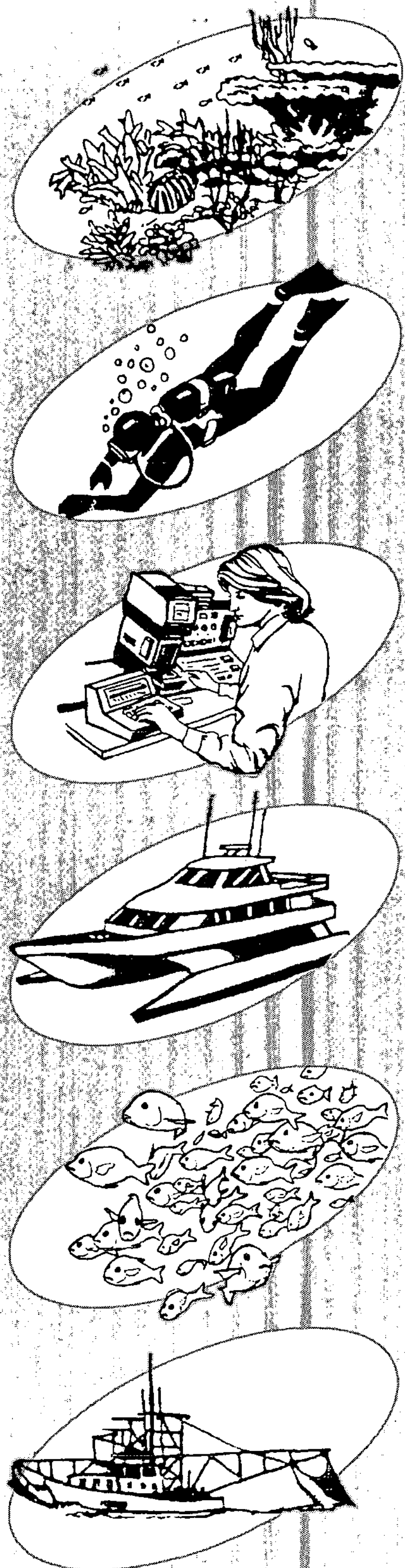
CRC REEF RESEARCH

TECHNICAL REPORT



A long-term study on population structure of coral trout on reefs open and closed to fishing in the central Great Barrier Reef

Garry R. Russ, Dong C. Lou & Beatrice P. Ferreira

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A LONG-TERM STUDY ON POPULATION STRUCTURE OF THE CORAL TROUT *PLECTROPOMUS LEOPARDUS* ON REEFS OPEN AND CLOSED TO FISHING IN THE CENTRAL GREAT BARRIER REEF

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EXECUTIVE SUMMARY

The objectives of this study were to measure the effects of line fishing on the average size, age and sex ratio of coral trout, *Plectropomus leopardus* in the central Great Barrier Reef (GBR). From 1990 to 1993 coral trout were collected by line fishing at two coral reefs, Glow and Yankee, closed to fishing since 1987, and at two other reefs, Grub and Hopkinson, that have always been open to fishing. There was no significant difference in average size or age of coral trout on reefs closed and open to fishing, despite the reefs having been closed for 6 years by 1993. This may have resulted from illegal fishing on the closed reefs and/or fishing pressure on the open reefs being low. There were significant differences in average size and age of trout between the open reefs (Grub, Hopkinson) and the closed reefs (Glow and Yankee), reflecting natural variability in populations between reefs or variations in accessibility of open reefs, with Grub being a much better anchorage than Hopkinson and thus being more heavily fished.

On the two reefs closed to fishing, the population structure was dominated by a strong cohort (year class) which settled onto the reefs in early 1984 (i.e. 6, 7, 8, 9 years old in 1990, 1991, 1992 and 1993 respectively). The strong cohort accounted for 54%, 45%, 42% and 36% of the experimental hook and line catches on reefs closed to fishing in 1990 to 1993 respectively. Note that maximum age for coral trout is around fourteen years on Townsville reefs. This is the first time a dominant age class has been tracked over time for any coral reef fish by examination of age structures. The results demonstrate that strong interannual fluctuations in recruitment can influence the abundance of coral trout populations substantially, and that the effect of strong recruitment events can be retained in the age structure of coral trout populations. On the closed reefs an event that occurred in 1984 was still dominating the fishery 9 years later in 1993. This finding has important implications for the management of the fishery and zoning (reef closure) strategy of the Great Barrier Reef Marine Park. It suggests the possibility that abundance of coral trout in the fishery may be predicted two to four years in advance using yearly surveys of newly settled juveniles, in a similar way to the use of settlement intensities of larval lobsters to predict catches of western rock lobsters four years in advance. Furthermore GBRMPA may, in future, be able to arrange timing and location of reef closures, based on counts of newly settled juveniles, to best maintain regional populations of trout.

A similar strong cohort was not observed on the fished reefs close by, although there was a suggestion of such a cohort on Hopkinson reef. If such a strong cohort did settle onto the open reefs fishing may have reduced its abundance relative to other age classes in the population. However, this would imply the unlikely scenario of the strong age class somehow being more vulnerable to the line fishing gear than the other age classes. The size structure of populations at all four reefs remained relatively consistent, with no dominant size group in the population over time at both closed and open reefs. Large variability in size at a given age meant that age but not size structure provided a good indicator of population dynamics.

By examining the stages of development of the gonads throughout the year the annual spawning season was confirmed to be from early spring to early summer off Townsville. Age at first reproduction was around two to three years old (30 to 35cm, total length). Coral trout change sex from female to male. Age and size at sex change was very variable. Sex change was observed in coral trout from ages three to twelve years and from lengths 30 to 55cm total length. Thus it was difficult to detect a clear effect of fishing on the size and age at sex change. Since line fishing tends to be selective for larger animals, fishing may affect the sex ratio by reducing the proportion of males (which on average are larger than females). The sex ratio varied among reefs and showed a slightly higher proportion of males on the closed reefs. However, there were no significant differences in size or age of males between reefs closed and open to fishing. The main conclusion of this part of the work was that closure to fishing did not have a strong effect on the sex structure of coral trout off Townsville. Again, this may have resulted from illegal fishing on closed reefs and/or fishing pressure on the open reefs being low.

In summary, the effects of fishing on the average size, age and sex ratio of coral trout were inconclusive. However, the presence of a dominant year class in the population of trout on the two closed reefs showed that strong interannual fluctuations in recruitment can influence the abundance of coral trout populations substantially. This effect of strong recruitment events can be retained in the age structure of coral trout populations. On the closed reefs a recruitment event that occurred in 1984 was still dominating the fishery nine years later in 1993. This suggests the possibility that abundance of coral trout in the fishery may be predicted two to four years in advance using yearly surveys of newly settled juveniles.

John Robertson
GBRMPA Coordinator
Effects of Fishing

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1. INTRODUCTION

Fishing is one of the most important human exploitative activities on coral reefs (Munro and Williams, 1985; Russ, 1991). The effect of fisheries on populations and communities of coral reef fishes has been a concern as it is often suggested that fishing may have a greater impact upon fish populations and communities of coral reefs than upon those of temperate seas (Russ, 1991). Large predatory species are especially affected by overfishing, due to life history characteristics such as slow growth, high longevity, low rates of natural mortality and limited adult mobility (P.D.T., 1990; Russ, 1991).

A widely recognised management strategy in the conservation of reefs is the implementation of Marine Fisheries Reserves, areas designed to protect stocks of reef fish and habitats from all forms of exploitation (P.D.T., 1990; Williams and Russ, 1994). In modern times, the first marine protected area was established in Florida in 1930. Since then, protected marine areas have been implemented all over the world (P.D.T., 1990). In Australia, the first protected marine areas were established in the Capricornian Section of the Great Barrier Reef Marine Park (GBRMP) in 1981, under the first zoning plan to come into operation.

Evidence indicates that long term spatial closure to fishing increases the density, biomass and average size of reef fishes (see P.D.T., 1990; Russ, 1991). Furthermore, by enabling populations of reef fishes to attain or maintain natural levels, marine reserves have been suggested to help maintain critical spawning stocks or even enhance local yield of fishes in areas adjacent to the reserves (Russ, 1985; Alcala and Russ, 1990).

The spatial structure of coral reefs provides an excellent opportunity to test for the effects of different management alternatives (Hilborn and Walters, 1992). The importance of experimental investigations on the effects of fishing on coral reefs using reefs as replicate experimental units has been pointed out by various authors (Russ, 1991; Hilborn and Walters; 1992). Yet, in spite of the high expectation placed on the Marine Reserves, few direct tests exist on the effects of such protection on maintenance of spawning stocks or yields of marine resources (Alcala and Russ, 1990).

