Sampling Schedule and Distribution of Effort

Five sampling trips were done over the duration of the study. The number of fishers and duration of each trip is given in table 1. The April 1992 trip was done during neap tides whilst the latter four trips were done during either new moon or full moon spring tides. In April 1992 and 1993, it was not possible to fish the exposed areas of any of the reefs, with the exception of Beaver Reef, due to prevailing sea conditions. This resulted in the total effort for each reef being distributed amongst the back reef blocks (table 2, figure 3). In September 1992 and October 1993 all blocks of all reefs were fished, except for block 5 at Beaver Reef in October 1993 (table 2). The sampling effort for the April 1993 trip was reduced by more than 1.5 days due to mechanical breakdowns to both charter and fishing vessels and, as a result, 17 060 reef was not fished and only one 4 h session was done at Farquharson Reef.

Table 1. Starting date, duration, number of dories and tidal state for each research sampling trip

Trip	Starting date	Duration (d)	No. Dories	Tide
a	1 April 1992	10	10	neap
b	23 September 1992	6	8	spring
c	16 April 1993	6	8	spring
d	22 October 1993	6	6	spring
e	9 February 1994	6	6	spring

The distribution of the sampling effort for the February 1994 trip differed from the previous trips. Rather than distributing the total effort evenly between the five reefs, the effort was concentrated in those areas where there was the greatest difference between the level of movement indicated by the public and research returns.

Table 2. Distribution of sampling effort (line hours) among blocks within reefs by trip. B=back reef block, F=front reef block. Block numbers correspond to those in figure 2.

Reef	Block	Trip					Total
		a	b	c	d	e	
Beaver	1B	12.02	4.88	15.57	1.73	9.90	44.10
	2F	9.28	7.12	2.57	4.48	3.22	26.67
	3F	17.45	5.95	8.98	6.87	11.23	50.48
	4B	16.65	5.73	2.98	5.03	14.57	44.97
	5B	8.73	6.32	2.97	-	-	18.02
	6B	14.53	5.42	18.75	7.22	5.43	51.35
	Total	**78.66**	**35.42**	**51.82**	**25.33**	**44.35**	**235.58**
Taylor	1B	12.73	7.15	13.25	7.38	4.68	45.20
	2B	21.33	6.93	11.33	6.30	2.97	48.86
	3B	19.40	8.75	5.92	2.67	18.03	54.77
	4F	-	6.77	-	7.03	9.67	23.47
	5F	-	3.47	-	2.50	-	5.97
	6F	-	4.93	-	3.80	-	8.73
	Total	**53.47**	**38.00**	**30.50**	**29.68**	**35.35**	**187.00**
Farquharson	1B	28.70	5.93	-	5.12	5.05	44.80
	2B	-	8.22	4.88	5.67	5.43	50.67
	3B	-	5.48	-	3.00	-	29.33
	4F	-	0.83	-	2.70	-	3.53
	5F	-	2.18	-	4.10	-	6.28
	6F	-	1.50	-	3.30	-	4.80
	7F	-	12.55	-	3.28	-	15.83
	8B	26.47	6.98	-	6.87	0.95	14.80
	9B	20.85	3.80	2.53	9.45	5.73	21.52
	Total	**76.02**	**47.48**	**7.42**	**43.48**	**17.17**	**191.57**
Little Potter	1	25.78	11.43	0.00	14.65	19.45	71.32
	2	0.00	13.63	0.00	11.35	9.00	33.98
	Total	**25.78**	**25.07**	**0.00**	**26.00**	**28.40**	**105.25**
Potter	1B	15.28	9.77	8.47	4.20	-	37.72
	2B	34.55	11.52	10.95	7.00	7.82	71.83
	3B	21.12	12.27	8.53	8.22	14.75	64.88
	4F	-	2.83	-	8.85	7.15	18.83
	5F	-	8.95	-	3.83	-	12.78
	6F	-	4.08	-	3.05	-	7.13
	Total	**70.95**	**49.42**	**27.95**	**35.15**	**29.72**	**213.18**
Cluster		**304.88**	**195.38**	**117.68**	**159.65**	**154.98**	**932.58**

Analysis

Catch Composition

The effects of trip, reef and species on catch composition were tested with a three dimensional contingency table (Zar 1984), where rows were species (*P. leopardus, Cephalopholis cyanostigma, Lutjanus bohar, L. carponotatus, Lethrinus atkinsoni, L. miniatus* and others), columns reefs (Beaver, Farquharson, Little Potter, Potter and Taylor Reefs) and tiers trips (April 1992 = a, September 1992 = b, April 1993 = c, October 1993 = d and February 1994 = e). Correspondence analyses of species by trip and species by reef were used to illustrate the significant effects from the contingency table analysis.

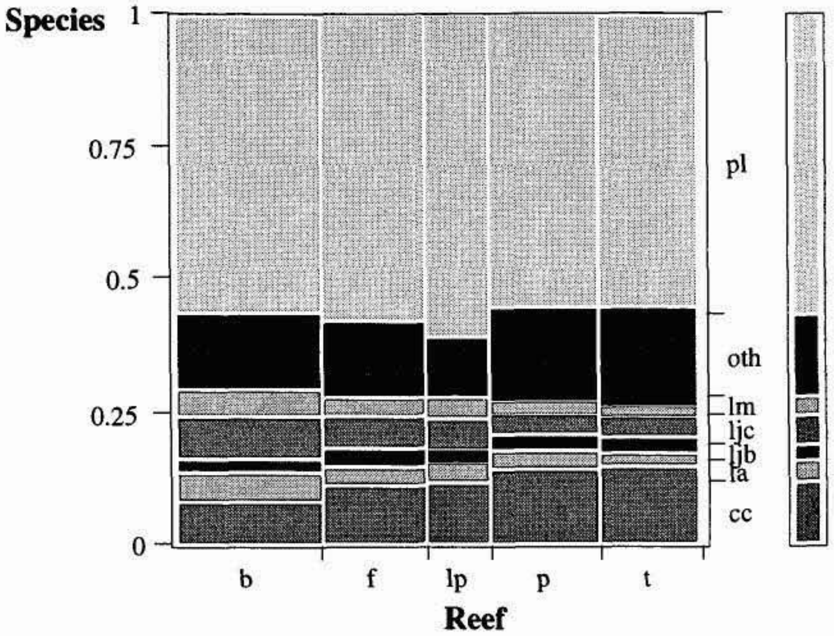

Figure 3. Mosaic plot of species composition of catch by reef. The species are *Cephalopholis cyanostigma* (cc), *Plectropomus leopardus* (pl), *Lutjanus bohar* (ljb), *L. carponotatus* (ljc), *Lethrinus atkinsoni* (la), *L. miniatus* (lm) and others (oth). Trips are April 1992 (a), September 1992 (b), April 1993 (c), October 1993 (d) and February 1994 (e).

Catch Per Unit Effort

Catch per unit effort (CPUE) data were analysed using a hang by a dory as a replicate, with effort units of line hours (line h^{-1}). This measure of effort includes the time between setting and hauling of the anchor only. It provides the best standardised unit of effort as it does not include travelling or search time, which tend to vary among fishermen and reefs and over trips. Patterns in CPUE of *P. leopardus* among trips, reefs and blocks are presented as mean CPUE with standard errors.

The effects of trip, reef and block on mean CPUE of *P. leopardus* were tested with a three-way mixed model analysis of variance (ANOVA), with trip and reef as crossed, fixed factors and block, as a random factor, nested within reef. Block includes the confounded effect of dory, as all dories did not fish all blocks on all trips. However, as there was considerable turnover of fishers during the course of the study and fishers were not systematically allocated to blocks, a consistent bias due to combinations of blocks and dories is considered unlikely.

Size Structure

Size structure data are presented as length frequency histograms by trip by reef for *P. leopardus* only. The effects of trip, reef and block on mean length of *P. leopardus* were tested with a three-way mixed model ANOVA, with trip and reef as crossed, fixed factors and block, a random factor, nested within reef.

Due to the unbalanced number of blocks fished on each reef for each trip, only the following data were used in the ANOVAs of CPUE and length of *P. leopardus*: TRIPS: a, b, d, e (trip c was omitted as the distribution of effort was severely restricted and cannot be considered representative); REEFS: all reefs were included; BLOCKS: only back reef blocks (figure 2). These omissions resulted in a more balanced data set for the analyses. All data were tested for normality (D'Agostino 1971a, b in Zar 1984) and homoscedasticity (Bartlett 1937 in Zar 1984) prior to performing the analysis and transformed accordingly ($x' = \log_{10}(x + 1)$). Where transformation failed to significantly improve the distribution of the data, analyses were performed on the untransformed data.

Tag Loss and Tag Comparison

Rates of tag loss were estimated using the regression models described by Wetherall (1982) which generalise the earlier models of Chapman et al. (1965), Bayliff and Morbran (1972) and Kirkwood (1981). Diagnostic plots of $\ln K_i$ by t_i, were used to identify whether it was most appropriate to fit a linear or nonlinear model, where the probability of tag i being retained is given by

$$K_i = 2r_{di} / r_{si} + 2r_{di}$$

where, r_{di} is the number of returns retaining two tags, r_{si} is the number of returns retaining a single tag, and t_i is the mid-point of the i^{th} period since release in the case where the two tags are identical and assumed to have the same probability of being shed. In the case of the comparison of the dart tags and the TBA tags, alternative estimators were used for the two tag types:

$$K_{Ai} = r_{di} / r_{Bi} + r_{di}$$

and,

$$K_{Bi} = r_{di} / r_{Ai} + r_{di}$$

where K_{Ai} is the estimated probability that a TBA tag is retained, K_{Bi} is the estimated probability that a dart tag is retained, r_{di} is the number of returns retaining both tags, r_{Ai} is the number of returns retaining only the TBA tag and r_{Bi} is the number of returns retaining only the dart tag.

In all cases the 2 parameter Bayliff-Morbran model

$$\ln K_i = \ln p - Lt_i$$

(where, $\ln p$ is Type I tag loss, L is the instantaneous constant rate of tag shedding (Type II tag loss) and it is the mid-point of the i^{th} period since release) was fitted using a weighted linear regression, with the r_i (number of returns per t_i) used as the weighting factor. The model assumes that instantaneous tag shedding is constant with time, that fishing mortality is constant within t_i and returns are evenly distributed within t_i.

Research and public returns were analysed separately and regression parameter estimates compared with ANCOVA techniques (Zar 1984). Where there was no significant difference between regressions, the tag loss parameter estimates were obtained from a common regression computed from the pooled research and public return data.

Two-way contingency tables (Zar 1984) were used to test for the effect of tag type (standard dart tags and standard TBA tags), tag colour (yellow, green, orange, pink, white, blue) (TBA tags only), and source of returns (public and research).

Movement

The return data were separated into two categories: i) those recaptured during the research tag-recovery exercises (research) and; ii) those returned by commercial and recreational fishers (public). This provides an indication of the reliability of the public returns. The more detailed data on location of recapture available from the research returns means that movements among blocks within reefs may also be examined. Research returns were standardised by recapture effort for comparison of rate of return among reefs. Both research and public returns were standardised by releases for comparison of per cent returns among trips, reef and sources of returns. Movement is expressed as the percentage of the total number of returns from a reef other than the one on which fish were released. Within trip returns have been excluded from all estimates of movement. The effect of reef on frequency of inter-block movement, from research returns, by *P. leopardus* was tested using a 2-way contingency table.

Analysis of variance and multiple comparisons were performed with SAS for windows (SAS 1987). All other analyses were done with JMP 2.0 for MacIntosh (SAS 1989).

RESULTS

Catch Composition

A total of 8043 fish were caught over the five trips. Catch was dominated by three families; Serranidae, Lutjanidae and Lethrinidae, which accounted for more than 97% of the total catch. Six species, *P. leopardus* (57%), *C. cyanostigma* (12%), *L. bohar* (3%), *L. carponotatus* (6%), *L. atkinsoni* (4%) and *L. miniatus* (3%) dominated the catch (85% of total catch) (table 3). Other common but less abundant species included *Epinephelus merra, Epinephelus quoyanus, Epinephelus fuscoguttatus, Plectropomus laevis, Lutjanus sebae, Lutjanus russelli, Lutjanus vitta, Symphorus nemataphorus, Lethrinus semicinctus* and *Lethrinus* sp. 2.

The general pattern of catch composition among reefs and trips was similar, with *P. leopardus* dominant on all reefs, followed by *C. cyanostigma, L. carponotatus* and *L. atkinsoni* (tables 3 and 4). The rank of *L. bohar* and *L. miniatus* alternated between five and six among reefs (tables 3 and 4). However, despite this general pattern, there was significant effect of reef on the frequency of occurrence of each species in the total catch also ($\text{Chi-sq}_{0.05, 24} = 216.328$, $p = 0.0000$, figure 3). Correspondence analysis suggested this was the result of *C. cyanostigma*, and to a lesser extent *L. bohar*, comprising a greater percentage of the catch at Potter and Taylor Reefs while *L. carponotatus* and *L. atkinsoni* were proportionally more abundant at Beaver Reef (figure 4).

There was a significant effect of trip on species composition ($\text{Chi-sq}_{0.05, 24} = 248.45$, $p = 0.0000$, figure 5). Correspondence analysis suggested that this was caused by an increased frequency of occurrence of *P. leopardus* in the catch in September 1992 and October 1993, while there were proportionally more *C. cyanostigma, L. carponotatus* and *L. atkinsoni* during April 1992, 1993 and February 1994 (figure 6).

