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EFFECT OF ZONING CHANGES ON THE FISH POPULATIONS OF UNEXPLOITED REEFS

STAGE 1: PRE-OPENING ASSESSMENT

REPORT TO THE GREAT BARRIER REEF MARINE PARK AUTHORITY

by

I.W. BROWN, L. SQUIRE and L. MIKULA

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DPI
QUEENSLAND
DEPARTMENT OF PRIMARY INDUSTRIES
SOUTH EAST REGION

EFFECT OF ZONING CHANGES ON THE FISH POPULATIONS OF UNEXPLOITED REEFS. STAGE I: PRE-OPENING ASSESSMENT.

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I.W. Brown[1], L. Squire[2] and L. Mikula[1]

EXECUTIVE SUMMARY

Much of the available information on the effects which fishing activities may have on the abundance of fish stocks on the GBR has come from visual census surveys by divers. These surveys have provided estimates of fish density at a large number of reefs, and the various techniques used have been the source of some discussion over the past few years (Samoilys 1992). Few attempts have been made to assess the effects of fishing on population processes in the important species of serranids, lethrinids and lutjanids which are targetted by both the recreational and the commercial line-fishery along the GBR.

In Stage 1 of this pilot study we examined the cumulative effects of differential GBRMPA zoning legislation on two pairs of adjacent reefs off Innisfail in the southern part of the Cairns Section of the GBR Marine Park. Each pair of reefs comprised one (zoned MNPA) which was open to fishing, and one (MNPB) which had been closed to fishing for the past eight years. Using spearfishing and handlining methods we sampled the major predator species (coral trout, stripeys, redfish and redthroat emperor) for age-structure analysis and ultimately to compare estimates of total mortality rate on open and closed reefs. At the same time we were able to obtain catch-effort information from the linefishing operation and counts per swim-distance from the spearfishing operation to provide estimates of relative population density to compare with those made at the same reefs and very nearly the same time as part of a broader independent UVC survey.

Our diver counts indicated a greater abundance of coral trout (*Plectropomus leopardus*) on the closed reefs than on the open reefs. This difference was due to "large" fish (estimated >40 cm TL), the difference for those <40 cm being non-significant. The handline CPUE (fish per fisher-hr), however, suggested the opposite - i.e. that coral trout are more abundant on the open reefs. The reason for this contradictory evidence has yet to be elucidated. Stripeys (*Lutjanus carponotatus*) were far more abundant on the open reefs, a finding which concurs with that of the independent UVC survey. This species appeared to be substantially less vulnerable to line-fishing than to spearfishing. Bluespot or footballer trout (*Plectropomus laevis*) counts were made only at one of the reef-pairs; they were significantly more numerous at the closed reef.

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Analysis of age-frequency distributions of populations of coral trout, based on age estimates from whole otolith readings, revealed significant collection method, reef group and treatment (zoning status) effects. Fewer fish in age classes 1-3 were captured by line than by spear, and a greater proportion of the total catch at open reefs belonged to these early age-classes than was the case at the closed reefs. Zoning status and reef group appeared to have a significant influence on the age distribution of spear-caught stripeys. The distributions were bimodal, largely because of one apparently very strong year-class. There is still some uncertainty about the relationship between estimates of stripey age derived from whole vs. sectioned otoliths. This question is being addressed, and a resolution should be forthcoming so that any necessary adjustments to the current data set can be incorporated in any analyses undertaken during Stage 2 of the study.

Estimates of the instantaneous rates of total mortality (Z) in coral trout based on samples taken by line and spear differed slightly (0.27 and 0.36 respectively) but the difference was non-significant. Z estimates for coral trout at open and closed reefs were identical (0.33). This raises some interesting questions about potential changes in natural mortality rates which may result from fishing activity removing top predators. It also suggests that our perceptions of the exploitation histories of reefs of differing zoning status might need to be reviewed, and highlights the essential need for obtaining reliable estimates of fishing effort (both recreational and commercial) at the scale of the individual reef.

The second stage of this study will involve a re-assessment of the demersal fish populations at the same four reefs one year after the new Cairns Section zoning plan came into effect. It is to be hoped that some information on fishing effort (however basic) expended at these reefs over the 12-month period will have been accumulated, to enable at least an indicative background of fishing exploitation levels against which to interpret any changes in population density or age structure that might have occurred in that time.

It is recommended that a similar sampling strategy be used in Stage 2, but that more field-time be allowed for sample collection, given the relative paucity of material other than *P. leopardus* which we were able to obtain during Stage 1. Some increase in the time allowed for laboratory processing will be required (based on our experience in Stage 1). We consider that an analysis of the diets of *L. carponotatus* would be a valuable additional objective, to help identify factors affecting the relative population density of this species on open and closed reefs.

INTRODUCTION

One of the major problems facing agencies responsible for managing the valuable fishery resources on the Great Barrier Reef is the scarcity of convincing quantitative evidence of the impact of recreational and commercial fishing activities on the populations, communities and stocks of fish along the Great Barrier Reef.

The Great Barrier Reef Marine Park Authority's regional zoning strategy provides the basis of an experimental investigation of the impacts of fishing on reef fish stocks. The re-zoning of the Cairns Section after eight years includes changes to the status of a number of reefs and reef complexes, some of which (by virtue of their previously closed status) were potentially able to be used in a "before and after" experiment to assess the effects of fishing.

Comparison of the relative densities of fish on protected and exploited GBR reefs has been the subject of several underwater visual census surveys in recent years. During a series of visual surveys of protected and open reefs in the Capricorn-Bunker Group, Ayling and Ayling (1986a) estimated the mean population density of coral trout to be 5.7 fish per 1000 m^2 around protected reefs (North, Wreck, Heron 1, Heron 2, Llewellyn and Boult) compared to 4.9 around fished reefs (Tryon, North-West, Wistari, Lamont, Fitzroy and Lady Musgrave). Mean density estimates varied considerably between reefs within zoning category, from 3.7 to 8.0 amongst protected reefs, and from 0.9 to 9.1 amongst exploited reefs. The difference between overall zoning category means was not statistically significant ($p>0.05$). When subdivided into sublegal (<35 cm TL) and legal (>=35 cm TL) size groups, however, significant differences in density between protected and fished reefs were apparent. Small coral trout were more abundant (by a factor of 2) on the open reefs, while there was a higher proportion of large trout on the protected reefs. The authors estimated that coral trout on the protected reefs were, on average, nearly 10 cm larger than those on reefs open to exploitation.

Ayling and Aylings' (1992) report on the results of UVC surveys conducted in 1983 and 1991 are of direct relevance to the present study as they relate in part to the mid-shelf reefs (Wardle, Nathan, Nor'Easter and Potter) in our study area. Little change in the relative population density of coral trout was evident between 1983 and 1991 at Wardle Reef, a protected reef and the only one of the four to have been surveyed in both years (5.2 and 5.8 fish per 1000 m^2 respectively). Interestingly, the mean count per 1000 m^2 at the other protected reef - Nor'Easter - in 1991 was substantially lower (2.5) than at Wardle in the same year, while in contrast a nearby exploited reef (Potter) yielded rather higher counts (7.2).

In a study of the short-term effects of fishing a previously closed reef in the Capricorn-Bunker Group, Beinssen (1989) found that two weeks' intensive fishing immediately after the widely-publicised opening of Boult Reef resulted in a decrease in trout density of approximately 30%, from 4.6 to 3.2 per 5-min swim transect. Prior to the opening of Boult Reef, the modal size of coral trout vulnerable to hook-and-line (45 cm) was substantially greater than it was at nearby Fitzroy Reef (38 cm) which had been continuously open to fishing. By May 1988, eighteen months after the re-zoning event, the proportional representation of larger size-classes in the Boult Reef trout population had declined markedly, and the modal size had declined to around 40 cm. Unfortunately no parallel UVC estimates of population density are given for 1988.

Brown (unpublished data) compared the length frequency distributions of coral trout between another protected reef (Llewellyn) and a suite of exploited local reefs in the Capricorn-Bunker Group. This comparison revealed a situation very similar to that reported by Beinssen (1989); the modal fork length of the "protected" coral trout population on Llewellyn Reef exceeded that of the pooled "exploited" populations by 10 cm (47 and 37 cm FL respectively).

Beinssen and Beinssen (1991) reported that the modal lengths of both coral trout and red-throat emperor were larger in the closed zone than the adjacent open zone on the reef surrounding Heron Island. The mid-points of the reported modal length classes (interpreted from Beinssen's figures 6 and 7) were 52.5 and 37.5 cm for coral trout, and 47.5 and 37.5 for redthroat emperors. On the other hand, an analysis of relative population density (counts per UVC transect) failed to reveal any significant zone effect - i.e. there was no statistical difference between fished and unfished zones in the numbers of either coral trout or redthroat emperor seen per unit search-time. Conversely, the authors recorded a significant difference between zones in the line-catch rate, the CPUE values for both species being higher in the closed areas. Considering the UVC result, this finding was attributed to a difference in catchability.

While the available information is generally supportive of common-sense hypotheses regarding the likely effects of exploitation on population density and size structure, Walters and Sainsbury (1990) stressed that analysis of age-structured data for the primary and/or indicator stocks would be an essential requirement of any major study to determine the effects of fishing on the GBR.

A workshop of GBRMPA's Effects of Fishing Programme collaborators in November 1991 considered it essential that the opportunity be taken to examine the effects of opening a previously closed reef on the age structure of resident populations of major predator species. Of the five reefs to be opened to fishing (Ribbon No.4, Escape, Channel, Wardle and Nor'Easter), one was initially selected for the study, with an adjacent fished reef as the control.

Because of the extremely limited time-frame for this work (the re-zoning was to have come into effect at the end of January 1992) the initial experiment design involved just the one pair of reefs. However delays in the re-zoning process made it possible to incorporate a second pair of reefs in the design, providing an essential although minimal degree of replication.