The coral trout (*Plectropomus leopardus*) is a long-lived, protogynous hermaphroditic fish which represents a very important fishery resource over the whole Great Barrier Reef (GBR), Australia. Because of its importance, the coral trout has been the subject of many studies investigating the effects of fishing. These studies compared the abundance and size structure of populations from open and closed reefs on the GBR (see Williams and Russ, 1994, for review). Most of these studies were conducted using underwater visual census (UVC) techniques. Increased average size of coral trout on reefs closed to fishing was detected in most cases (Craik, 1981; Ayling and Ayling, 1984, 1986). Beinssen (1989a) used UVC, line fishing and mark-release-recapture techniques to investigate the effects of a 3.5 year closure on Boult Reef and detected a significant increase in average size of coral trout. The same reef was subsequently opened to fishing and after 18 months a significant decrease in the average size of coral trout was detected (Beinssen, 1989b). No study, however, has investigated the effects of fishing on the age and sex structure of coral trout populations. The age and growth of coral trout have been recently validated (Ferreira and Russ, 1994), making it possible to effectively use age as an indicator of changes in population structure under different levels of fishing pressure and through time.

1.1 *Background*

In 1987 a zoning plan was established in the central section of the GBRMP, dividing the area into zones which allowed different activities. Under this plan, fishing was allowed in the General Use Zones and excluded in the National Park Zones.

From 1990 to 1992 coral trout populations had been sampled by line fishing on two reefs, Glow and Yankee, located in the National Park Zone, and two other reefs, Grub and Hopkinson, located in the General Use Zone in the central GBR. Based on data of size, age and sex structure from 1990 to 1991 Ferreira and Russ (in press) concluded that there were no significant differences in mean size, age or sex structure between the closed and open reefs. However, on the two reefs closed to fishing the populations were dominated by a very strong year class that settled in early 1984 (6^+ fish in 1990 and 7^+ fish in 1991). A similar pattern was not observed on the reefs open to fishing. If the abundance of coral trout populations can be influenced strongly by interannual fluctuations in recruitment, which are retained in the age structure of the populations, this finding has important implications for the zoning strategy of the GBRMP.

However, the durations of closure in 1990 and 1991 were relatively short (3 and 4 years) in relation to the maximum longevity of 14 years for coral trout (Ferreira and Russ, 1994). A further study was necessary in order to determine longer-term effects of reef closure on the size, age and sex structure of coral trout populations, and to confirm the earlier finding of a strong year class.

1.2 *Project Description and Outcomes*

This project aimed to determine long-term size, age and sex structures of coral trout populations on the four reefs closed and open to fishing. It was a continuation of the study initiated by Ferreira and Russ (in press). The major tasks included the collection of coral trout belonging to the 1993 year class, determining age and sex structures of the samples collected in 1992 and 1994, and analysis of the data on size, age and sex structure on the four reefs over the four years (1990-1993). The outcomes of this project will provide a comprehensive report detailing the size, age and sex structures of coral trout populations on reefs closed and open to fishing off Townsville in the central GBR over a 4 year period (1990-1993), and a potential technique for predicting recruitment into the coral trout fishery three years in advance.

2. MATERIALS AND METHODS

2.1 *Location and Sample Collection*

Four mid-shelf reefs off Townsville, in the central GBR, were chosen as the sample reefs for this project. These were Glow, Yankee, Hopkinson and Grub, approximately 45 nautical miles north-east of Townsville (Fig.1). Two reefs, Grub and Hopkinson, were located in General Use Zones, and were open to line and spear-fishing. The other two, Glow and Yankee, were located in National Park Zones, and closed to fishing since September 1987.

From late June, 1990 to May 1994, a total of 945 coral trout were collected by line fishing (Table 1). Almost half of these fish were collected under the current project (ie, 1994 samples). For each sampling trip, four line fishers fished at one reef for a period of approximately four daylight hours. The fishing crew was relatively consistent in composition, with an overall fishing ability maintained from trip to trip as far as possible. The Challenger was used as the sampling vessel from 1990 to 1992 while the Amanda Jane was used in 1994. Both vessels were similar in size and engine-capacity.

Fishes sampled were measured to the nearest millimetre in fork length and weighed to the nearest 10 grams while fresh. Gonads of the fishes were removed fresh and preserved in FAACC (formaldehyde acetic acid calcium chloride) on board. The heads of fishes were frozen immediately upon collection, and processed for otolith analysis later in the laboratory.

Table 1. Date and number of coral trout collected in each sampling trip.

Fishing	Status		Closed	Open	
Month	Year	Glow	Yankee	Grub	Hopkinson
Jun/Jul	1990	52	18	9	14
Sep/Oct	1990	50	42	11	18
Jun/Jul	1991	74	54	14	29
Sep/Oct	1991	24	11	15	15
August	1992		33	24	
October	1992	62			23
March	1994	48			25
April	1994		57	22	
May	1994	52	71	24	54
Total	90-94	362	286	119	178

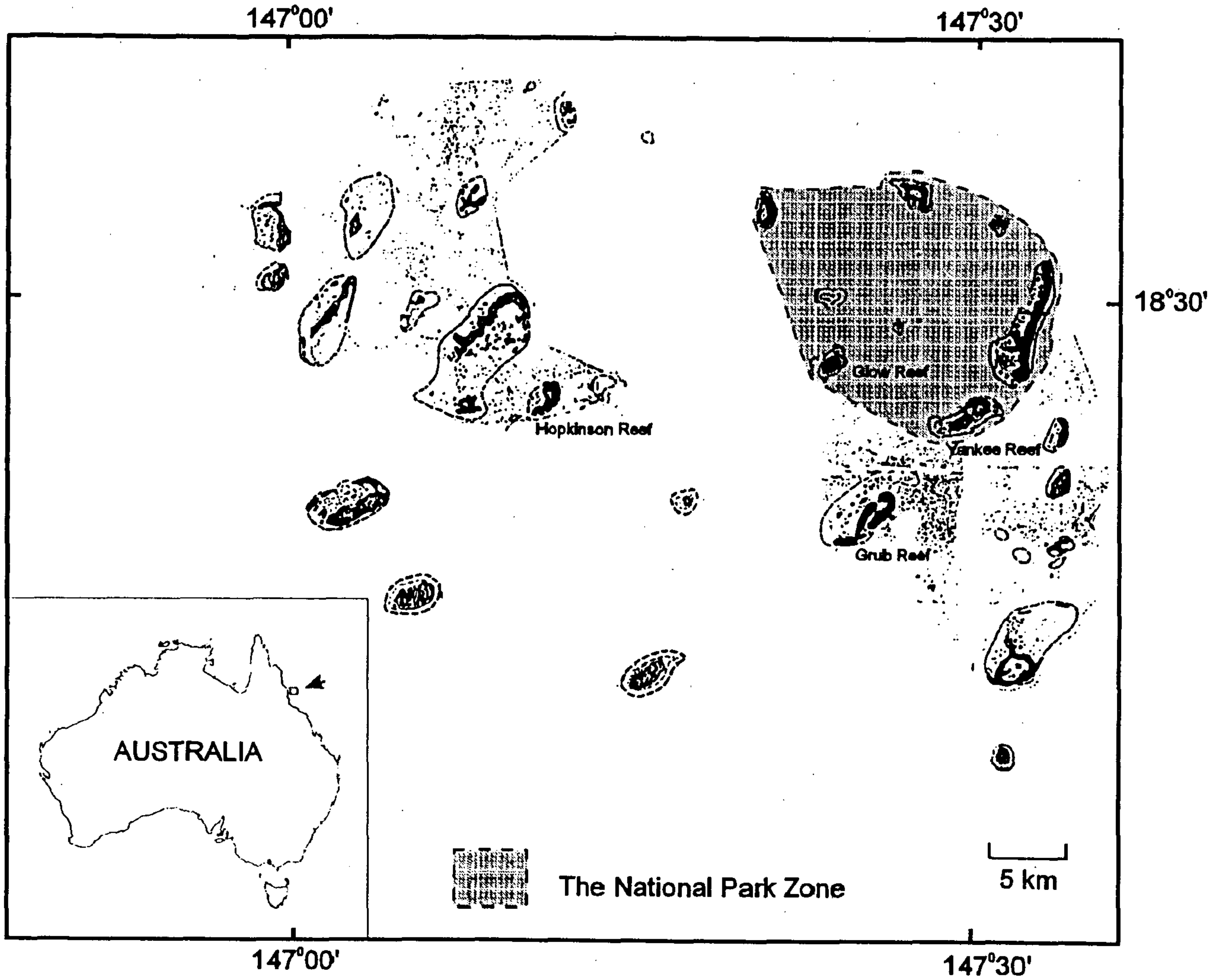

Fig.1 A map showing the location of sampled reefs:
Glow and Yankee (closed to fishing) and Grub and Hopkinson (open to fishing).