Table 3. Response profiles of dominant taxa by trip from contingency table analysis: April 1992 (a), September 1992 (b), April 1993 (c), October 1993 (d) and February 1994 (e)

Species	Trip					
	a	b	c	d	e	All
Cephelopholis cyanostigma	0.1332	0.0735	0.1548	0.0942	0.1498	0.1181
Plectropomus leopardus	0.5407	0.6300	0.5423	0.6140	0.5009	0.5671
Lutjanus bohar	0.0273	0.0359	0.0278	0.0235	0.0303	0.0291
L. carponotatus	0.0560	0.0405	0.0624	0.0638	0.0749	0.0587
Lethrinus atkinsoni	0.0426	0.0393	0.0290	0.0211	0.0681	0.0412
L. miniatus	0.0389	0.0479	0.0323	0.0347	0.0062	0.0327
Others	0.1614	0.1328	0.1514	0.1487	0.1697	0.1532
Total sample size	2162	1754	898	1614	1615	8043

Table 4. Response profiles of catch composition by reef from contingency table analysis: Beaver (b), Farquharson (f), Little Potter (lp), Potter (p) and Taylor (t)

Species	Reef					
	b	f	lp	p	t	All
Cephelopholis cyanostigma	0.0823	0.1133	0.1203	0.1419	0.1489	0.1181
Plectropomus leopardus	0.5642	0.5762	0.6086	0.5529	0.5506	0.5671
Lutjanus bohar	0.0239	0.0392	0.0204	0.0309	0.0298	0.0291
L. carponotatus	0.0827	0.0597	0.0612	0.0392	0.0417	0.0587
Lethrinus atkinsoni	0.0584	0.0342	0.0387	0.0392	0.0265	0.0412
L. miniatus	0.0496	0.0355	0.0418	0.0196	0.0132	0.0327
Others	0.1389	0.1419	0.1091	0.1764	0.1893	0.1532
Total sample size	2260	1607	981	1684	1511	8043

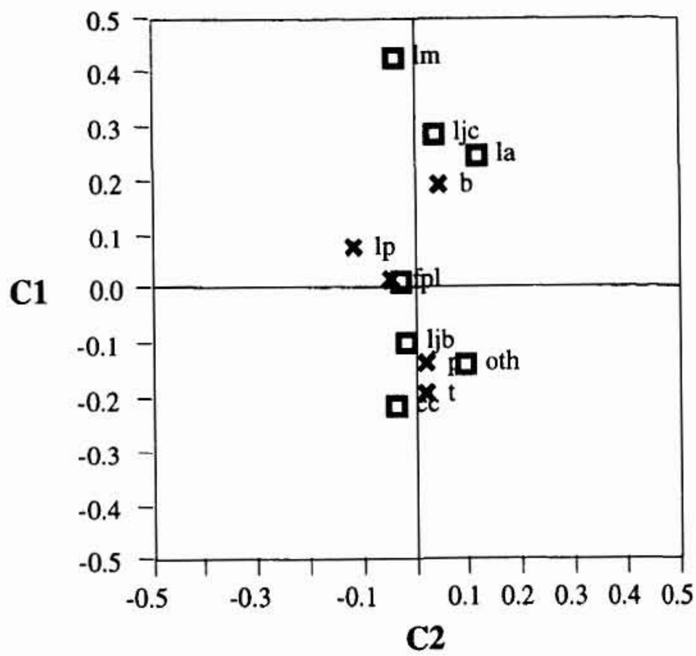

Figure 4. Correspondence analysis of species composition of catch by reef. The first two axes accounted for 90.2% of the total inertia, C1 (75.8%) and C2 (14.4%). The species are *Cephalopholis cyanostigma* (cc), *Plectropomus leopardus* (pl), *Lutjanus bohar* (ljb), *L. carponotatus* (ljc), *Lethrinus atkinsoni* (la), *L. miniatus* (lm), and others (oth). Reefs are Beaver (b), Taylor (t), Farquharson (f), Little Potter (lp), and Potter (p) Reefs.

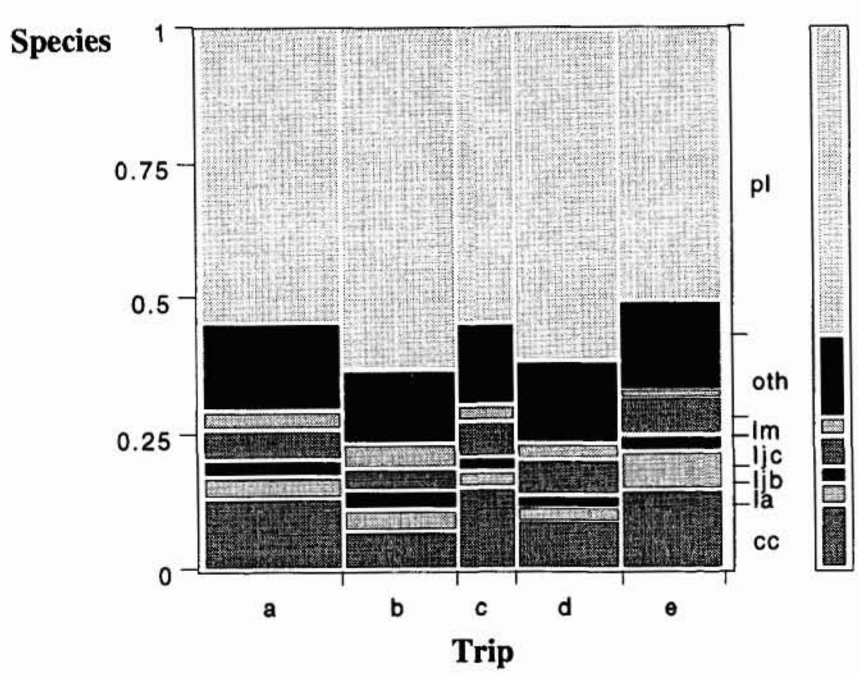

Figure 5. Mosaic plot of species composition of catch by trip. The species are *Cephalopholis cyanostigma* (cc), *Plectropomus leopardus* (pl), *Lutjanus bohar* (ljb), *L. carponotatus* (ljc), *Lethrinus atkinsoni* (la), *L. miniatus* (lm), and others (oth). Trips are April 1992 (a), September 1992 (b), April 1993 (c), October 1993 (d) and February 1994 (e).

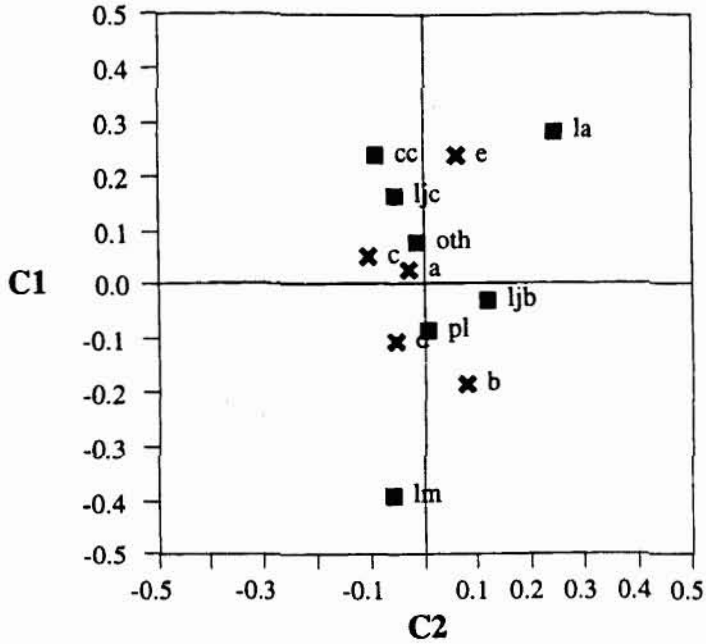

Figure 6. Correspondence analysis of species composition of catch by trip. The first two axes accounted for 90.2% of the total inertia, C1 (75.8%) and C2 (14.4%). The species are *Cephalopholis cyanostigma* (cc), *Plectropomus leopardus* (pl), *Lutjanus bohar* (ljb), *L. carponotatus* (ljc), *Lethrinus atkinsoni* (la), *L. miniatus* (lm), and others (oth). Trips are April 1992 (a), September 1992 (b), April 1993 (c), October 1993 (d) and February 1994 (e)

Catch Per Unit Effort

Effect of TRIP

Trip had a significant effect on the CPUE of *P. leopardus* ($F_{0.05,3,8} = 27.94$; $p = 0.0001$, table 5). Mean CPUE for *P. leopardus* was significantly higher in September 1992, October 1993 and February 1994 than in April 1992 (Tukey's HSD test $p < 0.05$). The highest mean CPUE for *P. leopardus* occurred in September 1992 and October 1993, which correspond to the peak in the *P. leopardus* spawning season, and the lowest during April 1992, February 1994 and, to a lesser extent, April 1993 (which was not included in the ANOVA) (figure 7).

Table 5. ANOVA table for 3-way mixed model ANOVA for effect of trip, reef and block on mean CPUE of *Plectropomus leopardus*. Includes data from back reef blocks of Beaver, Taylor, Farquharson and Potter Reefs and trips a, b, d, e only (see text, page 11). α= 0.05, data were $\log_{10}(x+1)$ transformed.

Source	DF	Type III SS	MS	F ratio	Pr>F	Sign.	% var
Corrected total	1470	1614.86					
TRIP	3	136.00	45.33	27.94	0.0001	***	8.42
REEF	3	0.95	0.31	0.13	0.9412		0.05
BLOCK(REEF)	8	19.78	2.47	2.53	0.0097	***	1.22
TRIP*REEF	9	10.95	1.22	0.75	0.6615		0.68
TRIP*BLOCK(REEF)	23	37.31	1.62	1.66	0.0253	*	2.30
Residual	1424	1388.94	0.98				85.98

Effect of REEF

Mean CPUE for *P. leopardus* did not vary significantly among reefs ($F_{0.05,3,8} = 0.13$; $p = 0.9412$, table 5). Although CPUE for *P. leopardus* was generally higher on Beaver Reef, it was not significantly different from the other reefs. Catch per unit effort for *P. leopardus* was consistently higher on Beaver, Farquharson and Little Potter (which was not included in the ANOVA) Reefs and lowest on Taylor and Potter Reefs (figure 7).

Effect of BLOCK

There was a significant effect of block on mean CPUE for *P. leopardus* ($F_{0.05,8,1424} = 2.53$; $p = 0.0097$, table 5) and a significant interaction between trip and block ($F_{0.05,23,1424} = 1.66$; $p = 0.0253$, table 5). It is apparent from figure 8, that the effect of block is likely to be the result of CPUE at block 1 of Beaver Reef being consistently higher than CPUE at block 4 and that the trip*block interaction is likely to be due to the very high CPUE recorded for Taylor Reef during trip d (figure 8).

Both CPUE and total catch of *P. leopardus* was generally higher in the back reef blocks of all reefs with the exception of Beaver Reef (figure 9, appendix 1a). This is most likely due to differences in the efficiency of the fishers (or gear) between the two reef locations rather than a real difference in the relative abundance of *P. leopardus*. The fishers tend to have greater difficulty finding and correctly anchoring on suitable hangs on the steep reef front slopes of Potter, Farquharson and Taylor Reefs and, as a result spend more time searching, do fewer hangs and have a higher percentage of zero catch hangs. The fact that CPUE and total catch of *P. leopardus* increased during trip d suggests that fishers may have learned to fish the reef fronts more effectively than on trip b (figure 9, table 11, appendix 1a).

Size Structure

Effect of TRIP

The mean length of *P. leopardus* decreased significantly over the 22 months of the study ($F_{0.05,3,8} = 5.17$; $p = 0.0070$, table 6). Although mean length of *P. leopardus* was not significantly different between April and September 1992, it decreased significantly from September 1992 to October 1993 and again from October 1993 to February 1994 (Tukey's HSD test, $p < 0.05$) (figure 10). This last decrease was most evident at Farquharson and Taylor Reefs (figure 10).

Effect of REEF

Mean length of *P. leopardus* varied significantly among reefs ($F_{0.05,3,8} = 5.44$; $p = 0.0247$, table 6). It was significantly greater on Taylor Reef than all other reefs (Tukey's HSD test $p < 0.05$) (figure 10). Farquharson and Potter Reefs had significantly larger mean length than Beaver Reef (Tukey's HSD test $p < 0.05$), but were not different from each other (Tukey's HSD test $p > 0.05$, figure 10). Mean length of *P. leopardus* at Beaver Reef was significantly lower than all other reefs (Tukey's HSD test $p < 0.05$, figure 10). Although not included in the ANOVA, the pattern in mean length at Little Potter Reef was similar to Beaver Reef, with mean length decreasing monotonically over trips (figure 10).

Effect of BLOCK

Mean length of *P. leopardus* varied significantly among blocks within reefs ($F_{0.05,8,2230} = 0.0041$; $p = 0.0041$, table 6) and there was a significant interaction between trip and block also ($F_{0.05,25,2230} = 1.62$; $p = 0.0311$). There was no clear pattern of mean length among blocks (figures 11 and 12).