The first stage of the study was to test hypotheses about the differences between reefs which had been fished and those which had been protected from fishing during the past eight years. The second stage will involve testing hypotheses about the changes that may occur within fish populations on the same reefs during the 12-month period following re-zoning of the closed reefs from MNPB to MNPA.

The primary objectives of the study (in Stage 1) were

a) to determine whether any discernable differences exist in the age- and size-structure of populations of target species between the open and closed reefs.

b) to estimate the instantaneous rate of fishing mortality from estimates of total mortality (Z) at the open reefs and natural mortality (N) at the closed reefs.

It was anticipated from previous work and advice from fishers that coral trout (*Plectropomus leopardus*) and stripeys (*Lutjanus carponotatus*) would be the most abundant demersal predator species on these reefs. Modest catches of other lutjanids (*L. sebae*, *L. sanguineus*, *L. malabaricus*) and lethrinids (*L. nebulosus* and *L. miniatus*) were also to be expected, but given the time and budgetary constraints to sampling effort, we did not expect to catch large enough samples of the latter species for statistically meaningful between-treatment comparisons.

MATERIALS AND METHODS

Study sites and sampling chronology

This study was carried out in the near-reef waters surrounding two pairs of mid-shelf reefs at the southern end of the Cairns Section of the GBR Marine Park. These particular reefs were selected partly because of their proximity to major population centres and the increased likelhihood that once the closed reefs were opened to fishing they would be subjected to a significant increase in fishing pressure. The northern pair comprised Wardle (MNPB) and Nathan (MNPA), and the southern pair Nor'Easter (MNPB) and Potter (MNPA) (Figure 1). The two pairs, east and south-east of Innisfail, are approximately 30 km apart, and the reefs within pairs are about 15 km apart. At this geographical scale the study areas obviously cannot be assumed to be representative of the entire Cairns Section.

Experimental Design

The balanced design experimental unit consisted therefore of four mid-shelf reefs, comprising two fished/protected pairs. At each reef between 29 and 39 replicate spearfishing collections were made, primarily in the back-reef habitat, over a three-day period. The starting-points for the collection transects were selected haphazardly, and the estimated transect lengths varied between 50 and 600 m depending upon the extent of appropriate habitat and depth-range at the particular site. The primary object of the spearfishing operation (described below) was to collect a sample of fish (150 per species per reef), priority being given to *Plectropomus leopardus* and *Lutjanus carponotatus*.

The statistical design and subsequent hypothesis testing were constrained to some extent by logistic considerations. Reef groups were not selected randomly from all possible population units; rather they were chosen to represent a contrast - the Wardle/Nathan group, because of its closer proximity to Innisfail, was expected to be more heavily fished than the more distant Nor'Easter/Potter group. Hence reef group can be regarded as a fixed effect in the analysis, as the main effect of location (in relation to population centres) and its interaction with zoning status are both of interest.

As it was not possible to sample all reefs during the one field operation (because of availability of the support vessel and fishing crews) the northern pair was sampled in January, and the southern pair in February 1992 (Table 1). This means that reef group differences may be confounded with time, but comparisons of the effects of closures are nevertheless valid.

Field methods

Field operations were carried out from three outboard-powered open alloy boats (2 x 5 m and 1 x 4 m), with logistic support from the Department's 18 m research trawler R.V. *Gwendoline May* which acted as the operational base throughout. Two teams of experienced fishermen, including QDPI staff and volunteers, were responsible for collecting the fish by line and spear, and maintaining catch and observation records. Our reliance upon volunteers for this work made it impossible to retain exactly the same team membership during both sampling trips, but fortunately the experienced core members were the same during both trips. The dive teams comprised Lyle C. Squire, Lyle V. Squire, Tony Torenbeck and Cadel Squire (Trip 1), and Lyle C. Squire, Sid Caswell, Brian Bulmer and Roman Szulick (Trip 2). The line-fishing teams were Paul Leeson, "Snow" Smith, Bill Spooner and Peter Spooner (Trip 1), and Paul Leeson, Anthony Roelofs, "Snow" Smith and Dean Lay (Trip 2).

The dive (spearfishing) team worked from one 5 m dinghy, using snorkel only (no SCUBA), and adopted the following procedure for each "drop" or "swim": two divers entered the water at a predetermined locality, and after assessing the speed and direction of the current and the number and agressiveness of sharks, decided upon an appropriate swim distance. The dinghy was then moved the agreed distance, which varied from 100 to 500 m, away from the divers. The swim distance was estimated, rather than measured, by one of the team (LCS) who has had considerable prior experience with measuring and estimating transect lengths for underwater visual census work. The two divers then worked their way towards the dinghy, endeavouring to capture as many individuals as possible of the target species, regardless of size. The primary targets were the coral trout *Plectropomus leopardus* and the stripey *Lutjanus carponotatus*, the two predator species we suspected would be most abundant on the mid-shelf reefs in this area.

In order to maintain a quasi-UVC count which could be used as an approximate estimator of relative population abundance, the divers kept individual tallies of the numbers of coral trout and stripeys observed but not captured during the course of the swim. For the coral trout sub-tallies were kept for small (<40 cm TL) and large (> =40 cm TL) fish, but no size-subdivision of the stripeys was attempted. On reaching the dinghy the two divers then immediately recorded the numbers of fish seen and taken in each size category during the swim. It must be stressed that because of the higher priority placed upon searching for and capturing fish, some aspects of the visual census operation could not be as rigorously controlled as would normally be expected in the design of a UVC survey. Rather than being seen as a weakness in this project's methodology, the underwater visual counts should be regarded as a low-cost spinoff from the main operation, providing potentially valuable ancillary comparative data.

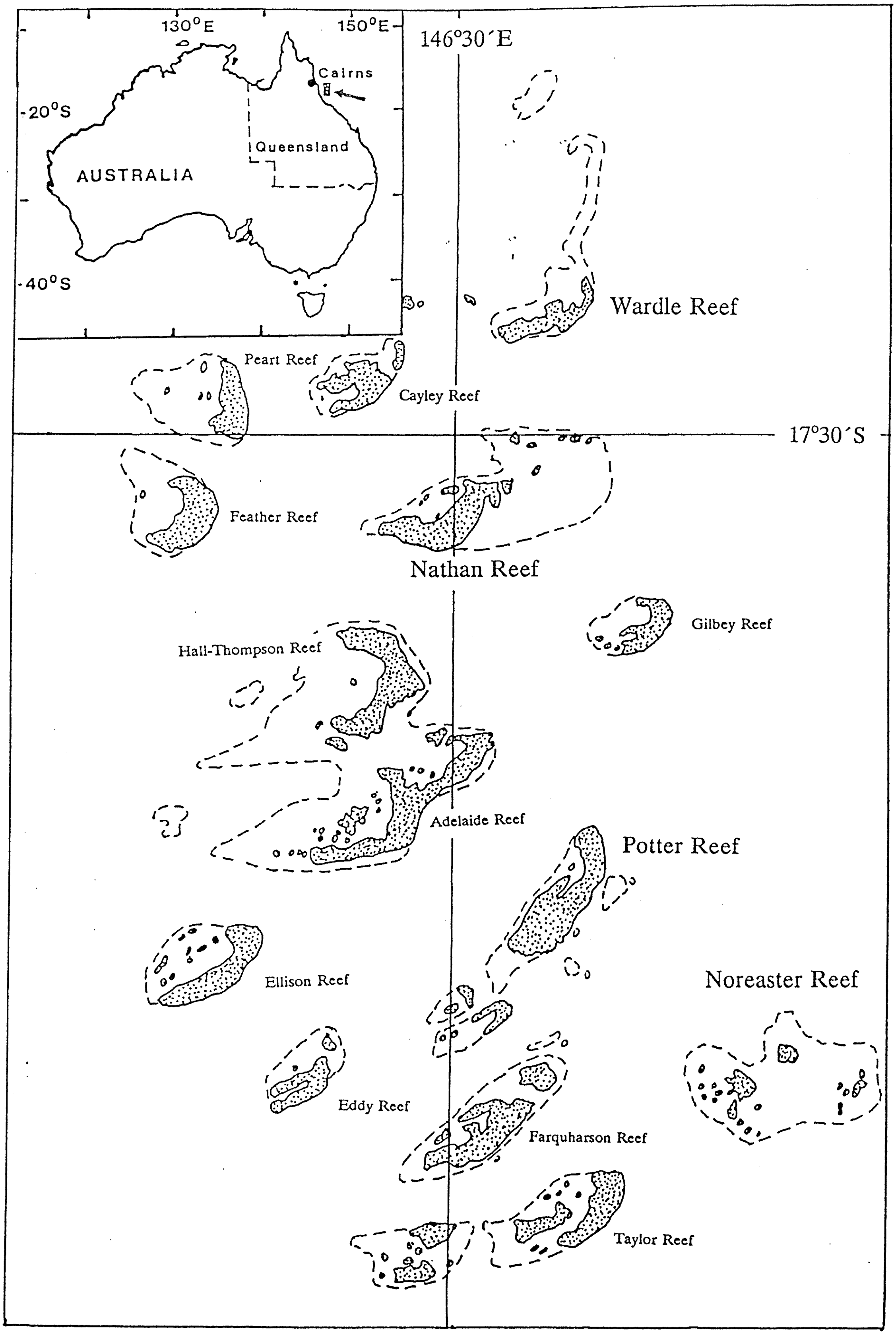

Figure 1. Southern part of the Cairns Section of the Great Barrier Reef Marine park, showing the four reefs (names in large type) sampled during this study.