2.2 *Otolith Preparation*

To determine the ages of fish, sectioned otoliths were read following the methodology described by Ferreira and Russ (1994). The sagitta was prepared for reading by first embedding in epoxy resin (Spurr, 1969) and then sectioning transversely through the core with a Buehler Isomet low-speed saw. Sections were then mounted on glass slides with Crystal Bond 509 adhesive, ground on 600- and 1200-grade sand paper, polished with 0.3 μm alumina micropolish and then examined under a dissecting microscope at 40X magnification with reflected light and a black background. Annuli were counted from the nucleus to the proximal surface of the sagitta along the ventral margin of the sulcus acousticus.

Coral trout recruitment occurs in the first months of the year (Doherty, 1991), so the birth date was assigned as 1st January. Opaque zones are formed once a year, from July to November (Ferreira and Russ, 1994), and were counted only when there was further deposition of a translucent zone, ie, from December onwards. Therefore, the number of rings corresponded to the real age of fishes. Furthermore, the outermost opaque zone of otoliths of coral trout collected from March to May 1994 was actually deposited in 1993. Thus, these samples were termed the 1993 year class in this report.

2.3 *Gonad Preparation*

The gonads were processed histologically in the laboratory according to Ferreira (1993). Middle portions of the gonads were embedded in paraffin, sectioned transversely at 6 μm thickness and stained with Mayer's haematoxylin-eosin. Each gonad was classified into one of the following gonadal developmental stages: immature female, mature female, transitional, young male and mature male. Within the stages of mature female and male, four status levels were used to describe the degree of maturity, namely: resting, ripening, ripe and spent (Fig.2). A histological description of these stages and status levels are given in Ferreira (1993).

2.4 *Statistical Analysis*

Nested analysis of variance was used to compare mean age and size of coral trout between closed and open reefs by using a general linear model (GLM) in the computer package Statistic Analysis System (SAS). The level of significance was set at 5% ($p<0.05$). The von Bertalanffy growth equation (von Bertalanffy 1938, 1957) was used to fit length-at-age data of coral trout for each reef. The formula used was:

$$L_t=L_\infty(1-e^{-k(t-t0)})$$

Where L_t - Fork length at age t;

L_∞ - The asymptotic fork length;

K - The growth coefficient;

to - Age when length theoretically would be zero.

In the calculation, the von Bertalanffy growth curve was generated using the FISAT computer program, using a non-linear fitting procedure.

3. RESULTS

3.1 *Growth*

The overall mean size and age from both closed and open reefs over four years are illustrated in Fig.3. The largest mean size of 45.1 cm was found at Glow while the smallest mean size of 42.6 cm was from Grub. A similar pattern was also found in the distribution of mean age, with the oldest mean of 7.2 years at Glow and the youngest mean of 5.8 years at Grub. The comparison of these mean sizes and ages showed there was no significant difference between the open and closed reefs (Table 2). However, the difference was significant among individual reefs in both mean size and age. To examine the longer-term effects of fishing on the closed reefs, a similar comparison of mean size and age was also carried out with 1993 data individually. The results, however, were similar to that of the overall test (Fig. 3 and Table 2), and are not presented here.

Growth of coral trout at all four reefs conformed to the von Bertalanffy growth function (Figure 4, Table 3). As estimates of growth parameters are affected greatly by different ranges of size-at-age data, and the range of size-at-age varied between the reefs, it was difficult to compare the growth of coral trout populations among these reefs based on these growth parameters (Table 3). Substantial overlap of the standard errors of all parameters at all four reefs indicates no significant differences in growth of trout at any of the four reefs.