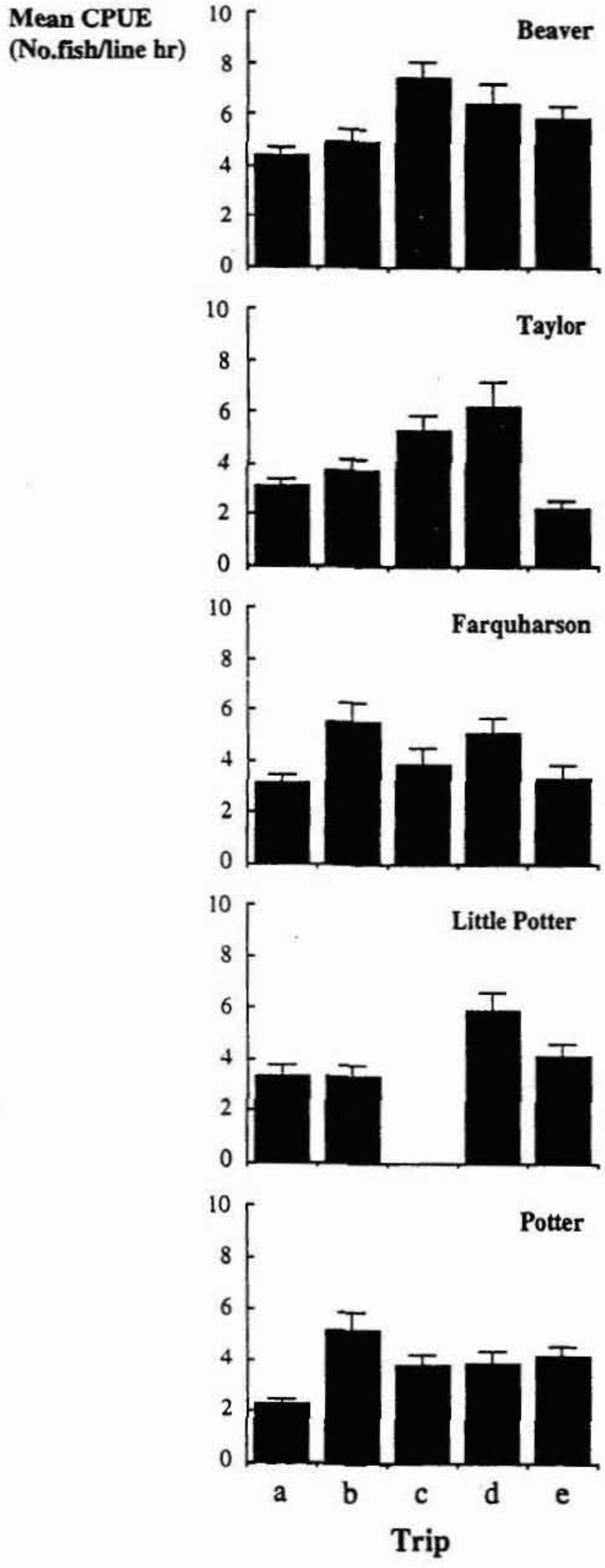

Figure 7. Mean CPUE (No. fish/line. hr) for *Plectropomus leopardus* by reef and trip. Trips are April 1992 (a), September 1992 (b), April 1993 (c), October 1993 (d) and February 1994 (e). Data from April 1993 (c) were not included in ANOVA for CPUE (see text, page 11). Data are untransformed. Error bars are standard errors.

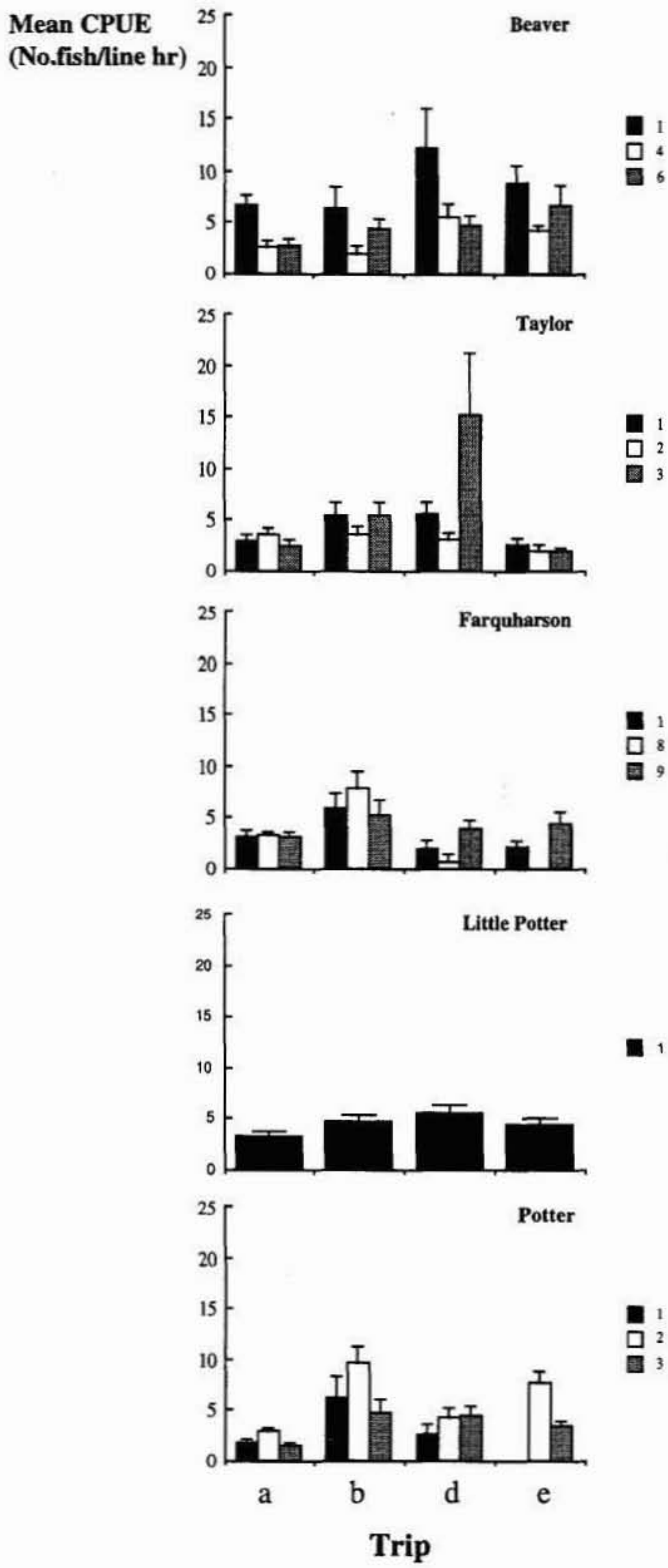

Figure 8. Mean CPUE (No. fish/line hr) for *Plectropomus leopardus* by block by reef by trip for back reef blocks only. Legend refers to block number in figure 2. Trips are April 1992 (a), September 1992 (b), October 1993 (d) and February 1994 (e). Data from April 1993 (c) were not included in ANOVA for CPUE (see text, page 11). Data are untransformed. Error bars are standard errors.

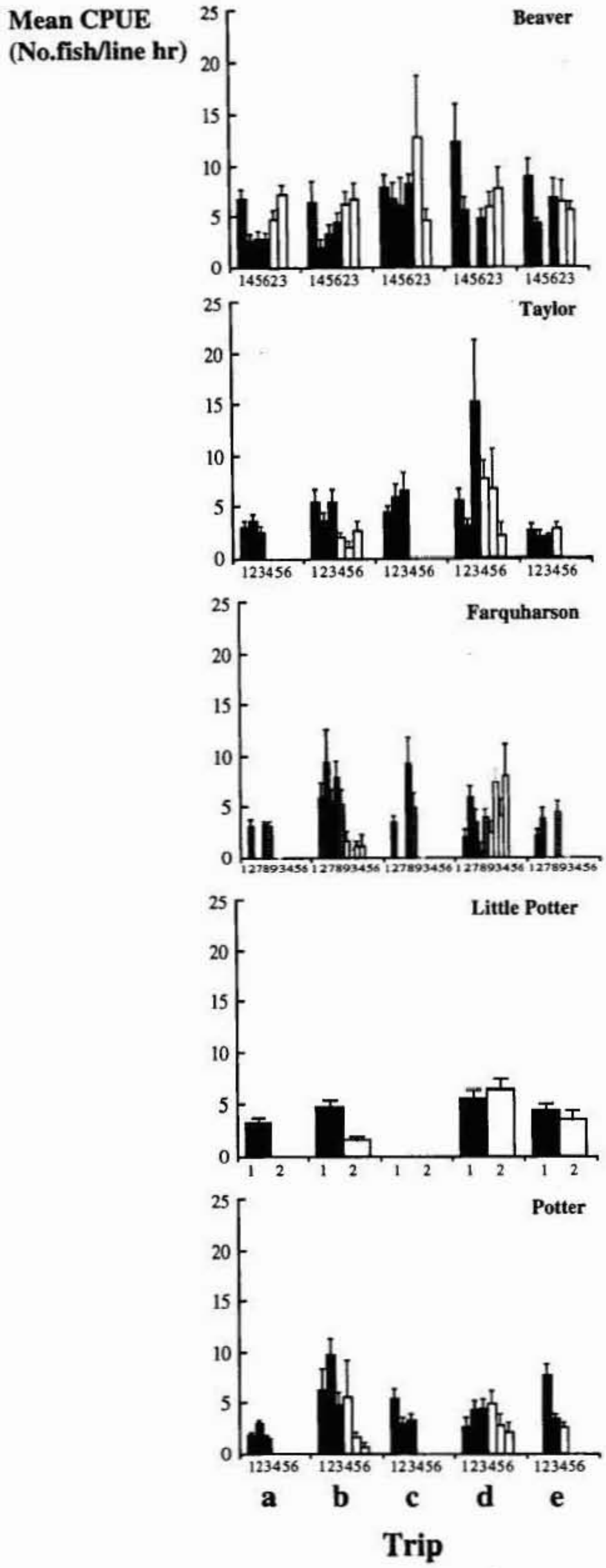

Figure 9. Mean CPUE (No. fish/line hr) for *Plectropomus leopardus* by block by reef by trip for all blocks. Filled columns are back reef blocks. Open columns are front reef blocks. Numbers under columns correspond to the number of each block. Trips are April 1992 (a), September 1992 (b), April 1993 (c), October 1993 (d) and February 1994 (e). Data from the front reef blocks and April 1993 (c) were not included in ANOVA for CPUE (see text, page 11). Data are untransformed. Error bars are standard errors.

Table 6. ANOVA table for 3-way mixed model ANOVA for effect of trip, reef and block on the mean length to caudal fork of *Plectropomus leopardus*. Includes data from back reef blocks of Beaver, Taylor, Farquharson and Potter Reefs and trips a, b, d, e only (see text, page 11). Data were untransformed, $\alpha = 0.05$

Source	DF	Type III SS	MS	F ratio	Pr>F	Sign.	% var
Corrected total	2276	11180341.25					
TRIP	3	114682.82	38227.61	5.17	0.0070	**	1.03
REEF	3	209492.92	69830.97	5.44	0.0247	*	1.87
BLOCK(REEF)	8	102720.73	12840.09	2.82	0.0041	**	0.92
TRIP*REEF	9	98975.55	10997.28	1.49	0.2108	ns	0.09
TRIP*BLOCK(REEF)	23	169938.27	7388.62	1.62	0.0311	*	1.90
Residual	2230	10155975.26	4554.25				90.84

Length Frequency Distribution of **Plectropomus leopardus**

It is evident that the lower mean length at Beaver Reef is the result of a high proportion of small (325 mm and 375 mm size classes) *P. leopardus*, which have recently been recruited to the line fishery, and relatively few large individuals (575 mm or larger) (figure 13). In contrast, Taylor Reef has a higher proportion of large *P. leopardus* (with the largest individuals caught coming from Taylor Reef) and fewer individuals in the smaller size classes relative to Beaver Reef (figure 13). As a result the modal size class at Beaver Reef (375 mm for all trips) is generally smaller than for Taylor Reef, which alternates between the 375 mm and 425 mm size classes (figure 13).

At Farquharson Reef, it is apparent that the dramatic reduction in mean length between trip d and trip e was due to a substantial reduction in the proportion of medium (475-525 mm) and large (greater than 575 mm) size classes, with the modal size class being 325 mm (figure 14). This pattern is not evident at Little Potter or Potter Reefs to the same extent, with a modal size class of 375 mm at Little Potter Reef and 375 or 425 mm at Potter Reef (figures 14 and 15).

Tag Loss

Rate of Tag Loss of t-bar Anchor Tags

A summary of the tag loss data for TBA tags from the public and research returns is presented in table 7. There was no significant difference in the rate of instantaneous tag loss of TBA tags between the research and public returns ($t_{0.05(2),8} = -1.105$: $p > 0.5$) (table 8). Therefore, a common regression was computed from the pooled research and public returns of TBA tags (figure 16). Both the intercept and slope were significantly different from zero (table 8), indicating both Type I and Type II tag loss contributed significantly to the tag shedding process. The estimate of the proportion of tags remaining following type I tag loss, ***p***, for the TBA tags was 0.8927 (95%C.I. = 0.8140;0.9791), while ***L***, the instantaneous rate of tag shedding was 0.0010 (±95%C.I. = 0.0005). The estimated proportion of TBA tags lost in the first year following release was 38%.