The line-fishing team worked in pairs from the other two dinghies. During daylight hours (0600 - 1800 hr) when working near the reef single-hook rigs were used with WA pilchards as bait. At night in slightly deeper off-reefwater double-hook rigs were used, with pilchards and squid in combination. It proved difficult for the line team at night to locate good "redfish" grounds within the GBRMPA zone boundary 500 m from the reef edge, with the result that samples of small- and large-mouth nannygai and red emperor (*Lutjanus sanguineus*, *L. malabaricus* and *L. sebae* respectively) were small.

Table 1. Details of sampling dates at individual reefs and reef pairs.

REEF PAIR	REEF	SAMPLING DATE
Northern	Nathan	20/1/92 - 22/1/92
	Wardle	23/1/92 - 25/1/92
Southern	Nor'Easter	24/2/92 - 26/2/92
	Potter	27/2/92 - 28/2/92

As the duration of individual line-fishing episodes was variable (range: 0.17 to 13.75 hr; mean: 3.81 hr) and the number of fishermen also varied, the resulting catches could only be compared realistically if they were first adjusted to compensate for the differing levels of fishing effort expended. Line-fishing effort was therefore defined as the "fisher-hour": the product of the number of persons fishing and the duration of the fishing episode. Effort was distributed amongst the four reefs as follows: Wardle 71.9, Nathan 75.1, Potter 53.0, and Nor'Easter 64.9 fisher-hours. Line-fishing operations were carried out during daylight hours (post-dawn), dusk, and at night (to pre-dawn). The distribution of effort over the three time periods was as follows: daytime 131.1, dusk 25.7, and nighttime 108.1 fisher-hours.

All fish caught by the line fishing teams were identified (where possible) and measured. In some instances fishes of uncertain taxonomic status were taken back to the support vessel, and ultimately to the Northern Fisheries Centre's laboratories for positive identification. Non-target species were returned to the water immediately after capture. The commencement and finishing times of each fishing operation, as well as details of the locality and (usually) the name of the captor were recorded by each team. An approximate running tally of captures of each species was maintained for both the spearing and the linefishing operations to help keep within the sample-size limits of the research permit, but this was only likely to be a concern with common coral trout because of the relative scarcity of the other target species and the limited time available for sampling. Data from a sample of about 70 trout collected simultaneously for another research project at one of the open reefs (Nathan) were made available to supplement this project's data set.

Sampled fish were in some cases filleted on board the mother-ship, where whole fish and/or frames (with viscera intact) were bagged, labelled and frozen in the vessel's blast freezer. Because of the physical demands on the divers during the day, and the fact that the line teams also fished at night, no biological processing of the samples was done at sea.

Laboratory methods

1. Sample processing

All biological material was transferred from R.V. *Gwendoline May* to a large holding freezer at the NFC laboratory on completion of each trip awaiting processing by QDPI NFC staff (primarily LCS) and volunteer assistants, including Ms J. St John (JCU). After thawing, the fish (or frames) were re-measured and weighed, the gonads were examined macroscopically for sex determination, guts of the trout were removed for analysis at JCU, and finally the otoliths were removed, washed, dried and stored in labeled vials.

The otoliths of all coral trout (*P. leopardus*) and some blue-spot trout (*P. laevis*) were retained at NFC for reading, while those of all the other species were freighted to the Southern Fisheries Centre (Deception Bay). As substantial components of the data set were completed during the processing phase, copies of the original recording sheets were mailed to SFC for entry into a dBASE IV relational database set.

2. Age determination

Coral trout otoliths were read whole by LCS using a protocol developed earlier this year by NFC staff in collaboration with JCU researchers Ms B Ferreira and Dr G Russ. The technique involves heating the whole otolith on a hotplate to slightly discolour the protein matrix in the growth check, which enhances the contrast between bands. The otoliths are then immersed in oil (clove or aniseed) and read against a black background under a low-power stereo-microscope. The number of bands observed in this manner have been shown elsewhere to compare well with those obtained from otolith sections. The annual periodicity of growth banding structure in the otoliths of *Plectropomus leopardus* has recently been validated by Ferreira and Russ (1993) using fluorescence marking of otoliths in tagged fish.

All otoliths were read on two independent occasions by one reader, and (if the first two readings were not identical) a third time by a second reader. If the third reading was required and it coincided with one of the previous two, the coinciding age estimate was used. In the small number (12) of cases where all three readings were different, the otoliths were set aside for sectioning.

Little information is available on the estimation of age from stripey (*L. carponotatus*) otoliths apart from some preliminary work at NFC (G. McPherson, pers. comm.). It is acknowledged that the banding structure in the otoliths of this species has not yet been validated, and it will not be possible to achieve such validation on our present material because of the narrow time-frame during which the fish were sampled. However we suggest that if our samples show significant heterogeneity in year-class strength (resulting, for example, from differential recruitment success), it may be possible to validate our otolith interpretation after the next set of samples is collected twelve months hence. Although whole otoliths with presumed ages up to four years appeared relatively easy to read using a procedure similar to that described above for coral trout (but without the heating stage), otolith growth allometry produced severe crowding of rings in fish older than 4 years. This resulted in some serious disparity in estimates by the two SFC readers (IWB and LM), and it was considered essential to section all otoliths which showed more than 4 bands, and a proportion of those 4 or less years old. Final resolution of the ages of stripeys was not possible in time for the production of this report, so the results of analyses involving the age structure of *L. carponotatus* populations should be considered only indicative at this stage. The data used in these analyses were one reader's estimates from sectioned material, as these were considered more reliable than either of the two readers' estimates based on whole otoliths.

This procedure was also adopted for small-mouth nannygai (*L. sanguineus*) and large-mouth nannygai (*L. malabaricus*) otoliths even though McPherson and Squire (1992) report that these species can both be aged effectively using whole otoliths. Otoliths of the redthroat and spangled emperors (*Lethrinus miniatus* and *L. nebulosus*) were, however read whole without sectioning, as were those of the red emperor *Lutjanus sebae*.

Statistical methods

A balanced factorial analysis of variance was used to determine the significance of the main effects of reef group (Wardle/Nathan vs. Potter/NorEaster) and zoning category (MNPA vs. MNPB) and their interactions on the relative abundance of stripeys and blue-spot trout as well as small (<40 cm) and large (>40 cm) coral trout. The raw counts recorded by the divers during swims of varying distances were adjusted to counts per 50 m for comparison with the UVC data reported by Ayling and Ayling (1992). It should be pointed out that such comparisons are not strictly valid, as our counts were not constrained within a pre-determined transect width, and the total swim distance was estimated rather than measured. Pre-analysis tests revealed that the adjusted data were highly skewed to the right (e.g. skewness = 0.92, 2.04 and 1.18 for small, large and total *P. leopardus* with $n=142$; $p<0.01$), but normalisation was achieved or adequately approximated by applying a $\log_e(x+1)$ transformation. The ANOVA and subsequent significance-testing were performed on the transformed data, and the $\log_e(x+1)$ means $(\bar{y})$ then back-transformed $(\exp(\bar{y})-1)$ to equivalent catch rates, which are quoted. Swims within days and days within reefs were treated equally as sample replicates.

The effects of the main factors (reef group, zone and collecting method) and interactions on the age composition of the catches of coral trout and stripeys (as determined by examination of otoliths) were examined using a log-linear contingency table analysis with Poisson distribution and log link (Bishop *et al.*, 1978) within Genstat 5 (Rel. 2.2; Lawes Agricultural Trust, Rothamsted Exptl Stn).

RESULTS

1. Underwater counts

Common coral trout

The untransformed counts, despite non-independent variances, are presented here (Table 2) to enable comparison with the almost contemporaneous UVC data of Ayling and Ayling (1992). This table indicates that coral trout were more abundant on the closed reefs than open reefs. There appears to be a strong effect amongst the larger fish (>40 cm FL) and a weak, inconsistent effect amongst the smaller size-classes. In addition, the relative density of both size-groups of trout appeared to be considerably greater at Group B reefs (Potter and Nor'Easter) than at Group A reefs (Wardle and Nathan), which are more remote from Innisfail, the nearest major population centre.

Table 2. Untransformed counts per 50 m swim for small (<40 cm TL), large (>=40 cm TL) and total coral trout (*P. leopardus*) at each of the four reefs sampled.

STATUS	GROUP	REEF	SIZE	n	MEAN	s.d.
Closed	A	Wardle	Large	38	1.20	0.82
			Small	38	1.48	1.14
			Total	38	2.68	1.60
Closed	B	Nor'Easter	Large	39	1.58	1.34
			Small	39	2.33	1.30
			Total	39	3.91	2.25
Open	A	Nathan	Large	36	0.33	0.33
			Small	36	1.43	1.14
			Total	36	1.93	1.42
Open	B	Potter	Large	29	0.99	0.87
			Small	29	1.74	1.27
			Total	29	2.72	1.50

Back-transformed equivalent means (Table 3) from analysis of the log-transformed data generally concur with the raw data summaries in Table 2. Densities of both small and large coral trout were consistently and significantly higher at Group B than Group A reefs, again with a stronger effect in the larger size-classes (Table 4). There was a significant effect of zoning status for large fish ($p<0.01$), with higher densities recorded on both of the closed reefs than on either of the the unprotected controls. There was, however, no significant difference in the abundance of small (<40 cm FL) fish between open and closed reefs.

Table 4 also shows that there was no significant interaction effect between locality and zoning status with respect to either small or large trout, which suggests that the main effect of the zoning is not modulated by factors related to geographical area.

The length-frequency plots derived from the measured catch at the closed reefs (Fig. 2) are approximately normal with a mode at around 38-40 cm. However at the open reefs (particularly Nathan), there is evidence of a strong representation of young trout in the 20-30 cm FL range. This may initially appear contradictory to the ANOVA results presented above (i.e. that small trout are equally abundant on reefs of different zoning status), but can be explained in terms of the compensating effect of fish in the 30-40 cm size group.