Classification of Coral Trout Gonads

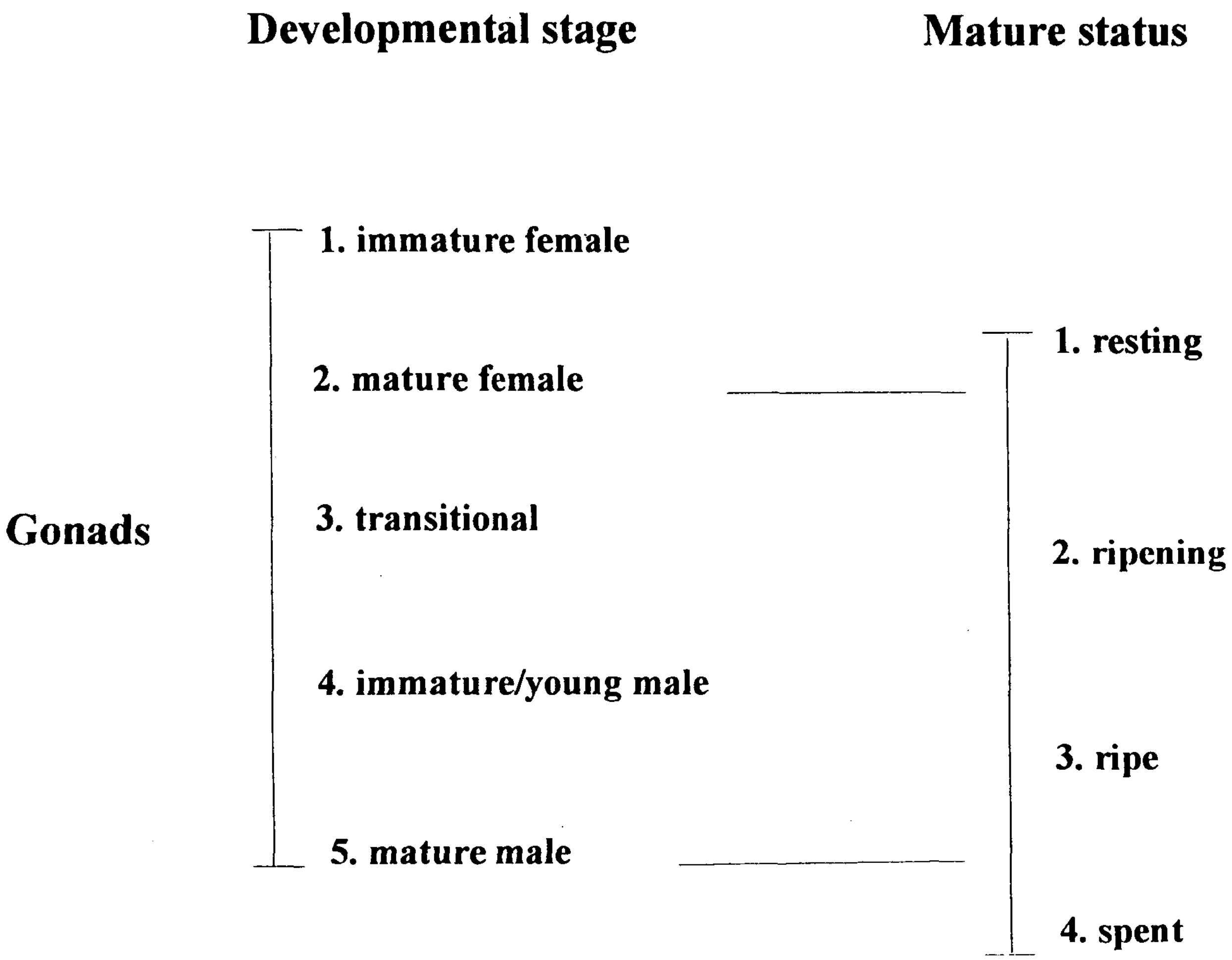

Fig.2 A schematic diagram showing the sexual classificaion of coral trout gonads

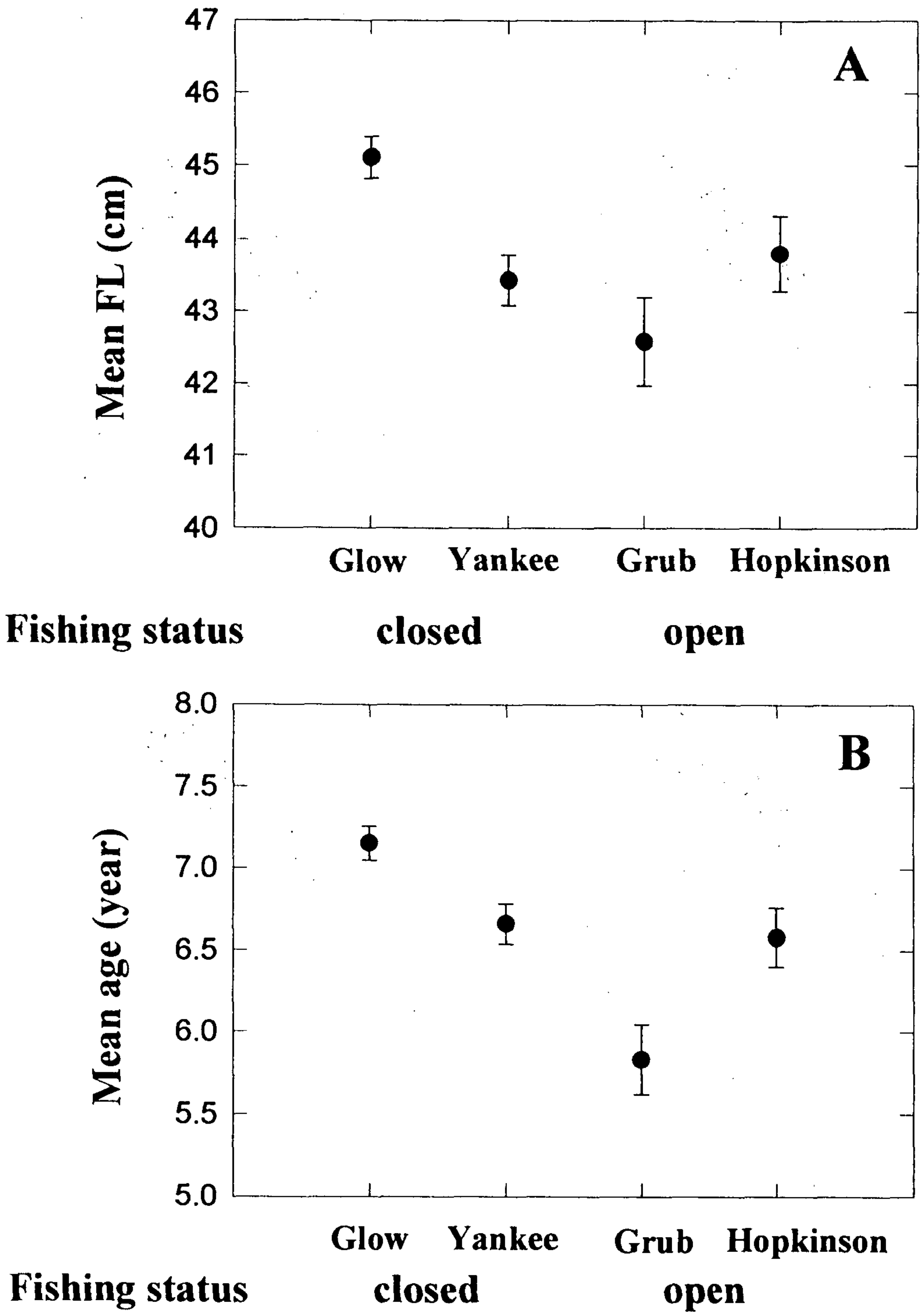

Fig.3 A. Mean fork length of coral trout from each reef; B. Mean age of coral trout from each reef. Error bars represent standard errors.

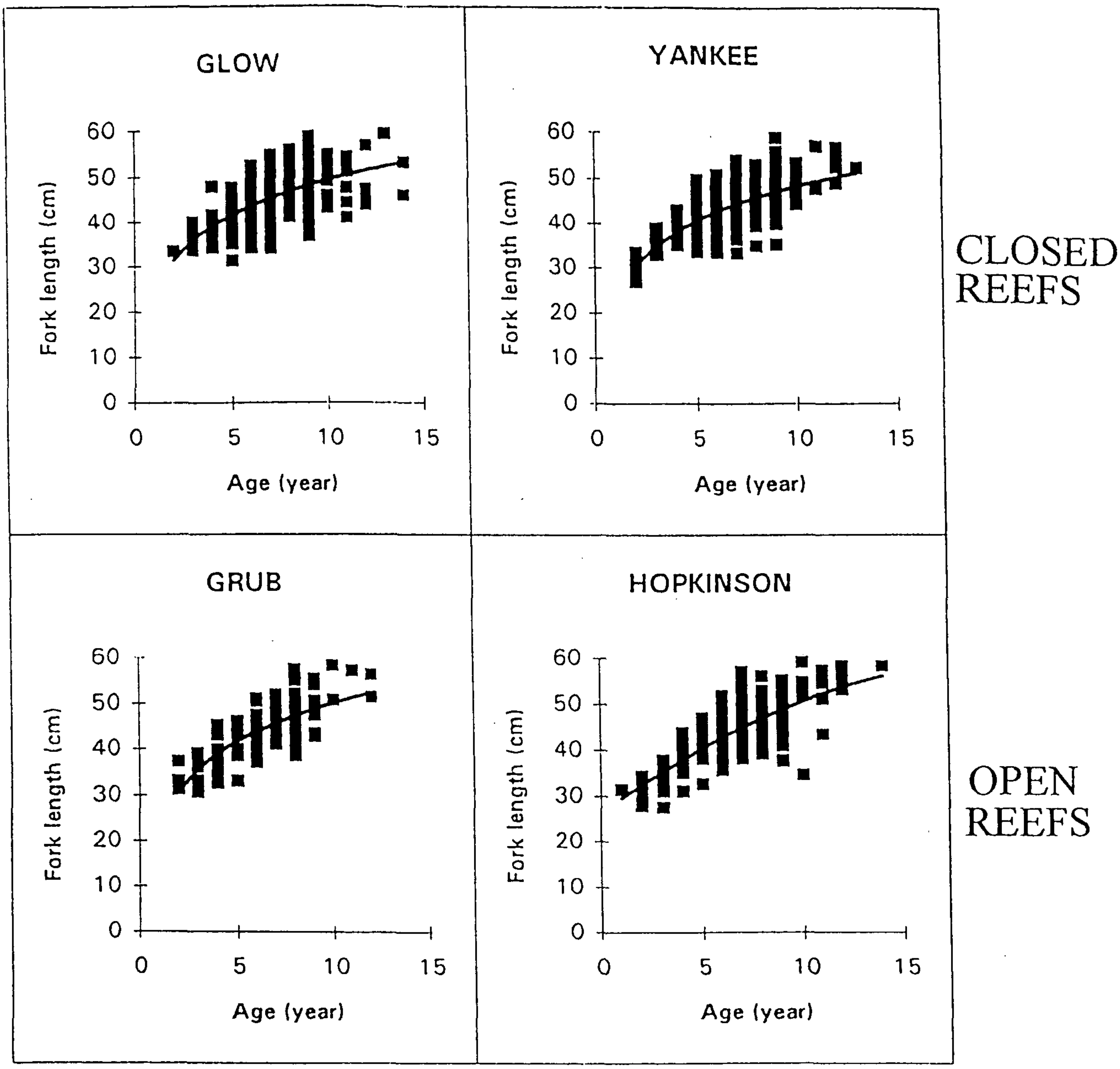

Fig 4. Von Bertalanffy growth curves of coral trout from all four reefs.

Table 2. Nested analysis of variance comparing the mean size and age of coral trout on closed and open reefs (fishing status).

Dependent variable	Source	df	Type III SS	MS	F-value	P-value
FL (cm)	Fishing status	1	227.065	227.065	0.82	0.4610
	Reef (Fishing status)	2	554.579	227.290	7.86	0.0004
	Residual	937	33037.155	35.258		
AGE (year)	Fishing status	1	92.854	92.854	2.46	0.2574
	Reef (Fishing status)	2	75.515	37.757	8.51	0.0002
	Residual	903	3994.313	4.438		

Table 3. Von Bertalanffy growth parameters (± SE) based on the size-at-age of coral trout samples from the four reefs.

Sampling Reef	L_∞ (cm)	K	t_0 (year)
Glow	53.53±3.55	0.183±0.069	-3.034±0.595
Yankee	60.32±7.83	0.115±0.052	-4.657±0.454
Grub	72.36±21.94	0.079±0.06	-5.618±2.959
Hopkinson	69.6±13.66	0.085±0.045	-5.310±2.244

3.2 *Size Structure*

On closed reefs, the overall size frequency remained fairly consistent from 1990 to 1993 on both Glow and Yankee (Fig. 5). Modal progression was not evident in the size distribution. A similar pattern was observed on the open reefs. Some size classes were absent or poorly represented due to the small number of specimens collected on Grub and Hopkinson (Fig. 6).

3.3 *Age Structure*

The age structure on the closed reefs was particularly informative. Separating age distribution by year (Fig. 7), it was clear that there was a very strong age class dominating the populations at Glow and Yankee from 1990 to 1993. That age class was 6, 7, 8 and 9 years old in 1990, 1991, 1992 and 1993 respectively, and occupied 38.8 to 53.4% of total catch in Glow and 35.5 to 54.4% in Yankee. This result rules out the possibility of selection towards one year class by fishing gear, or bias in the age determination. This strong year class, however, was not obvious on the open reefs (Fig. 8). There was not any obvious dominating age class through the population from 1990 to 1993 except a suggestion of it on Hopkinson.