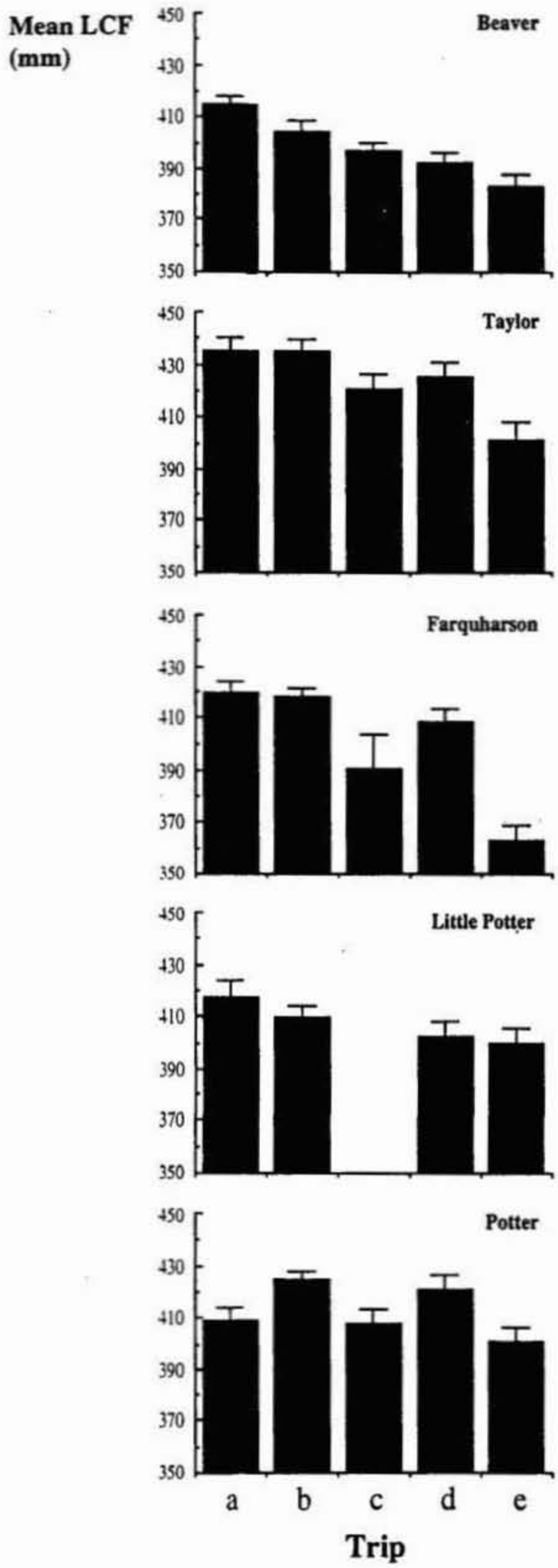

Figure 10. Mean length to caudal fork (mm) for *Plectropomus leopardus* by reef and trip. Trips are April 1992 (a), September 1992 (b), April 1993 (c), October 1993 (d) and February 1994 (e). Data from April 1993 (c) were not included in ANOVA for mean size (see text, page 11). Data are untransformed. Error bars are standard errors.

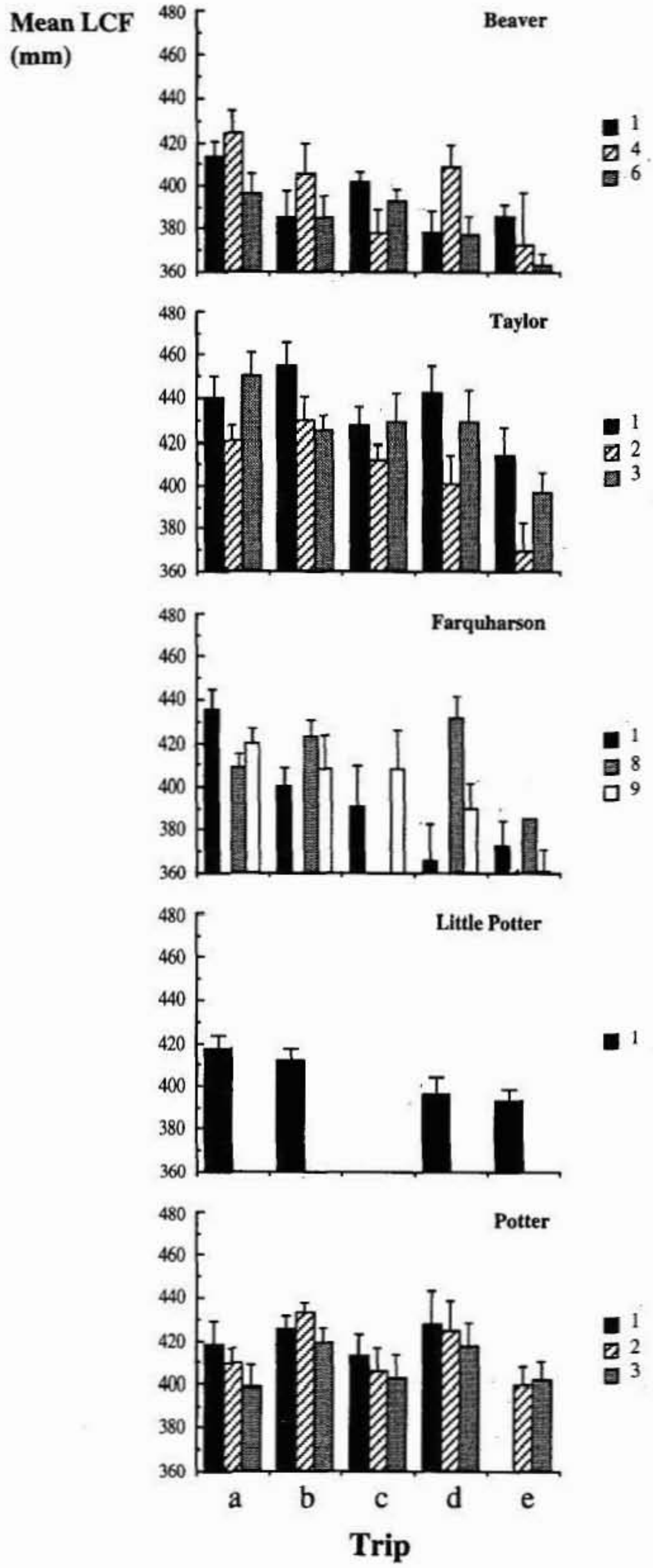

Figure 11. Mean length to caudal fork (mm) for *Plectropomus leopardus* by block by reef and trip. Legend refers to block numbers in figure 2. Only those blocks used in the ANOVA of mean length are presented (see text). Trips are April 1992 (a), September 1992 (b), April 1993 (c), October 1993 (d) and February 1994 (e). Data from April 1993 (c) were not included in the ANOVA for mean length (see text, page 11). Data are untransformed. Error bars are standard errors.

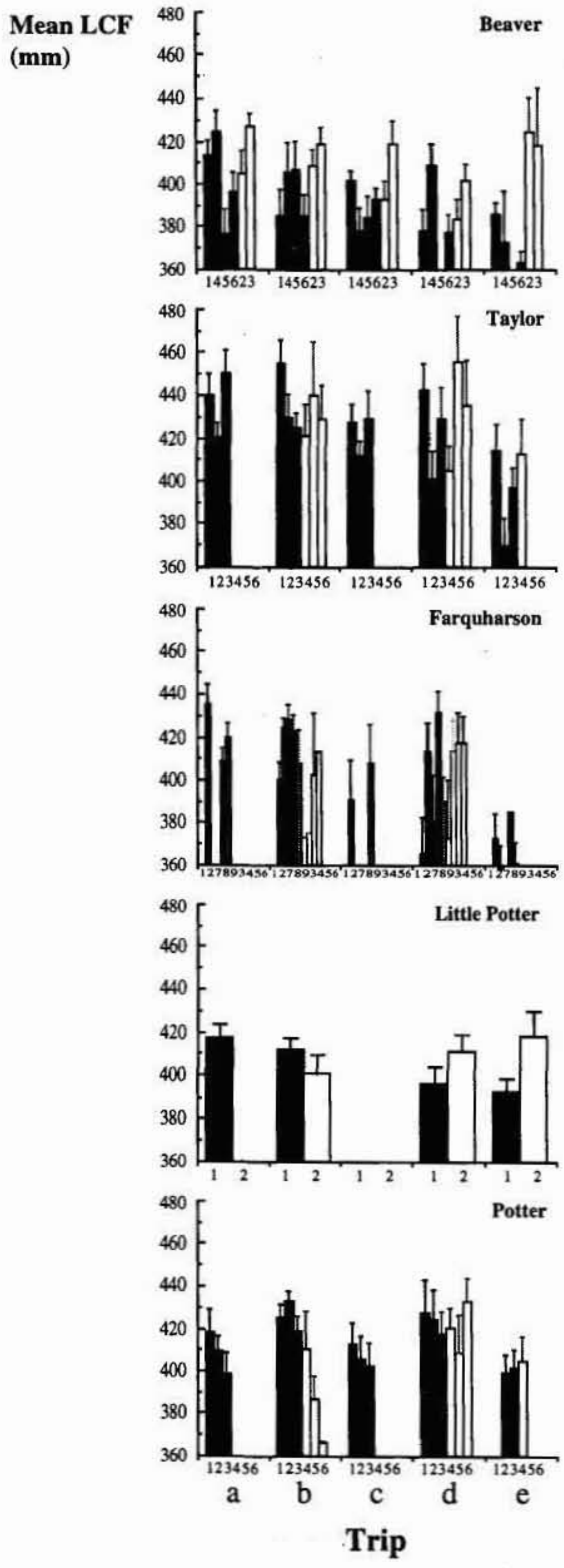

Figure 12. Mean length to caudal fork (mm) for *Plectropomus leopardus* by block by reef and trip. Filled columns are back reef blocks. Open columns are front reef blocks. Numbers under columns correspond to the number of each block. Trips are April 1992 (a), September 1992 (b), April 1993 (c), October 1993 (d) and February 1994 (e). Data from April 1993 (c) were not included in the ANOVA for mean length (see text, page 11). Data are untransformed. Error bars are standard errors.

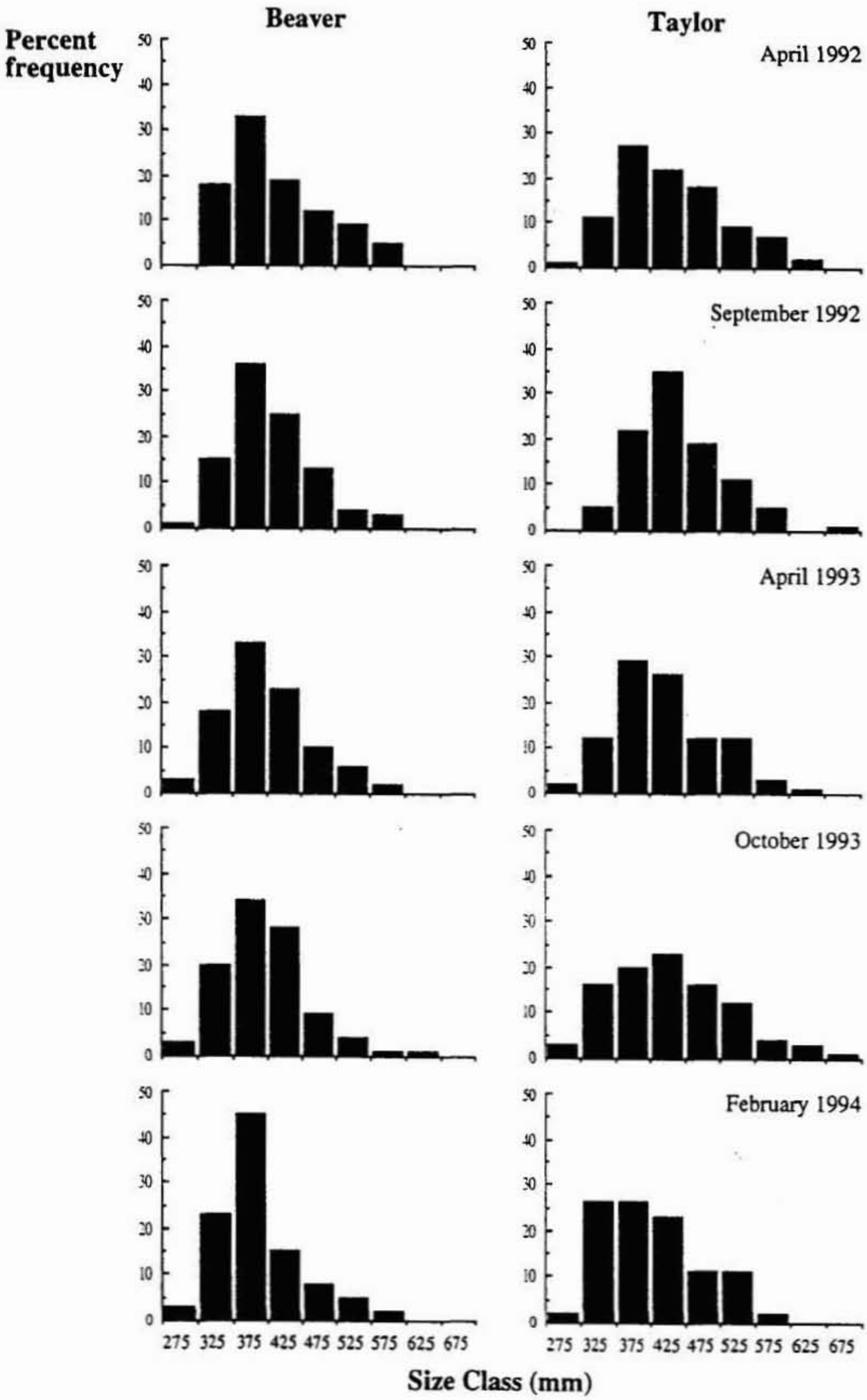

Figure 13. Length (LCF) frequency distributions for *Plectropomus leopardus* at Beaver and Taylor Reefs by trip (all blocks). Size classes are 50 mm. The mid-point of each size class is given. Trips are April 1992 (a), September 1992 (b), April 1993 (c), October 1993 (d) and February 1994 (e). Data from April 1993 (c) were not included in ANOVA for mean length (see text, page 11).