Table 3. Equivalent mean densities (adjusted counts) of small and large coral trout (*P. leopardus*) by zoning status and reef group.

ZONING STATUS	SIZE CATEGORY	REEF GROUP	
		A	B
Closed	Small	1.27	2.04
Open	Small	1.33	1.49
Closed	Large	1.09	1.32
Open	Large	0.35	0.81
Closed	Total	2.40	3.40
Open	Total	1.68	2.36

Table 4. Results of ANOVA of common coral trout density data. Asterisks signify probability levels as in Table 3.

SIZE	SOURCE	d.f.	M.S.	F
Small	Group	1	1.128	6.02 *
	Zoning	1	0.253	1.35
	Interactn	1	0.454	2.42
	Error	138	0.187	
Large	Group	1	1.413	10.14 **
	Zoning	1	4.108	29.49 **
	Interactn	1	0.304	2.18
	Error	138	0.139	
Total	Group	1	2.064	9.88 *
	Zoning	1	2.228	10.69 *
	Interactn	1	0.009	0.04
	Error	138	0.209	

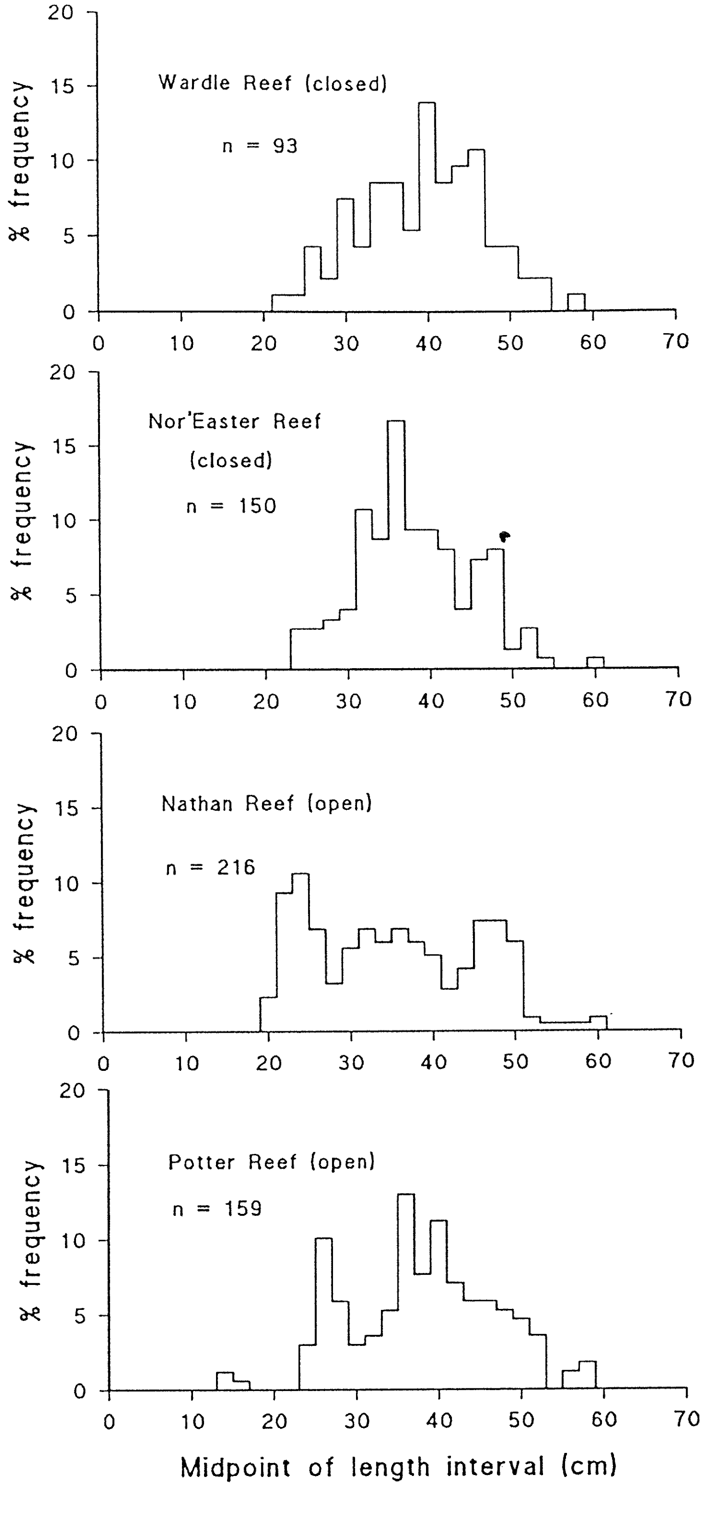

Figure 2. Pooled length-frequency distributions of handlined and speared common coral trout at each of the four reefs.

Bluespot trout

The decision to record underwater sightings of bluespot trout (*Plectropomus laevis*) was taken only as a result of the de-briefing following the first field operation (i.e. to Group A reefs). The analysis was therefore restricted to a comparison of coral trout densities between one fished and one unfished reef (Potter and Nor'Easter respectively). As only two small (<40 cm TL) bluespot trout were observed throughout the entire study, the analysis is further limited to a comparison of the relative population densities of large fish.

The equivalent back-transformed mean density of bluespot trout at Potter Reef (0.079 per 50 m) was significantly less ($p<0.05$) than that at Nor'Easter (0.260). Ayling and Ayling (1992) found that the overall difference in bluespot trout density between fished and protected reefs was non-significant. However it is interesting to note that while they reported sightings at Nor'Easter (0.17 per 50 m transect), none was recorded at Potter Reef at almost the same time as our survey.

Stripeys

Visual counts of stripeys (*Lutjanus carponotatus*) were likewise only recorded during the second field operation, and no attempt was made to categorise them by size, because of their relatively restricted size range. Thus the analysis is again a simple comparison between one closed reef and an adjacent open reef. Curiously, the back-transformed mean density of stripeys was an order of magnitude higher at Potter Reef (fished) than at Nor'Easter Reef (protected) (1.28 and 0.123 respectively). This difference was highly significant ($F = 84.82$; $p<0.01$), and supports the findings of Ayling and Ayling (1992), who reported that *L. carponotatus* was the only species they recorded at significantly higher densities on fished than unfished reefs.

The size-frequency data obtained from the spear and handline catches at each of the four reefs (Fig. 3) indicates that the modal length of stripeys at the protected reefs was somewhat greater than at the fished reefs. At the two open reefs (Nathan and Potter) the mode appeared to be around 28 cm, while at the closed reef from which an adequate sample was obtained (Wardle) the mode was around 34 cm. The multimodal pattern of these size-frequency figures may be related to age-class modes (see Fig. 7, subsequent section), but there was little consistency between reefs in this regard.

Comparison of UVC results

Fig. 4 provides a comparison between our (untransformed) UVC counts and those of Ayling and Ayling (1992) at the same reefs at almost the same time. There was a significant correlation between the two paired data sets ($r^2 = 0.44$; $p<0.05$), but considerable variability was evident.

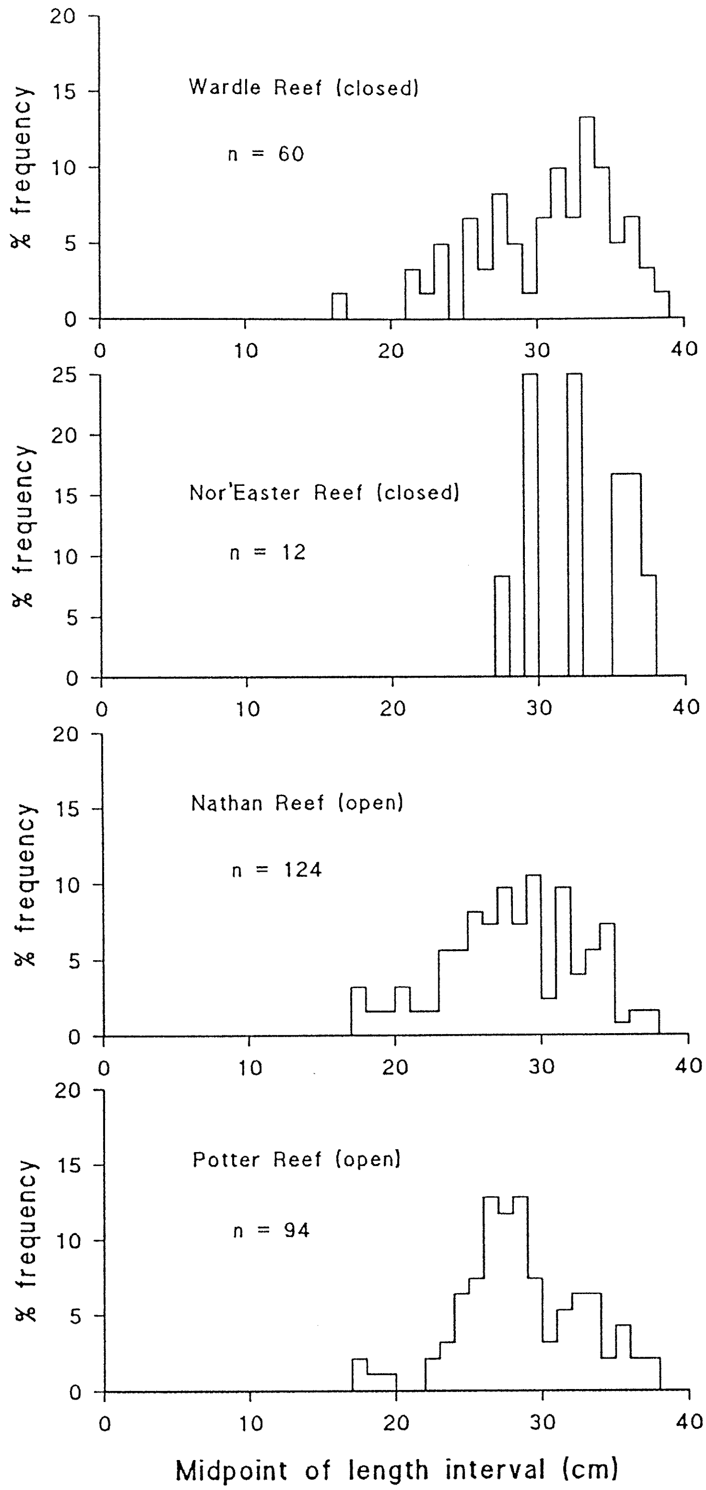

Figure 3. Pooled length-frequency distributions of spear and handline-caught stripeys at each of the four reefs.