This strong age class settled onto the reefs at the beginning of 1984 (Fig. 9). As Glow and Yankee have been closed to fishing since 1987, and age of recruitment to the fishery is approximately 3 years (Ferreira and Russ, in press), the individuals settling onto Glow and Yankee in 1984 were protected from fishing for most of their lives.

3.4 *Sex Structure*

The distribution of developmental stages by size (Fig.10) indicated that for all four reefs the minimal fork-length of first sexual maturity in females was approximately 30 to 35 cm. Sexual transition from female to male took place in a broad size range from a minimum of 30-35 cm up to approximately 55 cm. Mature females dominated at all reefs and mature males increased in frequency with length and dominated larger size groups. A similar pattern was found in the distribution of developmental stages by age (Fig.11). Most of the females became sexually mature at 3 years of age. Sex-change occurred over a broad range of ages from 3 upwards. Generally, mature males increased in frequency with age.

To assess effects of fishing on sex-change, the mean size and age of all potential males including transitional, young and mature males were compared between the closed and open reefs (Fig. 12). The results showed that there was no significant difference in the mean size or age between the closed and open reefs. However, the difference was significant among individual reefs in both mean size and age (Table 4).

Table 4. Nested analysis of variance comparing the mean size and age of male coral trout on the closed and open reefs (fishing status).

Dependent variable	Source	df	Type III SS	MS	F-value	P-value
FL (cm)	Fishing status	1	3.826	3.826	0.02	0.9005
	Reef (Fishing status)	2	382.829	191.415	4.50	0.0120
	Residual	278	11838.510	42.570		
AGE (year)	Fishing status	1	15.409	15.409	0.66	0.5011
	Reef (Fishing status)	2	46.489	23.244	5.44	0.0049
	Residual	229	978.813	4.274		

For the calculation of sex-ratio, frequencies of young males were pooled with frequencies of mature males, as all of these individuals were sexually, potential males. The overall composition of developmental stages and sex-ratio (Table 5) shows the sex-ratio varied among reefs. Generally, however, the sex-ratio (F:M) on the closed reefs was smaller than that on the open reefs. Thus, the proportion of males on closed reefs was higher than on open reefs. Fishing usually removes more large individuals, and these are predominantly male.

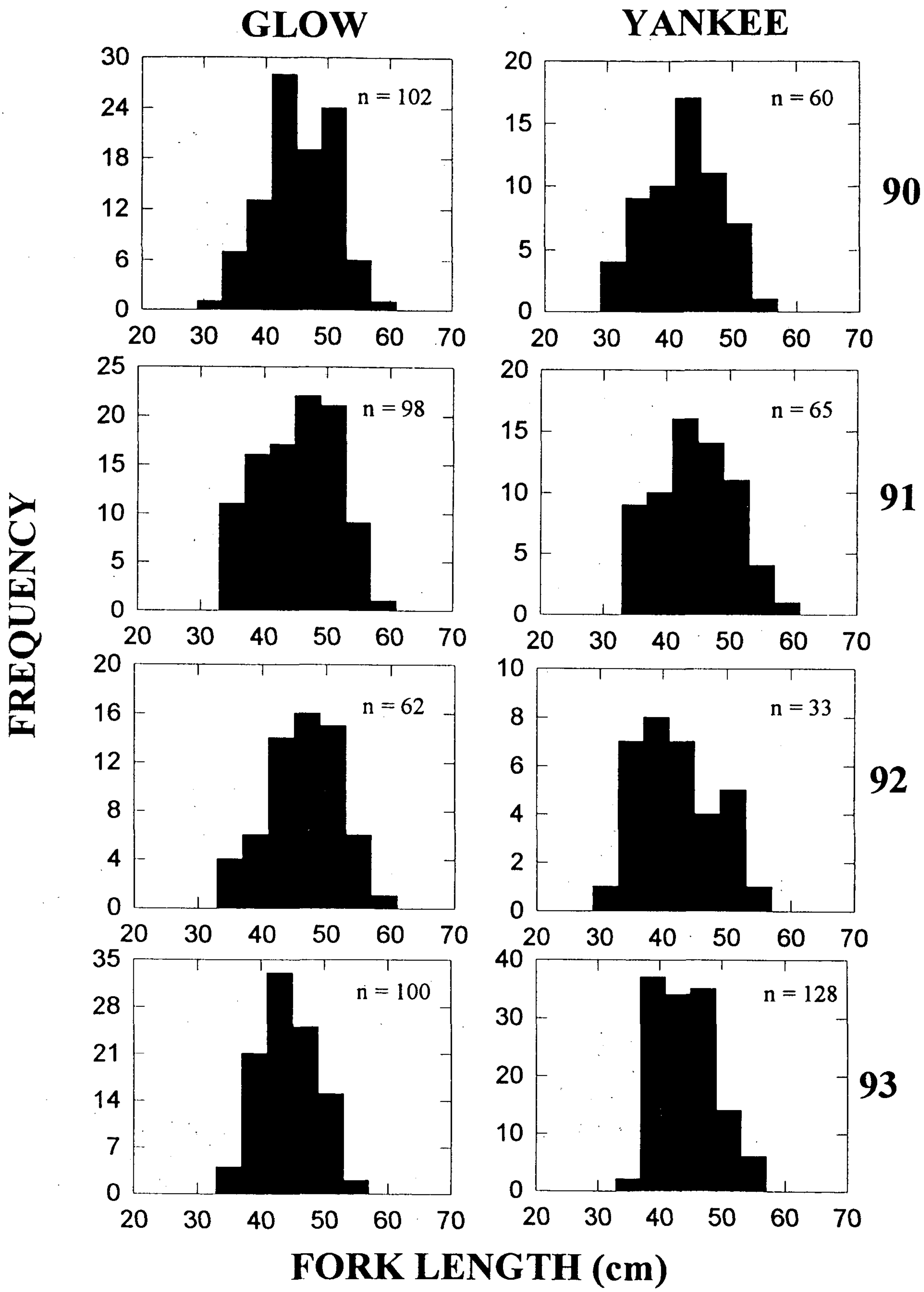

Fig.5 Size distribution of coral trout for the closed reefs in each sampling year, n = sample size.