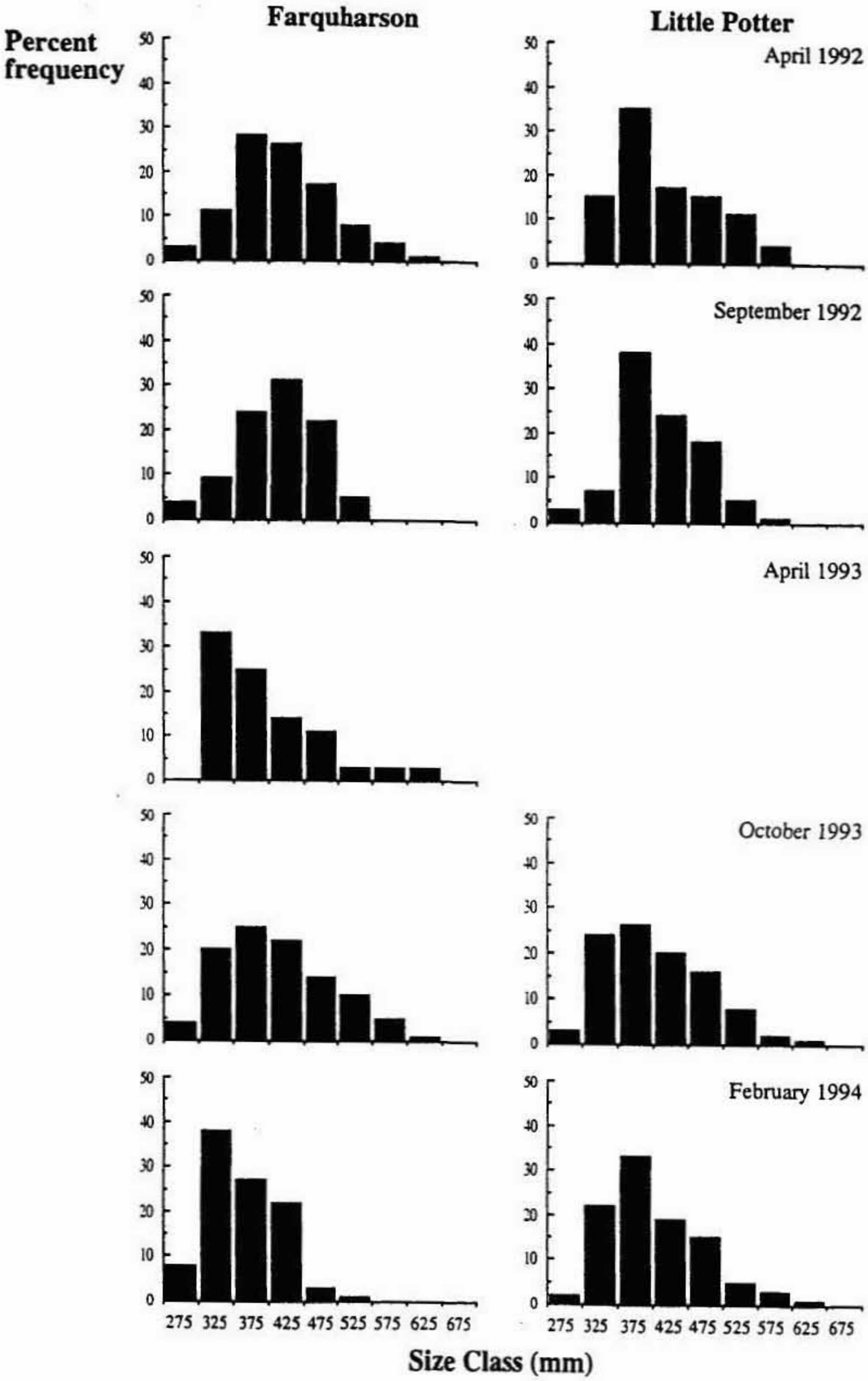

Figure 14. Length (LCF) frequency distributions for *Plectropomus leopardus* at Farquharson and Little Potter Reefs by trip (all blocks). Size classes are 50 mm. The mid-point of each size class is given. Trips are April 1992 (a), September 1992 (b), April 1993 (c), October 1993 (d), and February 1994 (e). Data from April 1993 (c) were not included in ANOVA for mean length (see text, page 11).

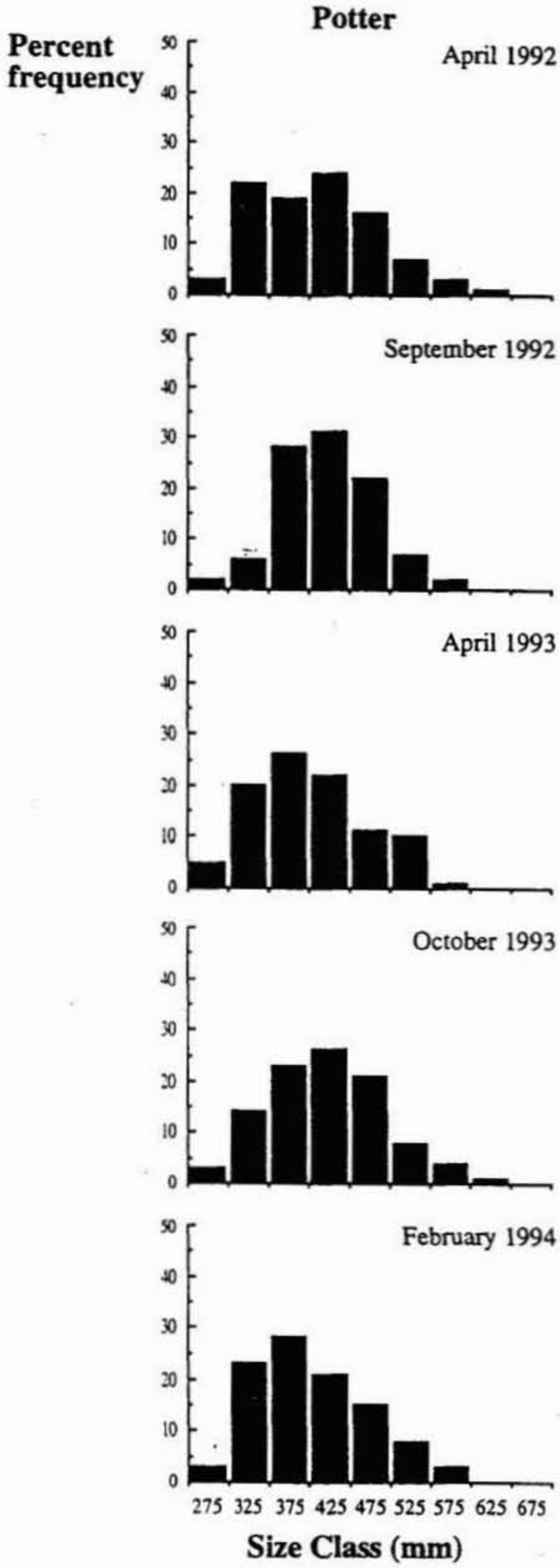

Figure 15. Length (LCF) frequency distributions for *Plectropomus leopardus* at Potter Reef by trip (all blocks). Size classes are 50 mm. The mid-point of each size class is given. Trips are April 1992 (a), September 1992 (b), April 1993 (c), October 1993 (d), and February 1994 (e). Data from April 1993 (c) were not included in ANOVA for mean length (see text, page 11).

Table 7. Summary of tag loss data for t-bar anchor tags from public and research tag returns of *Plectropomus leopardus* tagged with two t-bar anchor tags and returned up to 480 days following release. t_i is the mid-point of the i th time period (60 days) since release, r_{di} is the number of fish returned with two tags in the i th period, r_{si} is the number of fish returned with one tag in the i th period and K_i is the estimated probability of tag retention at t_i. * denotes data omitted from analysis.

t_i (days)	Public			Research		
	r_{di}	r_{si}	K_i	r_{di}	r_{si}	K_i
30	20	11	0.7843	9	0	1.0000
90	24	11	0.8135	14	11	0.7180
150	23	11	0.8070	10	9	0.6897
210	9	3	0.8571	4	4	0.6667
270*	10	10	0.6667	1	4	0.3333
330	7	2	0.8750	2	3	0.5714
390	1	0	1	5	9	0.5263
450	4	11	0.4211	0	0	-

Table 8. Estimates of tag shedding parameters ***p*** (type I) and ***L*** (type II) from the Bayliff and Morbran (1972) tag shedding model for t-bar anchor tag returns from the public and research exercises, and for the common regression. Sample size (n), proportion of total variance accounted for by the model (r^2) and significance level of parameter estimate (*Pr>t*) are given also. Standard errors of parameter estimates are in parentheses.

Source	*n*	r^2	ln *p*	*Pr>t*	*p*	*L*	*Pr>t*
Public	136	0.886	-0.0959 (0.0323)	0.04 *	0.9086	0.000885 (0.00016)	0.01 **
Research	80	0.821	-0.1446 (0.0663)	0.10 ns	0.8654	0.001328 (0.00031)	0.01 **
Commonreg	217	0.862	-0.1135 (0.0377)	0.03 *	0.8927	0.00101 (0.00018)	0.002 **

Comparison of Rates of Tag Loss of t-bar Anchor Tags and Dart Tags

A summary of the tag loss data for dart tags and TBA tags from the pooled public and research returns is presented in table 9. The regression for TBA tags and dart tags from the public returns was not significant ($F_{0.05,1,2} = 2.4183$; $p = 0.2602$). It was not possible to fit a regression to the research returns as there were too few returns in each time interval. Consequently, data from both sources were pooled (table 9). The regression for TBA tags for the pooled data was significant ($F_{0.05,1,5} = 16.2216$; $p = 0.0100$, figure 17a), with significant intercept and slope, and parameter estimates of $\boldsymbol{p} = 0.7160$ ($p = 0.0133$) and $\boldsymbol{L} = 0.00159$ ($p = 0.0100$) (table 10). However, the fit for dart tags was poor ($r^2 = 0.542$) and not significant ($F_{0.05,1,3} = 3.5471$; $p = 0.1562$) (figure 17b). Consequently it was not possible to make valid estimates of tag loss parameters for dart tags (table 10).

Comparison of Frequency of Return of t-bar Anchor Tags and Dart Tags

There was a significantly higher frequency of returns of fish retaining the TBA tag than those retaining the dart tag for *P. leopardus* tagged with both tag types and recaptured in the research recovery exercises ($\text{Chi-sq}_{0.05,1} = 10.678$; $p < 0.005$). However, there was no significant difference in the frequency of return of the two tag types for the returns from the public ($\text{Chi-sq}_{0.05,1} = 0.6127$; $p > 0.25$). The significant difference among tag types from the research returns suggests that the dart tags are shed more frequently than the TBA tags. 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 somewhat for their higher rate of shedding.

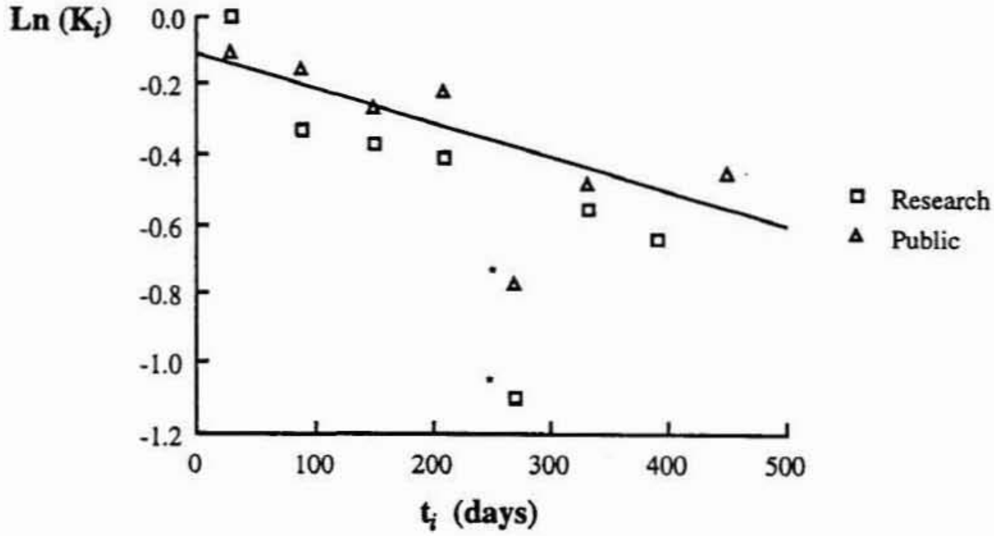

Figure 16a. Natural logarithm of estimated proportion of t-bar anchor tags retained ($\ln K_i$) over time (t_i), for tags returned from the public and those returned during research recovery exercises. The line has been fitted to the pooled data as there was no difference in rate of retention between the two sources of returns ($t_{0.05,(2),8} = -1.052$, $p > 0.5$).* denoted points which were omitted as outliers from the regression.

