## 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.

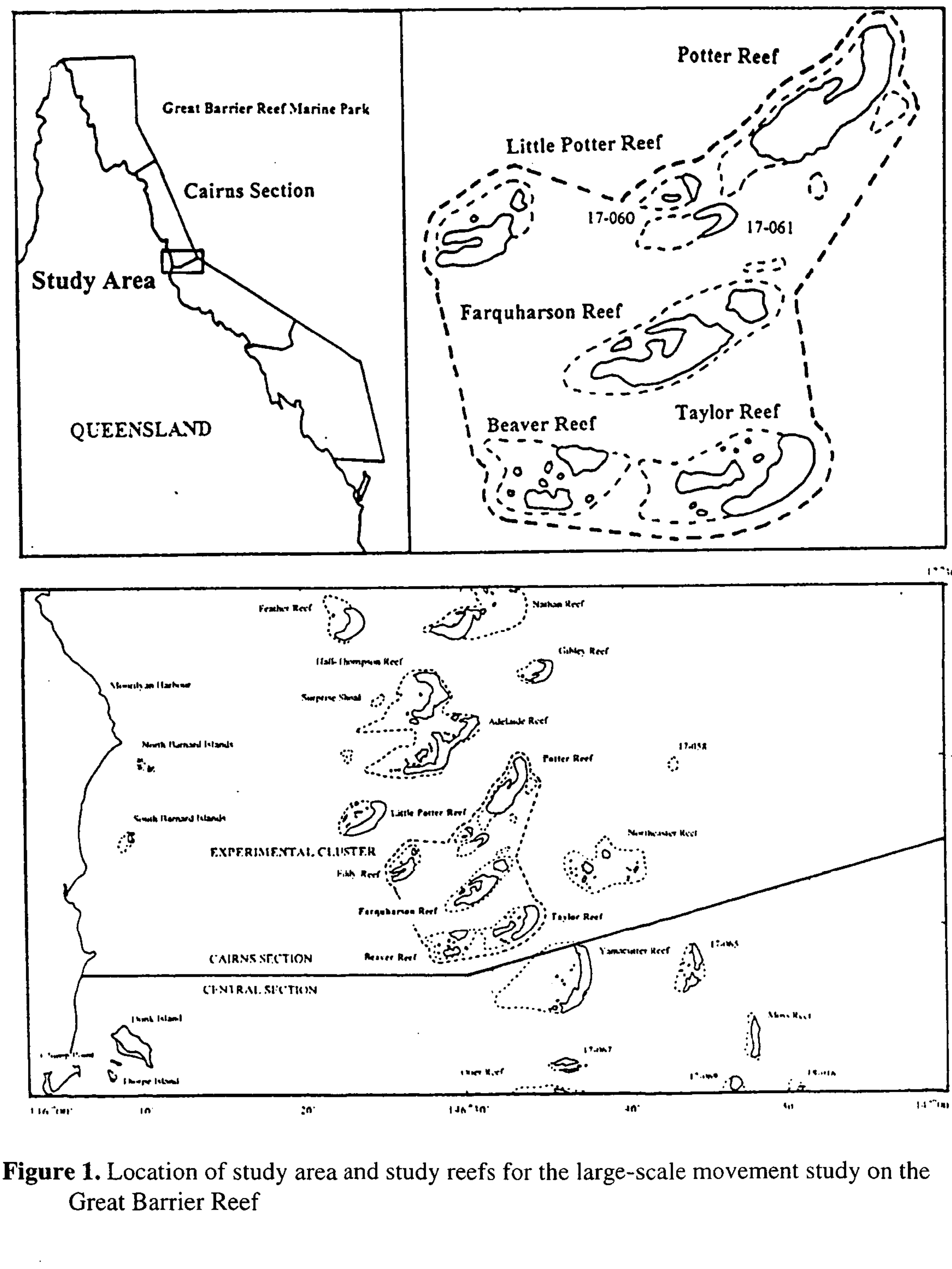


**Figure 1.** Location of study area and study reefs for the large-scale movement study on the Great Barrier Reef

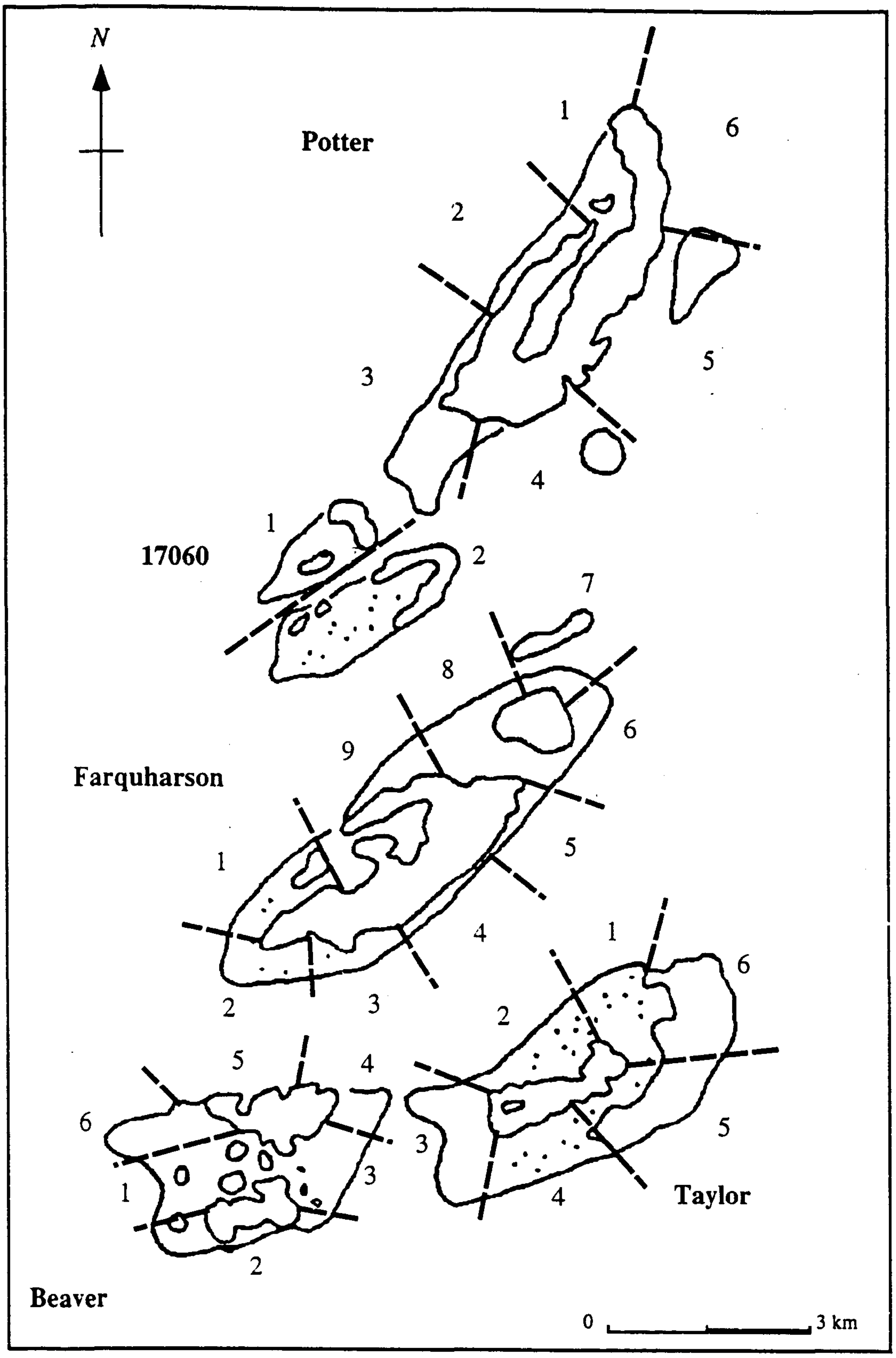


**Figure 2.** Location of sampling blocks within each reef of the cluster

**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.

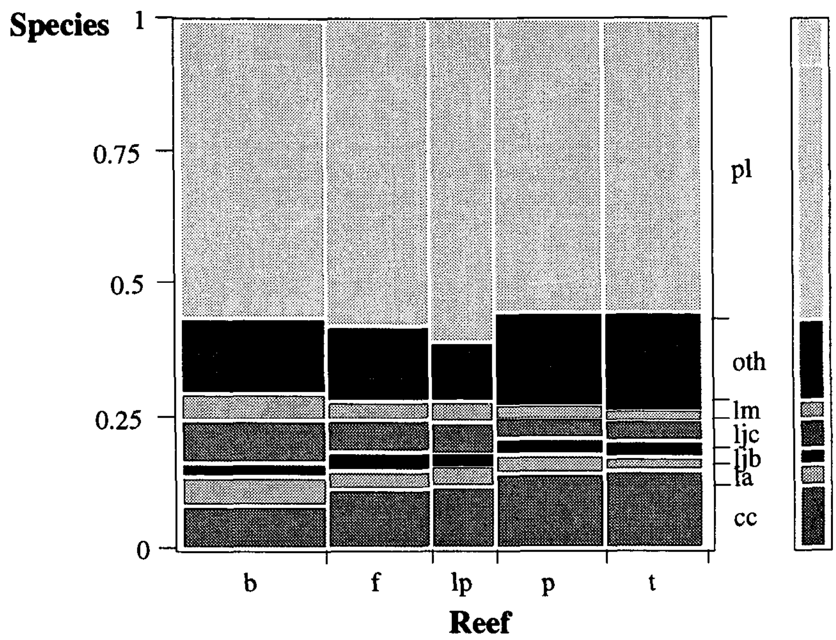


**Figure 3.** Mosaic plot of species composition of catch by reef. The species are *Cephalopholis cyanostigma* (cc), *Plectropomus leopardus* (pl), *Lutjanus bohar* (ljb), *L. carponotatus* (ljc), *Lethrinus atkinsoni* (la), *L. miniatus* (lm) and others (oth). Trips are April 1992 (a), September 1992 (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 ($x^1 = \log_{10}(x + 1)$). 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).