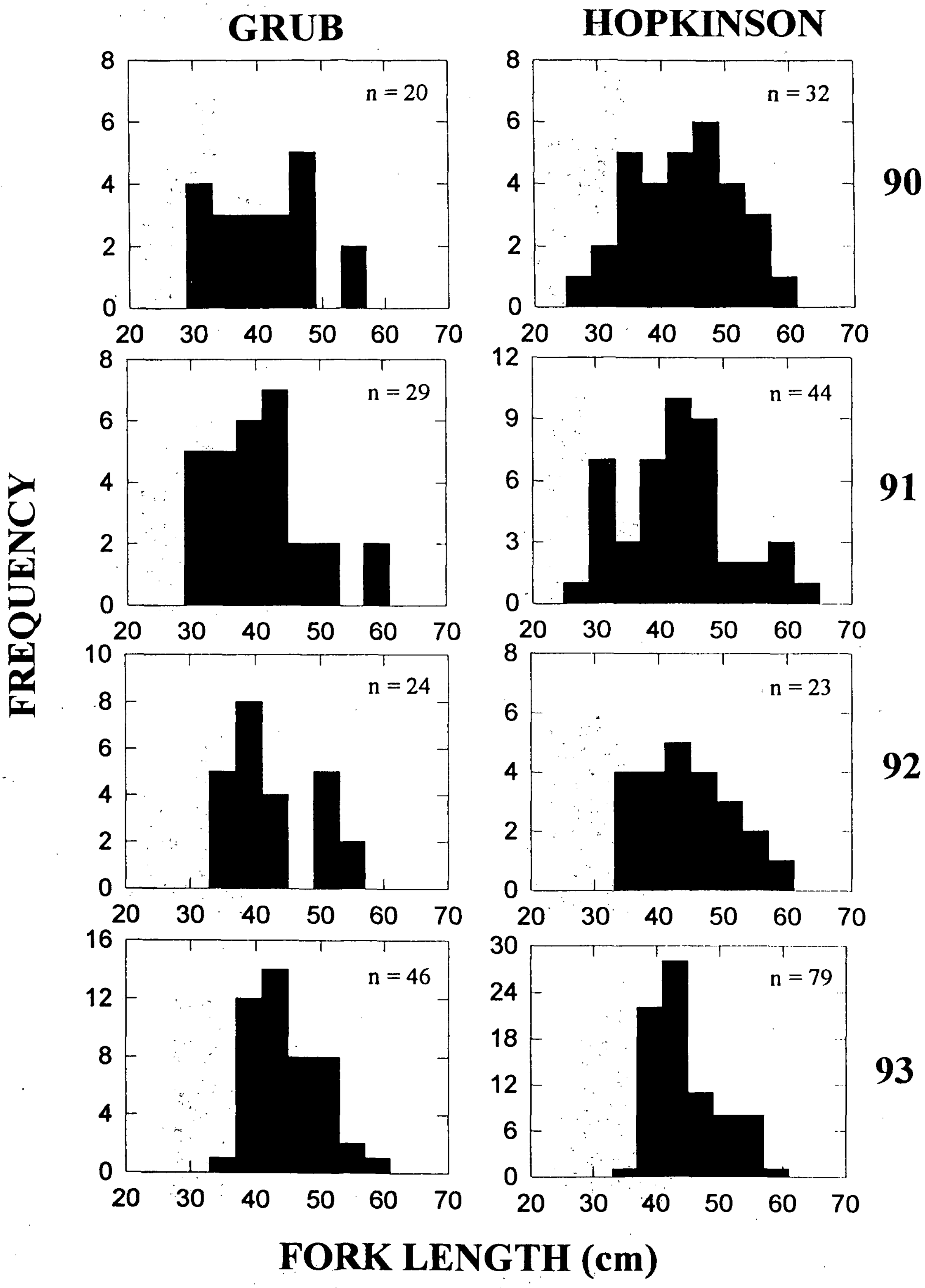

Fig.6 Size distribution of coral trout for the open reefs in each sampling year, n = sample size.

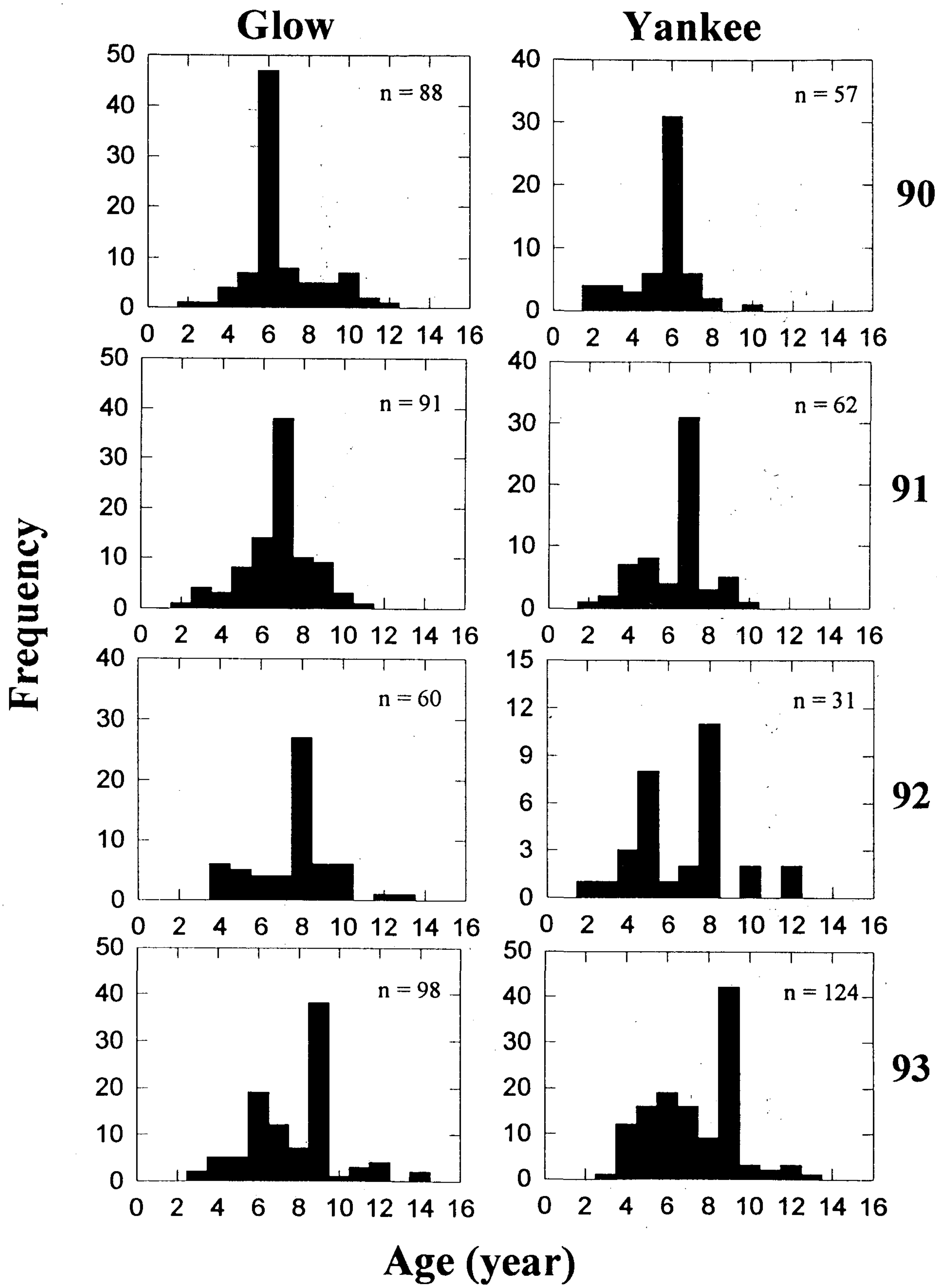

Fig.7 Age distribution of coral trout for the closed reef in each sampling year, n = sample size.

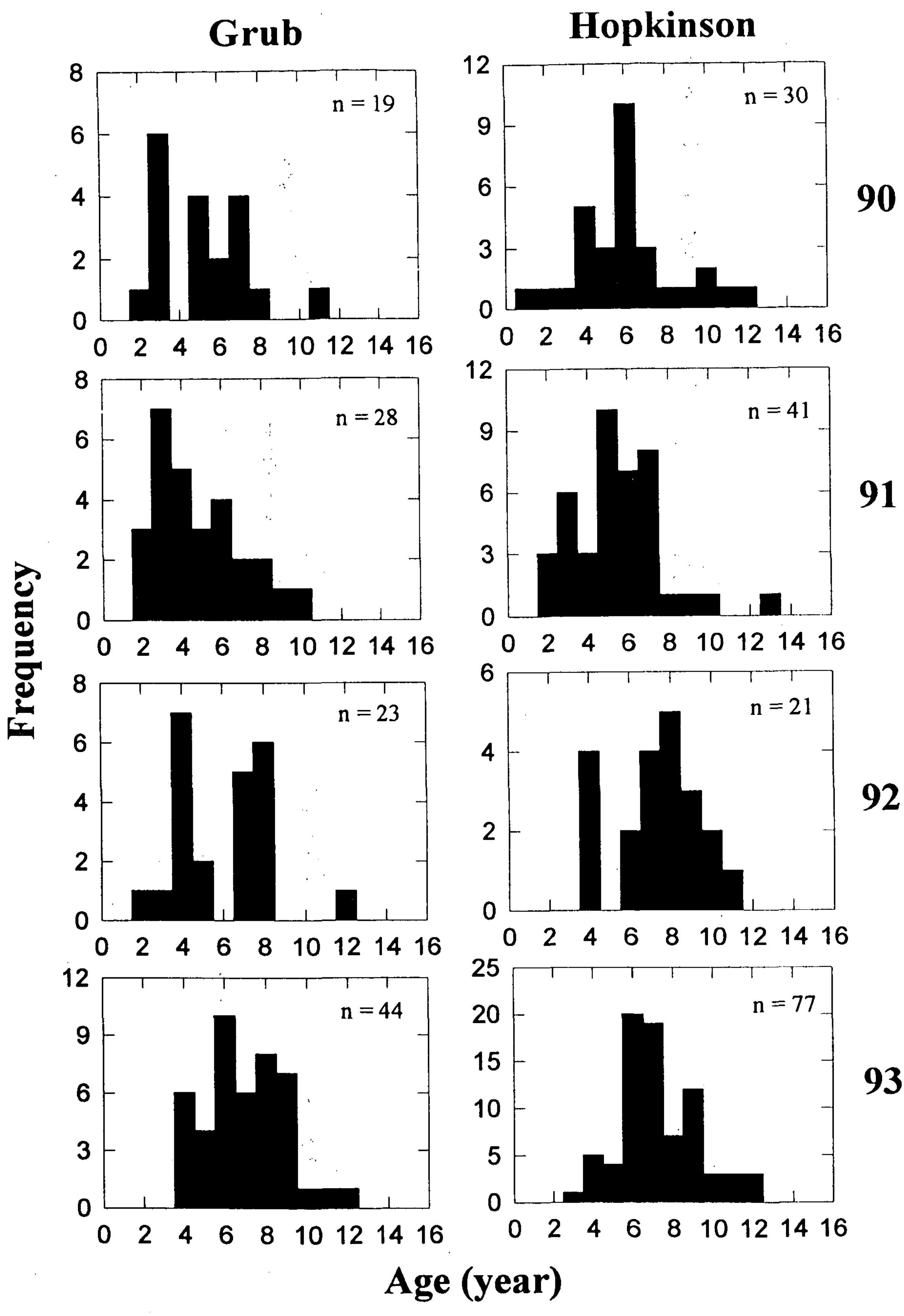

Fig.8 Age distribution of coral trout for the open reefs in each sampling year, n = sample size.