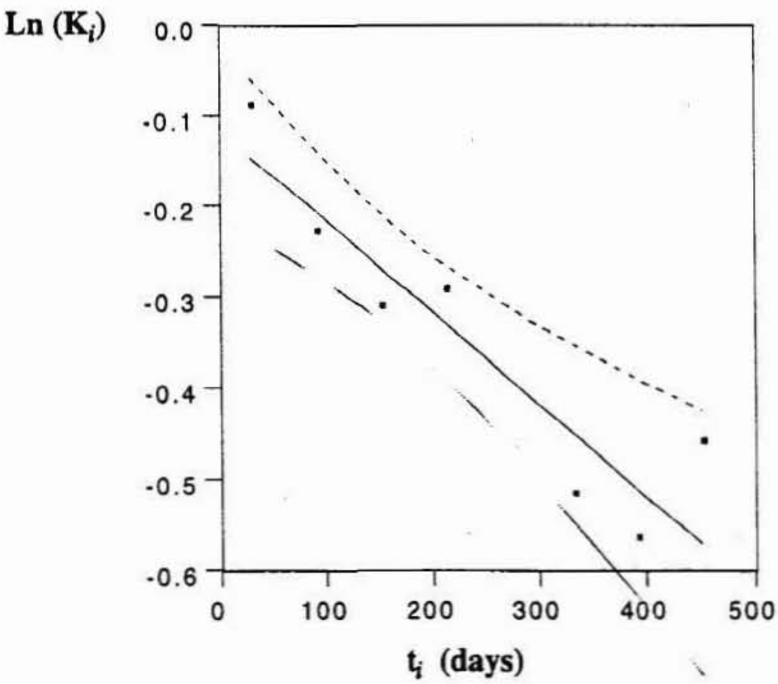

Figure 16b. Natural logarithm of estimated proportion of t-bar anchor tags retained ($\ln K_i$) over time (t_i), of pooled public and research returns for *Plectropomus leopardus* tagged with t-bar tags only, with confidence curves (95%). The regression is significant ($F_{0.05,1,5} = 31.1344$; $p < 0.0025$).

Table 9. Summary of tag loss data for t-bar anchor tags and dart tags from the pooled public and research tag returns of fish tagged with both tag types and returned up to 480 days following release. t_i is the mid-point of the i th time period (60 days) since release, r_{di} is the number of fish returned with two tags in the i th period, r_{Ai} is the number of fish returned with one t-bar anchor tag in the i th period, r_{Bi} is the number of fish returned with one dart tag in the i th period, A_i is the estimated probability of tag retention of a t-bar anchor tag at t_i and B_i is the estimated probability of tag retention of a dart tag at t_i. * indicates points omitted from analysis.

t_i (days)	Public and Research				
	r_{di}	r_{Ai}	r_{Bi}	A_i	B_i
30	7	1	1	0.8750	0.8750
90	5	8	4	0.5556	0.3846
150	8	11	7	0.5333	0.4211
210	2	3	2	0.5000	0.4000
270*	2	11	2	0.5000	0.1538
330	0	0	2	-	-
390	2	5	3	0.4000	0.2857
450	1	1	2	0.3333	0.5000

Effect of Colour on the Frequency of Return of t-bar Anchor Tags

There was no significant difference in the frequency of return of the six different colours of TBA anchor tag used in the study for the public returns (Chi-$sq_{0.05,5,154}$ = 1.413; $p = 0.9299$), the research returns (Chi-$sq_{0.05,5,83}$ = 5.438; $p = 0.3648$) or the pooled data (Chi-$sq_{0.05,5,243}$ = 1.902; $p = 0.8625$) (figure 18). This suggests that colour of the TBA tags has no significant effect on their rate of shedding or their rate of reporting.

Movement

Distribution of Releases of Plectropomus leopardus

A total of 4627 *P. leopardus* were tagged and released over five trips, with totals of 1541 fish at Beaver Reef, 777 fish at Taylor, 856 fish at Farquharson, 558 fish at Little Potter and 895 fish at Potter (table 11). Although the distribution of releases among trips, reefs and blocks is not even, 30-60 *P. leopardus* were released in each back reef block at each reef during each trip, with the exception of Farquharson Reef during trips c and e, Little Potter during trip c and Taylor during trip e (table 11).

The low number of releases in the front reef blocks of Taylor, Farquharson and Potter Reefs was due to the inaccessibility of these blocks during trips a and c and the very low catches when it was possible to fish them (table 11), rather than lack of effort (table 2). Although the effort in line hours is lower than the back reef blocks during trips b and d, the actual sampling effort in number of dories and time spent in each block was equal. This discrepancy is due to the difficulty the fishers have in finding 'fishable hangs' on the steep front reef slopes of Potter, Taylor and Farquharson Reefs. As a result they spend more time searching for hangs than fishing in the front reef blocks.

Distribution of Research Returns of Plectropomus leopardus

A total of 143 returns of *P. leopardus* were obtained during the four research tag-recovery exercises. One hundred and thirty of these were recaptured between trips and 13 within trips. Fish recaptured within the same trip were excluded from estimates of inter- or intra-reef movement. The majority of the research returns came from Beaver (43) and Potter Reefs (37), with fewer recaptured at Taylor (17), Farquharson (16) and Little Potter Reefs (17) (table 12).

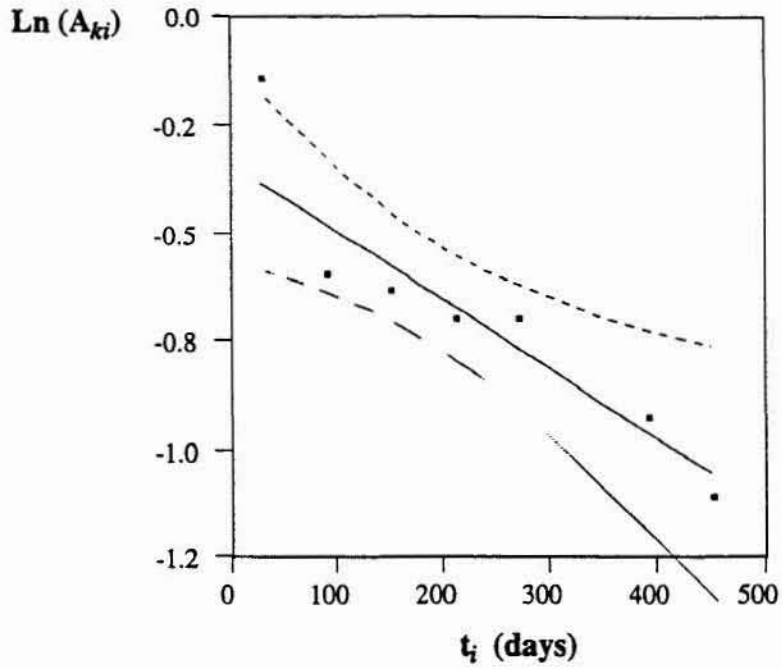

Figure 17a. Natural logarithm of estimated proportion of t-bar anchor tags retained (lnA_{ki}) over time (t_i), for pooled public and research returns of *Plectropomus leopardus* tagged with one t-bar and one dart tag, with confidence curves (95%). The regression is significant ($F_{0.05,1,5} = 16.2216$; $p < 0.01$).

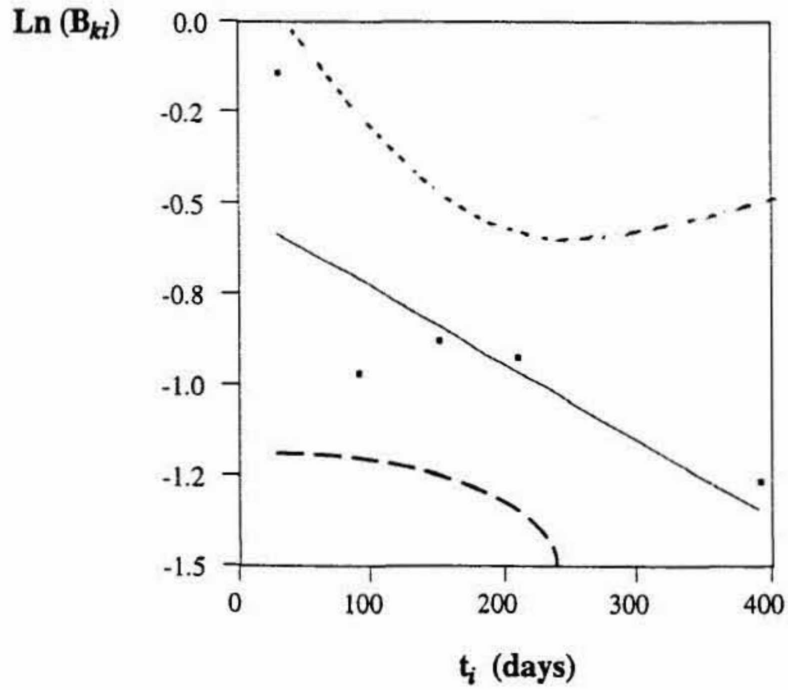

Figure 17b. Natural logarithm of estimated proportion of dart tags retained (lnB_{ki}) over time (t_i), for pooled public and research returns of *Plectropomus leopardus* tagged with one t-bar tag and one dart tag, with confidence curves (95%). The regression is not significant ($F_{0.05,1,3} = 3.5471$; $p > 0.15$).

Table 10. Estimates of tag shedding parameters p (type I) and L (type II) from the Bayliff and Morbran (1972) tag shedding model for t-bar anchor tags and dart tags from the common regression for the pooled public and research returns of *Plectropomus leopardus*. Sample size (n), proportion of total variance accounted for by the model (r^2) and significance level of parameter estimate ($Pr>t$) are given also. Ninety-five per cent confidence intervals of parameter estimates are in given in parentheses.

Tag type	n	r^2	$\ln p$	$Pr>t$	p	L	$Pr>t$
t-bar	88	0.764	-0.3341 (0.0891)	0.013 *	0.7160	0.00159 (0.0004)	0.010 *
dart	69	0.542	-0.5145 (0.2161)	0.098 **ns**	0.5978	0.00211 (0.0011)	0.156 **ns**

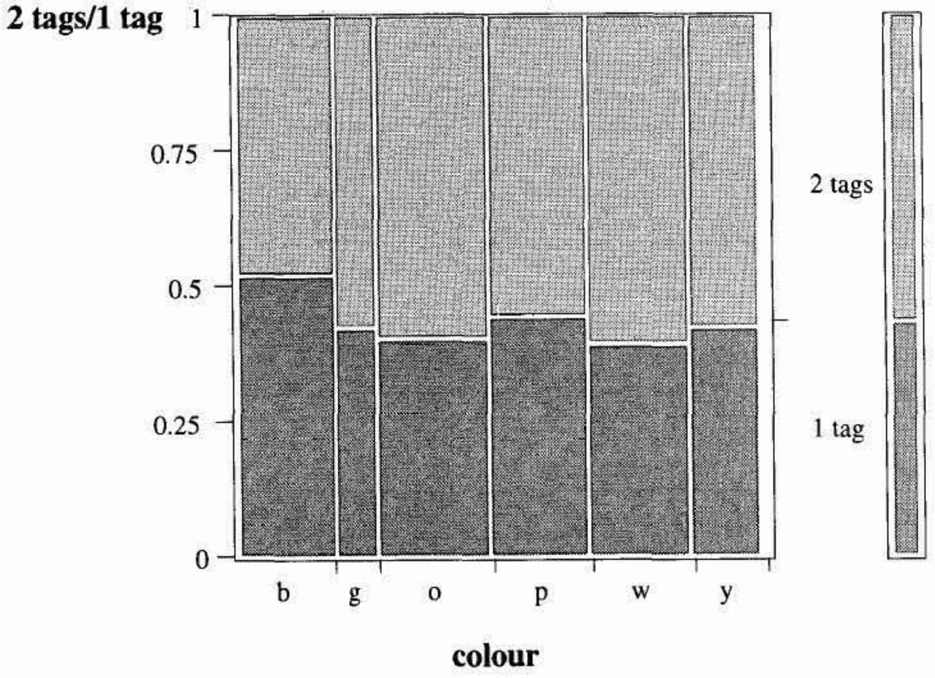

Figure 18. Mosaic plot from 6x2 contingency table analysis of proportion of fish returned with one and two tags by tag colour. Tag colours were blue (b), green (g), orange (o), pink (p), white (w) and yellow (y). There was no significant difference in the frequency of returns among the six colours of tags (Chi-sq$_{5243}$, = 1.902; p = 0.8625).

At Beaver Reef *P. leopardus* were returned from all blocks (table 12), with the majority (77%) from blocks 1, 3 and 6. In contrast, at Taylor, Farquharson, Little Potter and Potter Reefs the majority of *P. leopardus* were returned from the back reef blocks (table 12). This is likely to be due to the low number of releases and effort in the front reef blocks at these reefs (tables 2 and 11). Potter Reef had the second highest number of returns (37) with the majority (78%) returned from blocks 2 and 3 (table 12).

The overall rate of return (No. returns/effort) of *P. leopardus* was highest at Beaver (0.18), Potter (0.17) and Little Potter (0.16) Reefs, while at Farquharson (0.08) and Taylor (0.09) Reefs the rate of return was less than half that at Beaver (table 13). The rate of return varied considerably among trips and reefs, however there was a consistent increase in the rate across reefs during trip e, indicating that the targeting of the sampling effort at specific blocks, to increase the rate of return, had been effective.