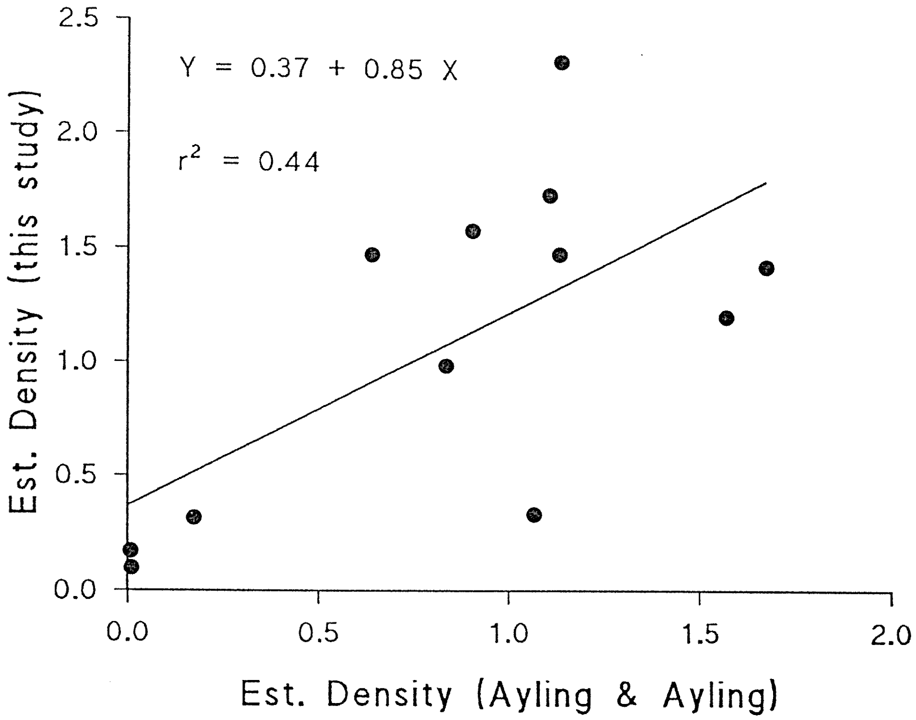

Figure 4. Relationship between UVC counts of three species (one subdivided by size) generated from two near-contemporaneous studies.

2. Handline catches

Handline catch data were summarised initially as untransformed CPUEs (numbers of individuals per fisher-hour). Figure 5 shows the mean CPUEs and associated standard errors for each species of which more than 20 individuals were caught during the two field operations. The data are displayed to show between-reef differences as well as differences in catch rate between the three time periods (day, dusk and night).

Ayling and Ayling (1992) reported that the redthroat emperor *Lethrinus miniatus* is one of the very few species they surveyed which differed significantly in population density between reefs of differing zoning status. We also found the handline CPUE to be significantly greater at the Group B protected reef (Nor'Easter) than at its fished partner (Potter), but catch rates at the Group A reefs were very small and the differences not significant (Fig. 5). The data in Fig. 5 also show that there is a substantial day-night effect, with nighttime CPUEs being consistently greater than those recorded during daylight hours.

None of the "redfish" species (red emperor [*L. sebae*], smallmouth nannygai [*L. erythropterus*] and largemouth nannygai [*L. malabaricus*]) showed a consistent difference in abundance, as estimated from handline CPUEs, between protected and fished reefs (Fig 5). Few if any UVC sightings of these species were reported by Ayling and Ayling

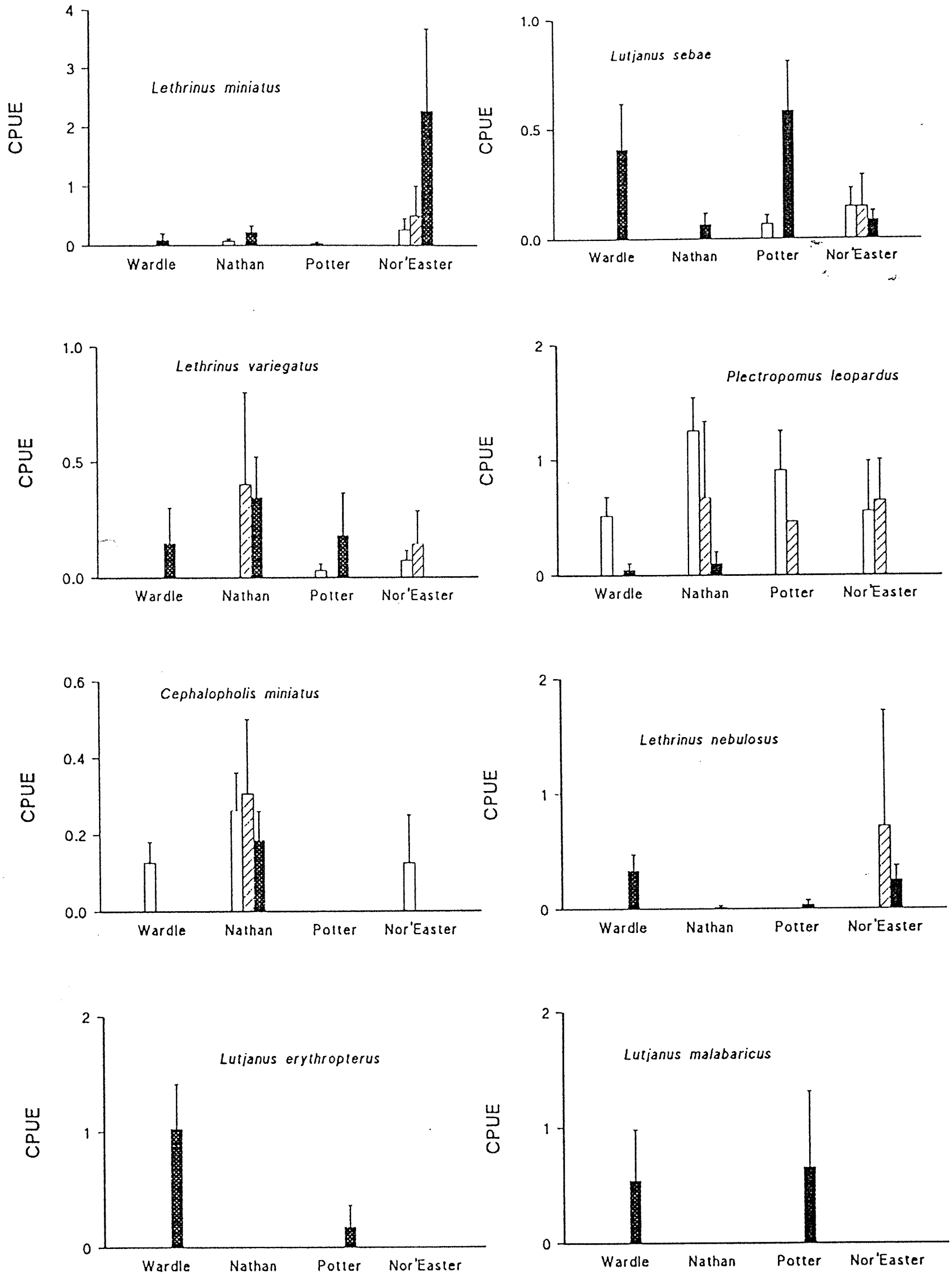

Fig. 5 Handline CPUEs (numbers of fish per fisher-hour) and associated S.E. for eight of the most abundant "miscellaneous" species at each of three time periods at each reef. The time-periods are identfied as follows: daytime- open, dusk- hatched, nighttime- solid. Numbers of observations (CPUE records) for each of the time-periods are as follows: Wardle 5, 0, 4; Nathan 4, 3, 4; Potter 4, 1, 2; and Nor'Easter 3, 2, 3 respectively.

(1992), presumably because red emperors tend to inhabit deeper water somewhat further offshore than the shallow UVC transects, and are the target of a primarily night-time fishery. The handline data presented here were derived totally from within the MNPB zone boundaries, and as the CPUEs were markedly greater at night than during the day, this might signify a behavioural response, with redfish moving into shallower inshore waters at night.

Catches of variegated emperor (*Lethrinus variegatus*) and coral cod (*Cephalopholis miniatus*) were quite variable (Fig. 5), and failed to show any consistent pattern that could be related to zoning category or reef group.

Spangled emperor (*L. nebulosus*) CPUEs appeared strongly influenced by zoning category, the two protected reefs yielding catch rates very much greater than those from the fished reefs. No spangled emperors were captured during daylight hours, the entire catch having been collected either at dusk or during the night (Fig. 5).

In contrast, coral trout (*Plectropomus leopardus*) were captured almost exclusively during the day (Fig. 5). Catch rates appeared somewhat higher at the open reefs, contrary to our UVC results (Tables 3 and 4) and the findings of Beinssen and Beinssen (1991). However this effect was due entirely to the disparity between CPUEs from the Group A reefs, the Group B reefs yielding equivalent catch rates.