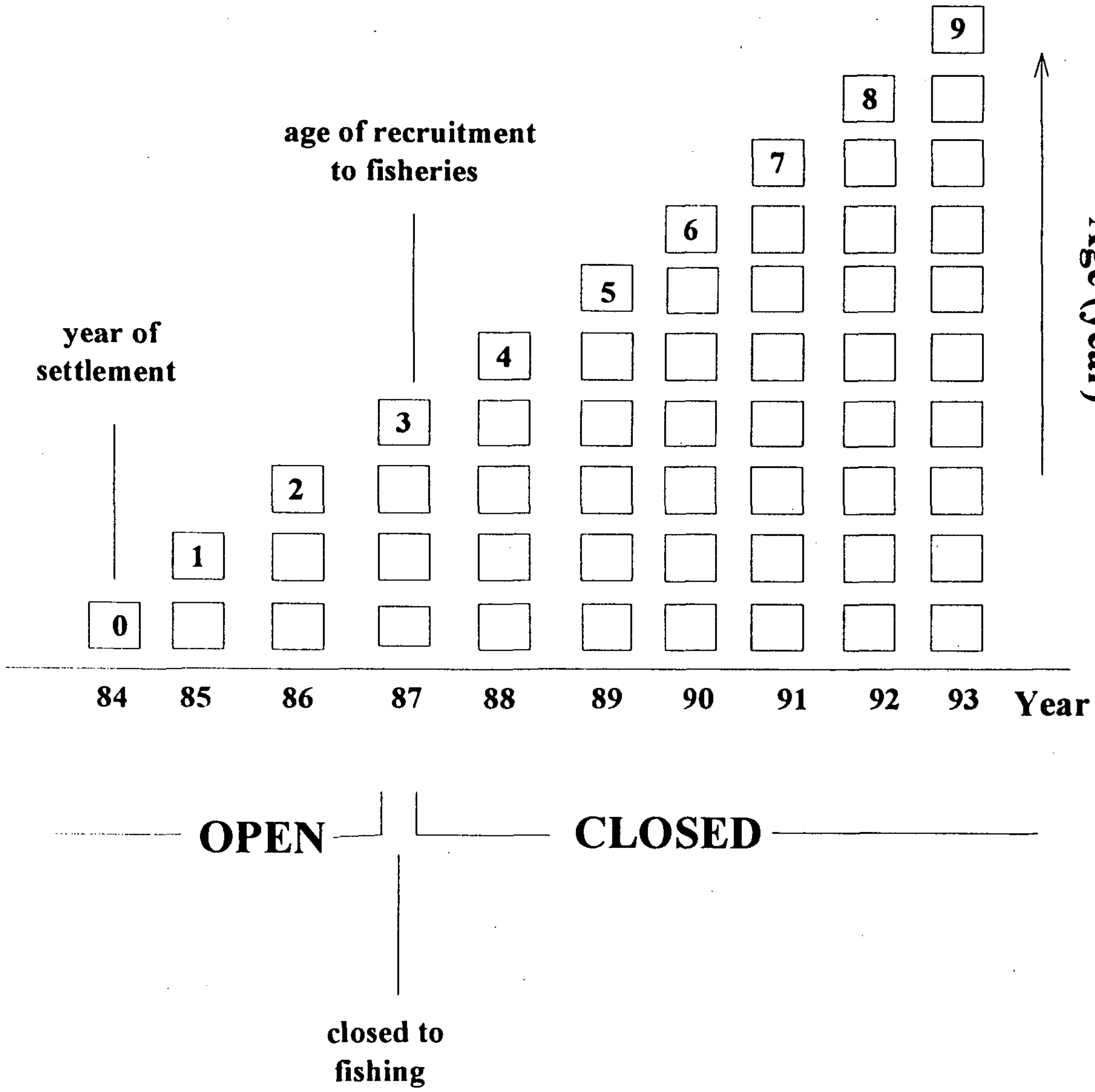

Fig. 9 A schematic diagram showing the history of the strong year class of coral trout in the closed reefs

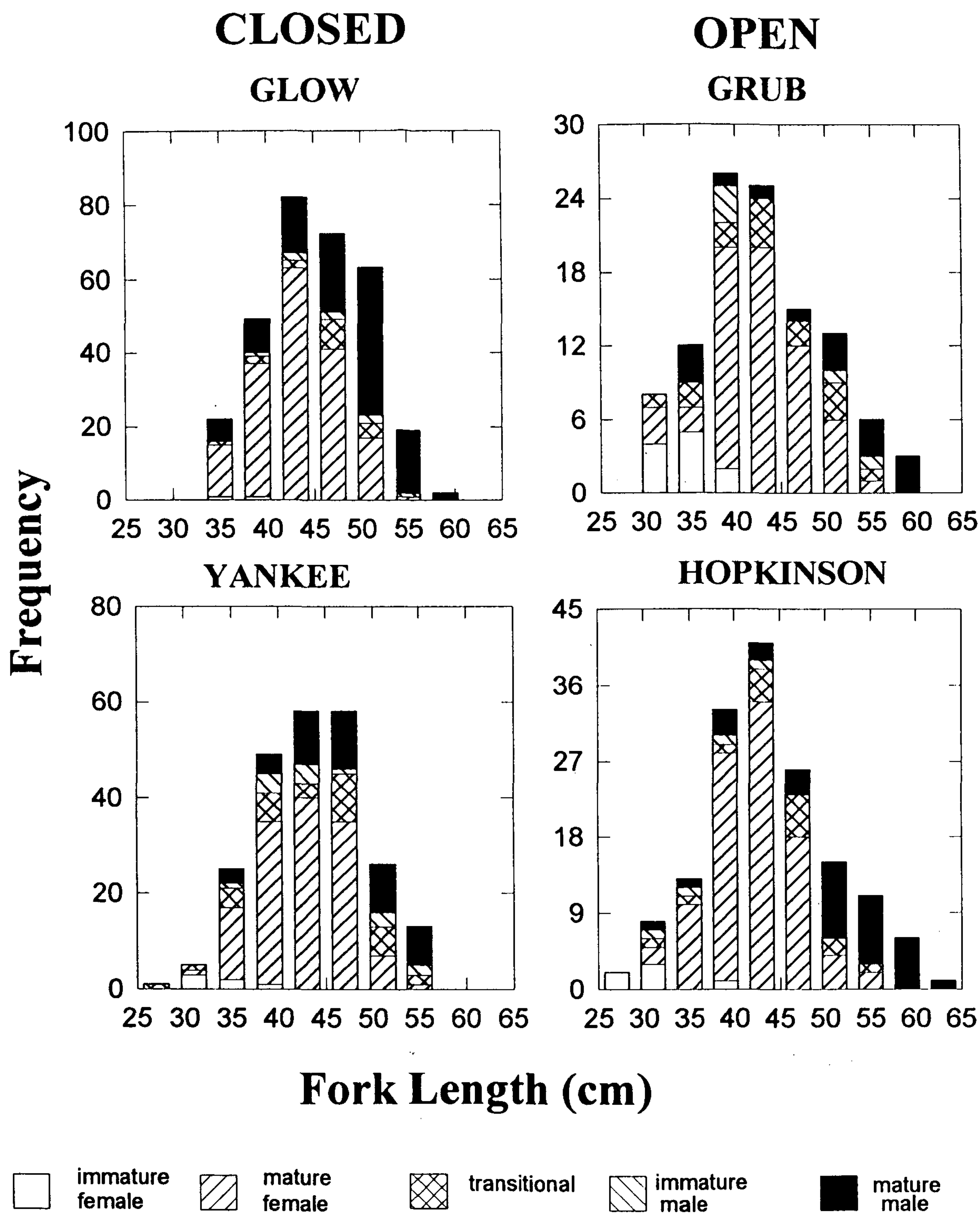

Fig.10 Distribution of developmental stages of coral trout at each reef by size (fork length).