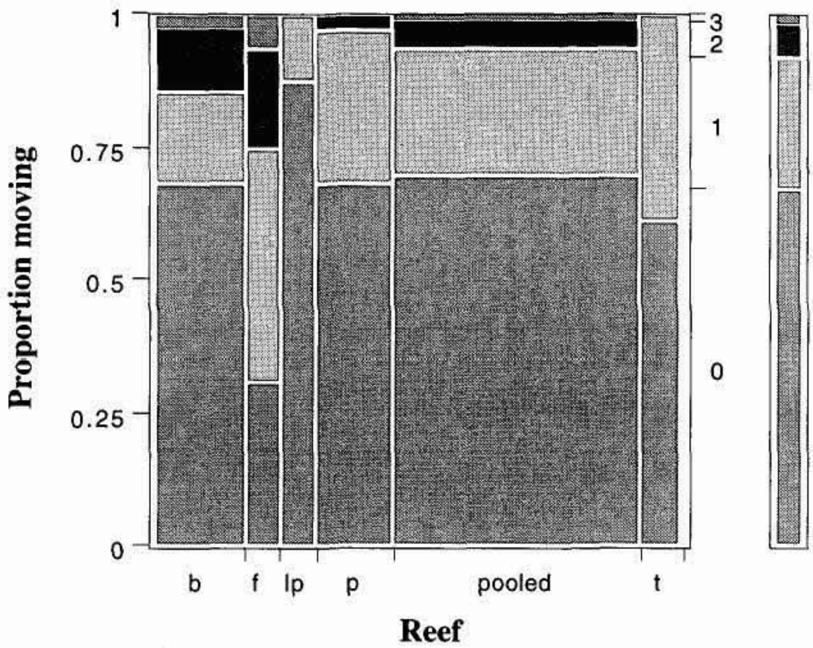

Figure 19. Mosaic plot of frequency of movement among blocks by reef from 5x4 contingency table analysis. Reefs are Beaver (b), Farquharson (f), Taylor (t), Little Potter (lp) and Potter (p) Reefs. Categories of movement are returned in original block (0), 1st block (1), 2nd adjacent block (2) and 3rd adjacent block (3).

Distribution of Public Returns of **Plectropomus leopardus**

Tags from a total of 300 fish were returned from the public (to February 1994) which included 282 *P. leopardus*. Of these, 273 were accompanied by sufficient information to be used to estimate inter-reef movement. The distribution of these returns among reefs and trips was relatively even, with a maximum of 81 returns from Taylor Reef and a minimum of 51 from Little Potter Reef (table 14).

Per Cent Returns of **Plectropomus leopardus** *by Trip by Reef*

The percentage of *P. leopardus* returned during the research exercises ranged from 0.2% at Farquharson Reef on trip c to 5.4% at Potter Reef on trip b (table 15). In general, the percentage returned was highest on the first recovery exercise (trip b), due to the low number of releases relative to the number of recaptures. Somewhat surprisingly, the number returned on the subsequent recovery exercises did not increase, despite the considerable increase in the number of releases. Consequently, the overall per cent of recaptures decreased (table 15), with the exception of the final recovery exercise.

The percentage of tags returned by the public ranged from zero at Beaver Reef (which was to be expected as Beaver Reef is closed to fishing) and Potter Reef (April-October 1993) to nearly 15% at Potter Reef between April 1992 and September 1992 (table 15). Generally, per cent returns of *P. leopardus* were higher on Potter, Little Potter and Taylor Reefs (table 15). In a similar pattern to the research returns, the per cent returns from the public decreased with time (table 15).

Patterns of Inter-reef Movement of **Plectropomus leopardus** *from Research Returns*

Of the 128 research returns one (0.78%) had moved between reefs (table 16) which represented 5.9% of the *P. leopardus* returned from Taylor Reef during the research recovery exercises.

This fish was tagged in block three of Taylor Reef and was recaptured in block three of Beaver Reef. The remaining 99% of *P. leopardus* were recaptured on the reef where they were released (table 19).

Table 11. Number of *Plectropomus leopardus* tagged and released by trip by reef by block

Reef	**block**	**Trip**					
		a	**b**	**c**	**d**	**e**	**Total**
Beaver	1B	86	26	141	22	104	379
	2F	46	52	46	35	19	198
	3F	146	48	42	48	77	361
	4B	54	16	20	45	69	204
	5B	29	24	21	-	-	74
	6B	54	27	161	39	44	325
	Total	**415**	**193**	**431**	**189**	**313**	**1541**
Taylor	1B	48	47	65	44	13	217
	2B	78	33	71	23	7	212
	3B	60	56	31	29	44	220
	4F	-	14	-	44	29	87
	5F	-	3	-	14	-	17
	6F	-	14	-	10	-	24
	Total	**186**	**167**	**167**	**164**	**93**	**777**
Farquharson	1B	101	32	17	14	12	176
	2B	-	74	-	37	23	134
	3F	-	7	-	9	-	16
	4F	-	1	-	19	-	20
	5F	-	2	-	18	-	20
	6F	-	1	-	27	-	28
	7F	-	57	-	15	-	72
	8B	67	66	-	63	1	197
	9B	80	21	14	46	32	193
	Total	**248**	**261**	**31**	**248**	**68**	**856**
Little Potter	1B	102	115	-	98	104	419
	2F	-	28	-	70	41	139
	Total	**102**	**143**	**0**	**168**	**145**	**558**
Potter	1B	43	70	51	14		178
	2B	105	128	35	32	71	371
	3B	36	56	35	38	60	225
	4F	-	12	-	50	22	84
	5F	-	13	-	13	-	26
	6F	-	2	-	9	-	11
	Total	**184**	**281**	**121**	**156**	**153**	**895**
Cluster	**Total**	**1135**	**1045**	**750**	**925**	**772**	**4627**

The 53 *P. leopardus* which were recaptured during the final recapture exercise in February 1994, which deliberately targeted areas within the cluster where the majority of the movements from the public returns had occurred (i.e. the channel between Beaver and Taylor Reefs), found no indication of inter-reef movement. Of the 13 *P. leopardus* returned from the blocks between Beaver and Taylor Reef 100% were returned from their reef of release as were all returns from Potter and Little Potter Reefs.

Furthermore, the 22 recaptures of species other than *P. leopardus* over the entire study, were all returned from the reef on which they were released (table 17). Thus, from the results of the research recovery exercises, it appears that inter-reef movement of *P. leopardus* is very low (< 1% overall) and, although the number of recaptures are low, the same appears to be the case for the other species of reef fish recaptured from the research recovery exercises.

Table 12. Distribution of research returns of *Plectropomus leopardus* by trip, reef and block

Reef	block	Trip				
		b	**c**	**d**	**e**	**Total**
Beaver	1B	0	0	0	10	10
	2F	1	2	2	0	5
	3F	6	3	1	6	16
	4B	0	1	0	2	3
	5B	2	0	0	0	2
	6B	1	4	2	0	7
	Total	**10**	**10**	**5**	**18**	**43**
Taylor	1B	0	3	1	0	4
	2B	0	3	1	0	4
	3B	1	1	1	4	7
	4F	0	0	0	1	1
	5F	0	0	1	0	1
	6F	0	0	0	0	0
	Total	**1**	**7**	**4**	**5**	**17**
Farquharson	1B	5	0	0	0	5
	2B	4	-	0	1	5
	3F	0	-	0	-	0
	4F	0	-	0	-	0
	5F	0	-	0	-	0
	6F	0	-	1	-	1
	7F	0	-	0	-	0
	8B	1	-	1	0	2
	9B	1	1	0	1	3
	Total	**11**	**1**	**2**	**2**	**16**
Little Potter	1B	3	-	1	10	14
	2F	0	-	0	3	3
	Total	**3**	**0**	**1**	**13**	**17**
Potter	1B	4	3	0	-	7
	2B	4	3	2	9	18
	3B	2	4	0	5	11
	4F	0	-	0	1	1
	5F	0	-	0	-	0
	6F	0	-	0	-	0
	Total	**10**	**10**	**2**	**15**	**37**
Cluster	**Total**	**35**	**28**	**14**	**53**	**130**

Table 13. Research recaptures of *Plectropomus leopardus* standardised by sampling effort (line hr) by trip and reef

Reef	Trip				
	b	**c**	**d**	**e**	**Total**
Beaver	0.28	0.19	0.20	0.41	0.18
Taylor	0.03	0.23	0.13	0.14	0.09
Farquharson	0.23	0.13	0.05	0.12	0.08
Little Potter	0.12	-	0.04	0.46	0.16
Potter	0.20	0.36	0.06	0.50	0.17
Overall proportion of tagged fish returned per trip	0.18	0.24	0.09	0.34	0.14

Patterns of Inter-reef Movement of **Plectropomus leopardus** *from Public Returns*

The pattern of inter-reef movement of *P. leopardus* from the public returns differed markedly from that of the research returns (table 18). Thirty-seven per cent of the *P. leopardus* returned by the public were returned from a different reef from where they were released (table 19). This included 43 *P. leopardus* which had moved from Beaver Reef to other reefs, the majority (70%) being reported from Taylor Reef, but with reported movements to Farquharson, Little Potter and Potter Reefs (table 18). It is worthy to note that of the total inter-reef movements from Beaver Reef, 80% of the *P. leopardus* were released in two blocks (3 and 4) directly adjacent to Taylor Reef.

Although the number of inter-reef movements from the other reefs were lower than from Beaver, they were considerably higher than the estimates from the research returns with 22%, 12% and 15% of the returns released on Taylor, Farquharson and Little Potter Reefs, respectively, being returned from other reefs (table 18). Potter Reef had the second highest percentage of inter-reef movements (40%) with 36 *P. leopardus* returned from other reefs. The difference in frequency of inter-reef movement among these four reefs was significant ($\text{Chi-sq}_{3,226} = 17.907$; $p = 0.0005$), with Potter Reef having a significantly higher frequency of movement than Taylor, Farquharson and Little Potter Reefs. Ninety-five per cent of the inter-reef movements from Potter Reef were released in blocks 1 (39%) and 2 (56%). Beaver Reef was excluded from the analysis as it was not possible to weight the inter-reef movements by fish returned from Beaver Reef.

Table 14. Distribution of public tag returns of *Plectropomus leopardus* by time period and reef

Reef	Time period				
	Apr'92-Sept'92	**Sept'92-Apr'93**	**Apr'93-Sept'93**	**Sept'93-Feb'94**	**Total**
Beaver	0	0	0	0	**0**
Taylor	26	9	22	24	**81**
Farquharson	17	20	18	14	**69**
Little Potter	13	18	18	2	**51**
Potter	27	27	0	22	**76**
Others	2	1	2	0	**5**
Total	**85**	**75**	**60**	**62**	**282**

Table 15. The rate of tag return of *Plectropomus leopardus* from each reef by the public, from the research recovery trips and from the two combined, expressed as a per cent of the cumulative total of *P. leopardus* released at each reef

Reef	Source	Time period			
		Apr'92-Sept'92	**Sept'92-Apr'93**	**Apr'93-Oct'93**	**Oct'93-Feb'94**
Beaver	Res	2.41	1.64	0.48	1.47
	Pub	0.00	0.00	0.00	0.00
Taylor	Res	0.54	1.98	0.77	0.73
	Pub	13.98	2.55	4.23	3.51
Farquharson	Res	4.44	0.20	0.37	0.25
	Pub	6.85	3.93	3.33	1.78
Little Potter	Res	2.94	-	0.41	3.15
	Pub	12.75	7.35	7.35	0.48
Potter	Res	5.43	2.15	0.34	2.02
	Pub	14.67	5.81	0.00	2.96
Total	Res	3.08	1.28	0.48	1.37
	Pub	7.49	3.44	2.05	1.61

Table 16. Pattern of inter-reef movement of *Plectropomus leopardus* from research returns. Includes *P. leopardus* which were recaptured among trips only: i.e. recaptures within the same trip have been excluded

Released	Returned						
	Beaver	Taylor	Farquharson	Little Potter	Potter	Other	Total
Beaver	**42**	0	0	0	0	0	**42**
Taylor	1	**17**	0	0	0	0	**18**
Farquharson	0	0	**16**	0	0	0	**16**
Little Potter	0	0	0	**16**	0	0	**16**
Potter	0	0	0	0	**37**	0	**37**
Total	**43**	**17**	**16**	**16**	**37**	**0**	**129**

Table 17. Pattern of inter-reef movement of *Plectropomus leopardus* from public returns

Released	Returned						
	Beaver	Taylor	Farquharson	Little Potter	Potter	Other	Total
Beaver	**0**	30	6	1	6	0	**43**
Taylor	0	**38**	5	0	6	0	**49**
Farquharson	0	0	**46**	0	3	3	**52**
Little Potter	0	1	1	**33**	4	0	**39**
Potter	0	10	5	19	**54**	2	**90**
Total	**0**	**79**	**63**	**53**	**73**	**5**	**273**

Table 18. Number and percentage of *Plectropomus leopardus* which moved from their reef of release for research and public returns by reef. * Note that it is not possible to weight the public returns of fish released at Beaver Reef

Reef	Research		Public	
	Number	%	Number	%
Beaver	0	0	43	100 *
Taylor	1	5.88	11	22.45
Farquharson	0	0	6	11.54
Little Potter	0	0	6	15.38
Potter	0	0	36	40.00
Total	1	0.78	102	37.36

Table 19. Percentage of inter-reef movements of *Plectropomus leopardus* from public returns to the 1st, 2nd and 3rd closest reef from reef of release

Released	Returned		
	1st closest	2nd closest	3rd closest
Beaver	84	2	14
Taylor	45	0	55
Farquharson	0	50	50
Little Potter	83	17	0
Potter	53	14	33
Average pooled across reefs	64	10	26

The majority of the inter-reef movement was from the reef of release to the next adjacent reef. However, the pattern of inter-reef movement is not indicative of a random diffusion process. Generally there was a higher percentage of movement from the reef of release to the 3rd closest reef, i.e. from Potter to Beaver Reef (table 19). The majority of these movements were to, or from, Potter Reef.