3. Population age distribution

Otolith-derived age-frequency data for coral trout were tabulated by reef and collection method separately. This enabled us to test, using an analysis of deviance (ANODE), the effects not only of zoning status and reef position, but also of collection method (spear vs. handline) and their interactions on the estimated age composition of coral trout populations. Since very few stripeys were caught by hook and line, the analysis for this species was done only on the speared catch. Relatively small numbers of individuals of either species older than about 9 yr were captured, so for the purposes of the analysis of deviance all counts for age>9 were pooled into the 10th age class.

a) Coral trout

Essential results of the ANODE for *P. leopardus* are shown in Table 5. Five of the six 2-way interaction terms, but no higher level terms, were statistically significant. Apart from the Group effect, no non-significant terms (including residuals) are presented in the table.

The significant interaction between age and treatment is shown in Table 6 and Figs 3 and 6. For ages 3 and above there is little difference between the two treatments, and the significance arises almost totally from the very much greater proportion of 1-yr old fish on the open reefs (Potter and Nathan) (Fig. 6). This abundance of very young fish does not, however, account for the disparity in line-fishing catch rates of coral trout between zoning regimes referred to in the previous section, as no age 1 fish were taken by line (Table 7; Fig. 6).

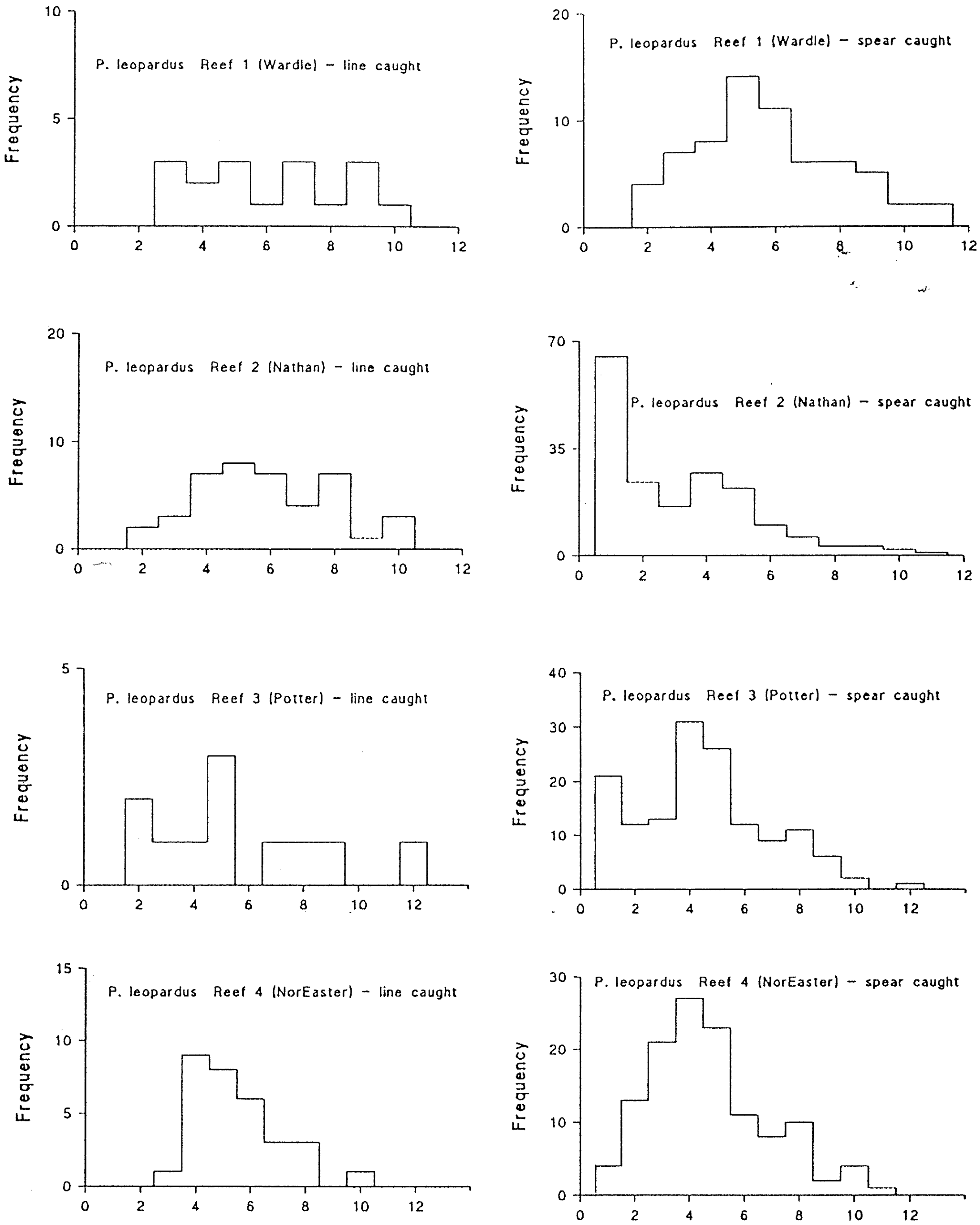

Figure 6. Age-frequency distributions of coral trout caught by hook and line (left) and spear (right) at each reef.

Table 5. Analysis of deviance results for common coral trout age structure.

TERM	d.f.	χ^2	Sig.
Method	1	303	**
Age	9	183	**
Treatment	1	32	**
Group	1	0.1	
G*T	1	35	**
A*M	9	57	**
G*M	1	4.1	*
T*M	1	6.5	*
A*T	9	50	**

Table 6. Back-transformed estimated counts per age-class for coral trout between closed and open reefs, averaged over reef group and fishing method.

AGE	CLOSED REEFS	OPEN REEFS
1	2.25	21.75
2	5.00	10.00
3	8.25	8.25
4	13.00	16.50
5	11.25	14.75
6	6.00	7.25
7	5.00	5.00
8	4.75	5.50
9	1.75	2.75
10	2.25	2.50

Table 7. Back-transformed estimated counts per age-class for coral trout caught by line and spear, averaged over reef group and zoning category.

AGE	LINE CATCH	SPEARED CATCH
1	0.00	24.00
2	1.00	14.00
3	2.00	14.50
4	4.75	24.75
5	5.50	20.50
6	3.50	9.75
7	2.75	7.25
8	3.00	7.25
9	1.25	3.25
10	1.50	3.25

The absence of significant three-way interaction terms suggests that sampling method does not have a significant influence on the effect of treatment (zoning status) on coral trout age-structure, and that neither reef group nor zoning status affects the relativity between age-structure patterns obtained by the different sampling methods.

b) Stripeys

The ANODE results for stripeys (*L. carponotatus*) are given in Table 8. There was no Method term in the analytical design because of near-zero line catches of this species. There was a significant difference in the age-distribution of stripeys due to zoning treatment effect (A*T interaction term), with disproportionately more young fish (ages 1-4) and very old fish (ages 10+) at the open reefs than at the closed reefs (Table 9; Figure 7).

Table 8. Analysis of deviance table for the age structure of the stripey (*Lutjanus carponotatus*).

TERM	d.f.	χ^2	Sig.
Treatment	1	72	**
Group	1	24	**
Age	9	91	**
G*T	1	19	**
A*T	9	19	*

Table 9. Back-transformed estimated counts per age-class for stripeys at closed and open reefs, averaged over reef group.

AGE	CLOSED REEFS	OPEN REEFS
1	0.50	7.50
2	1.00	5.00
3	8.00	26.00
4	0.50	10.00
5	0.50	4.00
6	3.50	6.50
7	6.00	8.50
8	4.00	9.50
9	7.50	14.50
10+	4.50	14.50

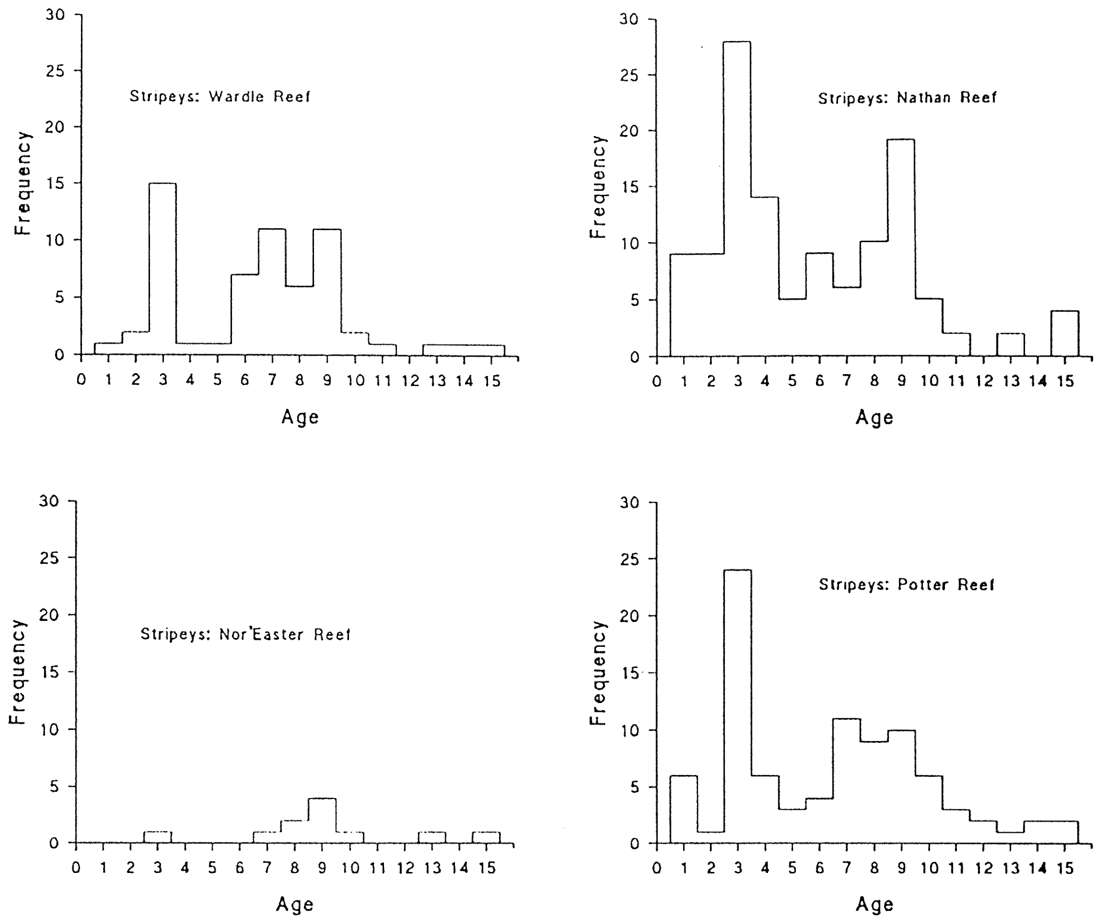

Figure 7. Age frequency distributions of stripeys (*Lutjanus carponotatus*) at each of the four reefs.

The age-frequency distributions for this species indicate that part of the A*T interaction effect was almost certainly due to what appears to be the exceptional strength of the 1989 year-class (age 3 yr at sampling). This phenomenon resulted in marked bimodality in populations at three of the four reefs, including both of the open reefs (Fig. 7), and may provide a means of validating the age-determination method for this species when the Stage 2 sampling is done.

c) Other species

Age-frequency data for populations of the other major species in the handline catch were pooled by zoning status because of the small sample sizes from individual reefs. Differences in the age-distribution patterns between open and closed reefs were slight (Fig. 8). However there was a tendency for modal lengths at open reefs to be slightly lower than at the closed reefs.

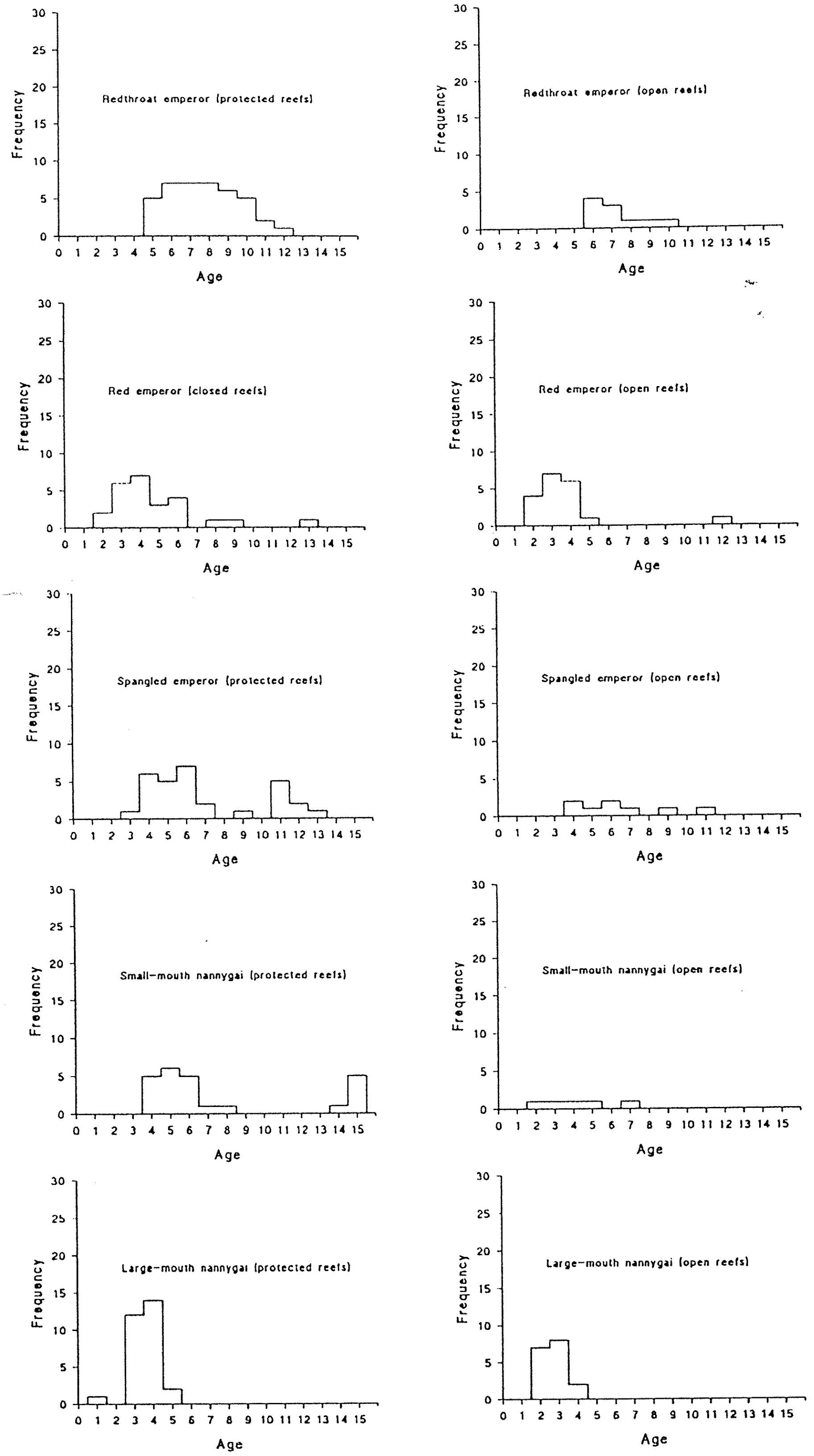

Figure 8. Age frequency distributions of populations of demersal fish species from the handline catch.

4. Mortality Estimation

The instantaneous rate of total mortality (Z) in populations of the coral trout (*Plectropomus leopardus*) was estimated from catch curves (Ricker 1975) based on age-frequency tables generated by the log-linear contingency model (Tables 8 and 9). While the analysis of deviance showed a significant effect of sampling method upon the age structure of the samples, (see previous section), this appeared to be due primarily to the first couple of age classes, which are probably not fully recruited into the handline fishery (Beinssen 1989). For this analysis we therefore included only age-classes 5 and above to estimate Z (-b in the regression).

Firstly the effects of sampling method were examined to determine whether the data could be pooled. The catch curves derived from spear and line-caught coral trout samples (Fig. 9) yielded estimates of Z equal to 0.36 and 0.27 respectively. The difference between these slopes was not significant ($t = 0.896$; $p > 0.05$ with 8 d.f.), indicating that the two fishing methods were not acting selectively with respect to each other on the older age-classes of coral trout.

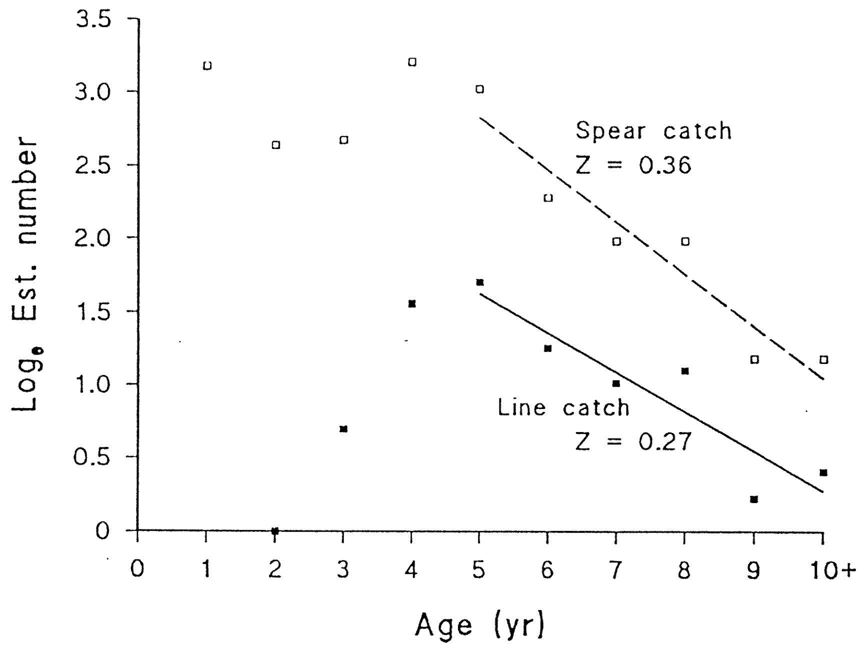

Figure 9. Catch curves and estimates of Z for pooled line and speared catches of coral trout (*P. leopardus*).

The log-linear model estimates averaged over fishing method and reef group (Table 6) were then used to estimate total mortality rates at closed and open reefs. Differences between these could then be used to estimate fishing mortality rate (F) on the open reefs (the alternative hypothesis being H_1: $Z_{(open)} > Z_{(closed)}$, where $Z_{(open)} = M_{(common)} + F_{(open)}$).

The catch curve analysis (Fig. 10) shows in fact that the slopes of the descending limbs of the curves are parallel, and consequently that the estimate of Z from trout populations on open reefs is identical to that from closed reefs (0.33). This suggests, contrary to all expectation, that a period of eight years without fishing pressure has had no discernable effect on the instantaneous rate of total mortality of coral trout populations on these particular coral reefs.