There were five returns of *P. leopardus* by the public from reefs not included in the study area: two from Potter Reef to Nathan Reef (to the north of Adelaide Reef), two from Farquharson Reef to Adelaide Reef and a third from Farquharson Reef to an unnamed shoal located between Farquharson and Little Potter Reefs (see figure 1 for locations of reefs).

The pattern of movement of *P. leopardus* from two of the major sources of public returns, A (27% of public returns) and B (17% of public returns) are presented in tables 20a and b. Sources A and B represent individual persons or boats whose identity or further details constitute confidential information. In both cases percentage of inter-reef movements is high, 37% and 55%, respectively. In the case of source A, 85% of the inter-reef movements were from Beaver Reef, with the majority to Taylor Reef (table 20a). One hundred per cent of the returns from Beaver Reef had been released in blocks 2, 3 and 4 of Beaver Reef. In contrast, 81% of the inter-reef movements from source B were from Potter Reef, with one movement from Beaver to Farquharson reef (table 20b). All the inter-reef movements from Potter Reef had been released in blocks 1 and 2 of Potter Reef.

Table 20a. Pattern of inter-reef movement of *Plectropomus leopardus* from returns from public source A (see above text for details)

Released	**Returned**					
	Beaver	**Taylor**	**Farquharson**	**Little Potter**	**Potter**	**Total**
Beaver	**0**	19	0	0	4	**23**
Taylor	0	**1**	0	0	0	**1**
Farquharson	0	0	**0**	0	2	**2**
Little Potter	0	0	0	**31**	1	**32**
Potter	0	1	0	0	**14**	**15**
Total	**0**	**21**	**0**	**31**	**21**	**73**

Table 20b. Pattern of inter-reef movement of *Plectropomus leopardus* from returns from public source B (see above text for details)

Released	**Returned**					
	Beaver	**Taylor**	**Farquharson**	**Little Potter**	**Potter**	**Total**
Beaver	**0**	0	1	0	0	**1**
Taylor	0	**14**	3	0	0	**17**
Farquharson	0	0	**7**	0	0	**7**
Little Potter	0	1	0	**0**	0	**1**
Potter	0	3	0	18	**0**	**21**
Total	**0**	**18**	**11**	**18**	**0**	**47**

Patterns of Inter-block Movement of* Plectropomus leopardus *from Research Returns

The majority of *P. leopardus* were returned from their block of release (table 21). However, there was a degree of movement among blocks at all reefs (table 21), with the frequency of inter-block movement at Farquharson Reef being significantly different than at the other reefs ($Chi\text{-}sq_{12,111} = 23.193$; $p = 0.0261$) (table 21). This is due to the higher frequency of movement to the first adjacent block, mostly between blocks one and two.

Table 21. Response profiles from 5x4 contingency table analysis of frequency of inter-block movement of *Plectropomus leopardus* from research returns. Includes *P. leopardus* which were recaptured among trips only, i.e. recaptures within the same trip have been excluded.

Reef	**Number of blocks moved**				
	0	**1**	**2**	**3**	**Total**
Beaver	0.68	0.17	0.12	0.02	41
Taylor	0.61	0.39	0.0	0.00	18
Farquharson	0.31	0.44	0.19	0.06	16
Little Potter	0.88	0.29	0.03	0.00	16
Potter	0.69	0.29	0.05	0.00	35
Average pooled across reefs	0.65	0.26	0.07	0.02	126

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 Boult Reef opening (Beinssen 1989a). In contrast, at Heron Island, approximately 40 km to the north of Boult 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 Boult 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 Boult 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 $\boldsymbol{p}$ (0.8927) and $\boldsymbol{L}$ (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 Boult 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*.

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Appendix 1a. Distribution of catch per unit effort of *Plectropomus leopardus* (no.line^{-1}h^{-1}) among blocks within reefs by trip. Data are sample sizes, means and standard errors by block. B=back reef block, F=front reef block. Block numbers correspond to those in figure 2

Reef	**Block**	**Trip**														
		a			b			c			d			e		
		n	Mn	SE	n	Mn	SE	n	Mn	SE	n	Mn	SE	n	Mn	SE
Beaver	1B	28	6.74	0.95	18	6.41	2.10	41	7.78	1.30	5	12.22	3.39	29	8.88	1.71
	2F	25	4.78	0.86	21	6.26	1.22	8	12.69	5.57	16	5.90	1.51	13	6.29	2.14
	3F	45	7.21	0.93	18	6.71	1.56	24	4.53	1.08	22	7.67	2.13	37	5.52	0.91
	4B	55	2.65	0.54	18	2.01	0.76	9	6.65	1.58	14	5.62	1.36	55	4.20	0.59
	5B	26	2.70	0.80	20	3.34	0.81	10	6.08	2.58	-	-	-	-	-	-
	6B	47	2.85	0.64	16	4.40	0.92	45	8.20	0.96	21	4.77	0.98	14	6.78	1.78
	Reef	**226**	**4.35**	**0.60**	**111**	**4.92**	**0.55**	**137**	**7.44**	**0.67**	**78**	**6.45**	**0.80**	**148**	**5.87**	**0.53**
Taylor	1B	34	2.92	0.66	18	5.43	1.30	46	4.40	0.70	19	5.56	1.16	17	2.53	0.74
	2B	59	3.62	0.58	21	3.57	0.90	27	5.90	1.22	20	3.06	0.74	13	1.94	0.72
	3B	52	2.52	0.50	27	5.39	1.33	17	6.60	1.64	9	15.16	5.78	68	1.95	0.37
	4F	-	-	-	17	1.92	0.52	-	-	-	20	7.67	1.86	38	2.73	0.68
	5F	-	-	-	8	0.98	0.54	-	-	-	8	6.77	3.59	-	-	-
	6F	-	-	-	19	2.56	1.08	-	-	-	9	2.14	1.31	-	-	-
	Reef	**145**	**3.06**	**0.33**	**110**	**3.45**	**0.19**	**90**	**5.26**	**0.60**	**85**	**6.24**	**0.94**	**136**	**2.24**	**0.29**
Farquharson	1B	53	3.12	0.60	13	5.82	1.66	16	3.42	0.67	20	2.01	0.69	20	2.06	0.63
	2B	-	-	-	23	9.39	3.14	-	-	-	17	5.86	1.17	22	3.84	0.99
	3B	-	-	-	23	1.60	1.06	-	-	-	11	2.44	1.05	-	-	-
	4F	-	-	-	3	0.80	0.80	-	-	-	9	7.36	1.23	-	-	-
	5F	-	-	-	3	1.17	0.60	-	-	-	14	4.07	1.63	-	-	-
	6F	-	-	-	3	1.11	1.11	-	-	-	11	7.95	3.03	-	-	-
	7F	-	-	-	25	5.59	1.13	-	-	-	11	3.46	1.31	-	-	-
	8B	71	3.24	0.42	17	7.83	1.71	-	-	-	23	9.07	2.65	4	0.71	0.71
	9B	78	3.11	0.46	11	5.22	1.36	8	4.83	1.38	30	3.99	0.79	23	4.48	1.07
	Reef	**202**	**3.16**	**0.28**	**121**	**5.06**	**0.72**	**24**	**3.89**	**0.64**	**146**	**5.09**	**0.59**	**69**	**3.36**	**0.52**
Little Potter	1B	73	3.33	0.45	54	4.71	0.69	-	-	-	40	5.52	0.85	63	4.41	0.69
	2F	-	-	-	41	1.60	0.35	-	-	-	37	6.32	1.04	36	3.60	0.78
	Reef	**73**	**3.33**	**0.45**	**95**	**3.40**	**0.45**	**-**	**-**	**-**	**77**	**5.90**	**0.66**	**99**	**4.15**	**0.52**
Potter	1B	43	1.78	0.39	26	6.18	2.14	25	5.34	1.02	12	2.67	0.85	-	-	-
	2B	102	2.93	0.39	31	9.71	1.49	34	2.93	0.62	22	4.17	1.09	23	7.62	1.13
	3B	62	1.50	0.29	38	4.73	1.24	25	3.33	0.65	21	4.45	1.02	51	3.36	0.53
	4F	-	-	-	6	5.62	3.30	-	-	-	28	4.92	1.27	25	2.58	0.56
	5F	-	-	-	22	1.57	0.56	-	-	-	12	2.71	1.17	-	-	-
	6F	-	-	-	16	0.63	0.44	-	-	-	11	2.19	0.92	-	-	-
	Reef	**207**	**2.26**	**0.45**	**139**	**4.84**	**0.65**	**84**	**3.77**	**0.45**	**106**	**3.88**	**0.49**	**99**	**4.15**	**0.44**

Appendix 1b. Distribution of mean length of *Plectropomus leopardus* (mm) among blocks within reefs by trip. Data are sample sizes, means and standard errors by block. B=back reef block, F=front reef block. Block numbers correspond to those in figure 2.

Reef	Block	Trip														
		a			b			c			d			e		
		n	Mn	SE	n	Mn	SE	n	Mn	SE	n	Mn	SE	n	Mn	SE
Beaver	1B	87	413	7.63	27	385	12.00	143	401	5.08	22	378	10.28	102	386	5.77
	2F	47	405	10.49	51	409	7.72	54	393	8.64	35	383	9.67	17	425	16.33
	3F	148	427	6.07	51	419	8.00	44	419	10.85	51	401	8.09	3	418	26.30
	4B	56	424	10.17	16	405	14.67	21	378	11.02	44	409	10.04	10	373	24.53
	5B	21	377	11.85	24	407	13.83	23	384	10.34	-	-	-	-	-	-
	6B	53	396	9.62	28	385	10.65	160	393	4.92	40	377	8.69	45	363	5.64
	Reef	**412**	**414**	**3.60**	**197**	**404**	**4.24**	**445**	**397**	**2.95**	**192**	**392**	**4.28**	**177**	**384**	**4.36**
Taylor	1B	49	440	9.83	49	455	10.69	68	427	9.00	48	442	12.67	21	414	13.29
	2B	82	420	7.31	34	430	10.30	75	411	7.39	25	401	13.56	12	369	13.15
	3B	63	450	10.82	58	425	7.26	34	429	13.47	31	429	15.36	49	397	9.48
	4F	-	-	-	14	421	14.62	-	-	-	46	405	11.57	27	413	16.46
	5F	-	-	-	3	440	25.06	-	-	-	15	456	20.82	-	-	-
	6F	-	-	-	15	429	16.22	-	-	-	11	435	21.17	-	-	-
	Reef	**194**	**435**	**5.37**	**173**	**435**	**4.83**	**177**	**421**	**5.35**	**176**	**425**	**6.19**	**109**	**401**	**6.67**
Farquharson	1B	68	436	8.86	37	400	8.65	19	391	18.79	16	365	17.55	15	372	12.18
	2B	-	-	-	86	425	4.75	-	-	-	46	414	12.84	24	359	10.67
	3F	-	-	-	8	352	20.98	-	-	-	9	372	27.73	-	-	-
	4F	-	-	-	1	375		-	-	-	19	414	14.54	-	-	-
	5F	-	-	-	2	403	28.50	-	-	-	18	417	14.68	-	-	-
	6F	-	-	-	1	413		-	-	-	31	417	12.13	-	-	-
	7F	-	-	-	61	428	7.53	-	-	-	15	381	20.75	-	-	-
	8B	104	408	6.69	71	422	7.99	-	-	-	65	431	9.75	1	385	-
	9B	83	420	7.50	21	408	15.71	14	408	18.34	46	390	11.38	33	361	9.90
	Reef	**255**	**419**	**4.40**	**288**	**418**	**3.45**	**36**	**391**	**12.91**	**265**	**408**	**4.80**	**73**	**363**	**6.21**
Little Potter	1B	104	417	6.77	120	412	5.21	-	-	-	101	396	7.60	109	393	5.68
	2F	-	-	-	31	401	8.69	-	-	-	73	411	7.88	42	418	12.13
	Reef	**104**	**417**	**6.81**	**151**	**410**	**4.52**	**-**	**-**	**-**	**174**	**402**	**5.54**	**151**	**400**	**5.39**
Potter	1B	39	418	11.31	70	425	6.52	56	412	10.38	14	428	15.88	-	-	-
	2B	106	410	6.96	131	433	5.42	40	406	11.09	32	424	14.03	74	399	8.50
	3B	43	398	10.33	56	419	6.69	42	402	10.61	40	418	11.04	61	401	8.91
	4F	-	-	-	12	410	18.19	-	-	-	51	420	9.78	23	405	11.37
	5F	-	-	-	13	387	10.92	-	-	-	13	409	18.22	-	-	-
	6F	-	-	-	2	367	0.50	-	-	-	9	433	10.84	-	-	-
	Reef	**188**	**409**	**5.16**	**284**	**425**	**3.43**	**138**	**407**	**6.19**	**159**	**421**	**5.45**	**158**	**401**	**5.50**