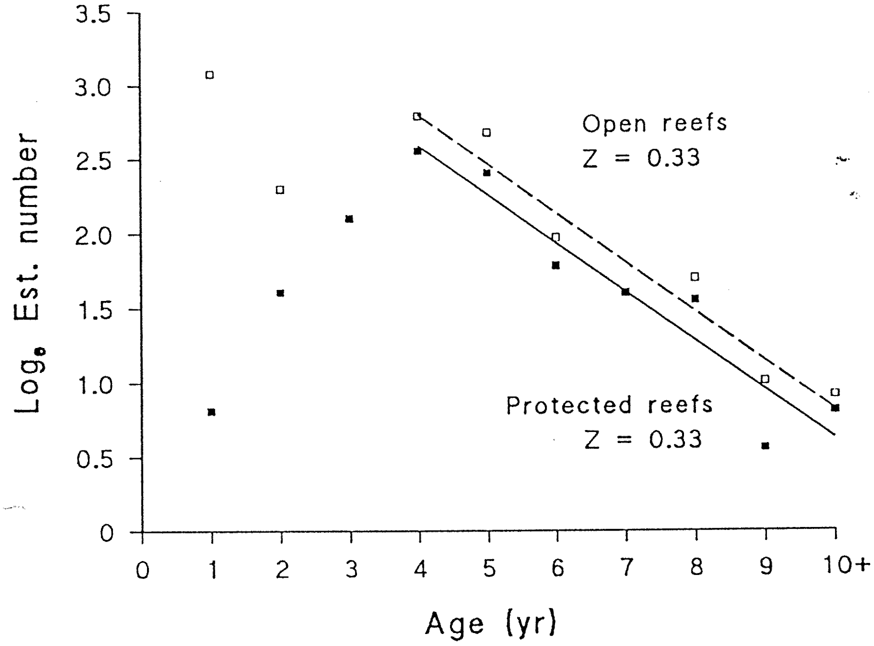

Figure 10. Catch curves and estimates of Z for populations of coral trout (*P. leopardus*) at protected and open reefs.

DISCUSSION

Collection of the relative population density data described in this report was a secondary objective to that of obtaining as large a sample as possible of several species of fish for age-structure analysis. Two such objectives cannot be mutually inclusive, and the biological sampling requirement meant that the requirements of a good survey protocol (random transect placement, fixed transect size etc) could often not be maintained. However as the field methodology was consistent throughout the sampling operation, we believe that the comparisons were not compromised.

There was a significant correlation between our visual estimates of the relative population density of small and large common coral trout, bluespot trout and stripeys and those of Ayling and Ayling (1992). The outliers in this comparison were the estimates for small (<40 cm) trout on Nor'Easter reef and large (>40 cm) trout on Nathan Reef. The fact that Ayling and Ayling used 35 cm TL as the criterion for defining size is not likely to have a great deal of effect on these comparisons. It is not clear whether Ayling and Ayling used raw or transformed counts in their analyses, but we found the application of a log transform essential because the raw scores were so highly skewed.

The ANOVA on divers' counts indicated significant differences in the relative density of small coral trout (*Plectropomus leopardus*) between the northern and southern reef groups, but not between reefs of differing zoning status. Ayling and Ayling similarly reported a very significant "reef" effect but no "zone" effect for small fish.

Our study indicated that large trout (as estimated by underwater counts) were significantly more numerous at the closed than the open reefs. Beinssen (1989 and 1991) found a similar situation for trout at a pair of adjacent but differently zoned reefs in the Capricorn-Bunker Group, and in different zones on a single reef respectively. Lock (1986) reported a negative relationship between average size of fish caught and the exploitation level at a number of reefs in the Port Moresby (PNG) region. It is interesting, therefore, that Ayling and Ayling reported only a small (non-significant) difference in population density of large trout between open and closed reefs. We found also that there was a significant location (reef) effect on density of coral trout, as did the Ayling survey.

Somewhat surprisingly, stripeys (*Lutjanus carponotatus*) appeared from the UVC counts to be more abundant at Potter Reef (open to exploitation) than at Nor'Easter (protected). No underwater counts were made at the two reefs sampled during the first field operation. While it could be argued that the (highly significant) difference may have been due to factors other than the zoning status of the reefs, it is interesting to note that Ayling and Ayling (1992) found this to be the only species consistently more abundant at fished than unfished reefs.

In contrast with the UVC data, the coral trout handline catch-effort indices from this study seem to suggest a quite different situation, with higher catch rates at the open reefs than at the closed reefs (but only at Group A reefs). This contrasts markedly with the handline catch of trout in MNPA and MNPB zones of Heron Is. reef reported by Beinssen (1991). The reason for this disparity between UVC and line catch data is unclear, particularly in that the effect is evident only at the reef groups which are presumed to be subject to the higher level of fishing pressure.

Age distributions of coral trout populations were influenced by the interaction of zoning status and location (reef group), and estimates from the spearfishing catches differed from those based on the line catch. The important feature of this analysis is that zoning status had a significant effect on age structure, which initially suggested that the exploitation history of the open reefs may have been sufficient to produce a measurable effect on total mortality. However the data indicate that the age distribution differences are due to a far greater proportion of 1- and 2-yr old fish on the open reefs, and that the frequency distributions for ages greater than 3 were very similar. Total mortality rates calculated on the basis of 3+ yr fish were in fact identical for the samples from open and closed reefs.

No estimates of total mortality rate were made for stripeys because of the extreme multimodality of the age-frequency plots. Of particular significance was the fact that three year old fish (the 1989 year-class) dominated at three of the four reefs (Wardle, Nathan and Potter). The sample from Nor'Easter was too small to be considered representative of the population. Two other age modes were conspicuous: 7 year olds were well represented at Wardle and Potter Reefs, and 9 year olds at Wardle, Nathan and Potter. This suggests strong recruitment pulses in 1983, 1985 and 1989, possibly as a result of environmental conditions (at least in the southern part of the Cairns Section) which either favoured the entrapment of pelagic larvae close to the reefs, or promoted the survival of post-settlement recruits. By way of contrast, it would appear from the relative paucity of 5 year olds at any of the four reefs that 1987 was a particularly poor year for larval settlement or recruit survival.

Despite these between-reef similarities in age structure, there was an overall statistically significant difference in averaged age distribution between open and protected reefs. This is largely the result of a disproportionate representation of very young fish (ages 1-4) and very old fish (ages 10+) in samples from the open reefs. These results are contrary to expectation, particularly with regard to the older fish which, according to theory, would be expected to be depleted as a result of exploitation. The abundance of young fish at the open reefs might perhaps reflect a predator-prey balance effect. If one of the stripey's major predators was reduced by fishing, and the stripeys themselves were not significantly fished down (because of a low natural vulnerability to capture by hook and line relative to that of the predator) then the population might flourish. At present, however, there is no indication of which species might be considered important predators of *L. carponotatus*, nor whether the abundance of such predators may have been reduced on the open reefs.

The evidence for fishing effects on the populations of coral trout is conflicting. Only our UVC data provide any indication that populations on protected reefs in this part of the GBR Marine Park are in a "healthier" state than those on adjacent exploited reefs. The age-frequency analysis, for which there is no *a priori* reason to suspect sampling bias between closed and open reefs, suggests that total mortality rates are just as high on the closed reefs as they are on the open reefs. At least four different explanations could account for this situation:

i) Natural mortality rate is lower on the open reefs than on the closed reefs, the difference equating approximately to the fishing mortality rate on the open reefs

ii) Large differences in year-class strength decrease the sensitivity of catch-curve comparisons and obscure real effects.

iii) Coral trout migrate between adjacent coral reefs in sufficient numbers to neutralise any effect of fishing on the population.

iv) Fishing mortality is greater than generally assumed on the closed reefs, and less than generally assumed on the open reefs.

The first scenario might conceivably arise through a significant reduction in the density of very large predators (e.g. sharks, mackerel) as a result of fishing activity. Sharks (particularly grey whalers) were reported by our dive team to have been much more in evidence on the MNPB reefs, but there is little information available on the diets of reef sharks, and the extent to which they normally prey on demersal fish such as serranids is not known.

Estimation of Z from the frequency distribution of age classes in the population is a regression technique involving a relatively small number of degrees of freedom (a function of the number of age-classes in the recruited sector of the population). For this reason variable year-class strength, which might occur as a result either of differential year-to-year survival rates or variable recruitment success, will affect the standard error of the slope estimate quite strongly. As there is evidence from the age-frequency data of some variability in year-class strength, and that the patterns are not necessarily the same at even adjacent reefs, this (statistical) effect may indeed need to be considered.

While the possibility of inter-reef migration obscuring the effects of fishing on local populations of (for example) coral trout cannot be entirely ruled out, the great majority of recent tagging work on demersal GBR fish (e.g. Beinssen 1989; Beinssen and Beinssen 1991; McPherson (unpublished data) and Brown (unpublished data)) indicates a high degree of reef-association, and even site-association within a reef by many of the major predator species including coral trout. It is anticipated that a more definitive statement on this issue will be forthcoming within the next 12-18 mo as results from the James Cook University's GBRMPA-funded Reef Fish Tagging project begin to accumulate.

The fourth possibility is potentially feasible, as the study area is not subject to constant surveillance and (unsubstantiated) reports of illegal fishing activities on "green" reefs in various parts of the GBRMP are not uncommon. It is important that available aerial surveillance data be examined to determine the extent of possible illegal fishing in this region. That such a scenario should even be considered indicates the need for care in making assumptions about the relationship between zoning status and exploitation history. Unfortunately the compulsory commercial fisheries logbook data are not recorded at a sufficiently localised scale to enable an analysis of fishing catch and effort between individual reefs, and appropriate data relating to the activities of the the growing recreational fishery are non-existent. We are aware, however, that at least the recreational fisheries in the general vicinity of our study area tend to target the lutjanid "redfish" (*L. malabaricus*, *L. erythropterus* and *L. sebae*) rather than coral trout. These factors in combination (i.e. illegal fishing on closed reefs and relatively light fishing on open reefs) may contribute to the absence of a distinct difference in total mortality rates of coral trout populations between reefs of different zoning status.

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