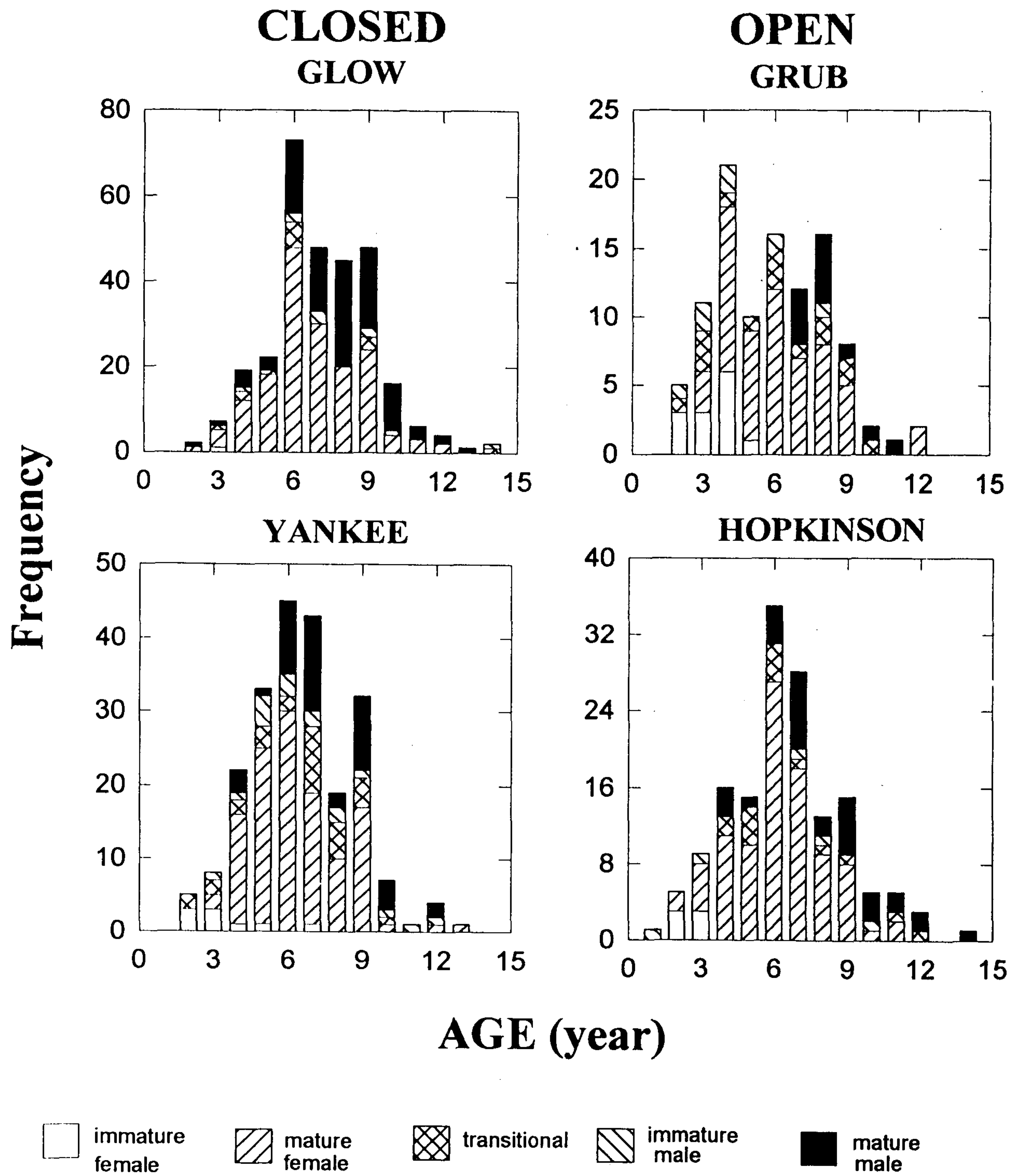

Fig.11 Distribution of developmental stages of coral trout in each reef by age (year).

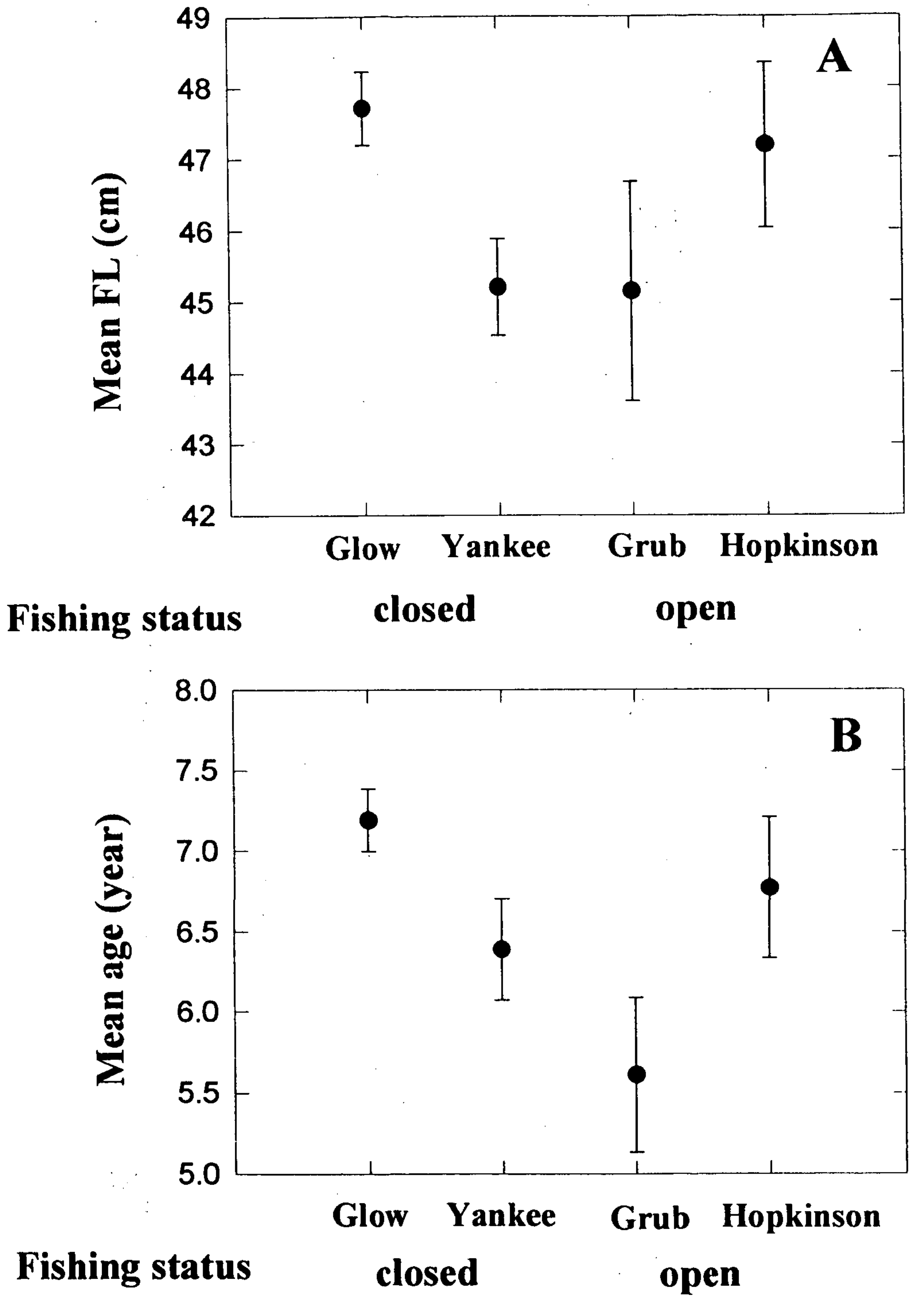

**Fig.12 A. Mean fork length of male coral trout from each reef.
B. Mean age of male coral trout from each reef. Error bars represent standard errors.**

Table 5. Frequency and percentage of each developmental stage at the four reefs and sex-ratio (mature females vs young and mature males).

Fishing status	Sampling reefs	Immature female	Mature female	Transitional	Young male	Mature male	Sex-ratio
Closed	Glow	2 (0.6%)	189 (54.9%)	16 (4.6%)	12 (3.5%)	125 (36.3%)	1.4:1
	Yankee	9 (4.0%)	122 (54.2%)	29 (12.8%)	19 (8.4%)	46 (20.4%)	1.9:1
Open	Grub	15 (13.3%)	59 (52.6%)	17 (15.2%)	9 (8.0%)	12 (10.7%)	2.8:1
	Hopkinson	10 (5.8%)	103 (60.2%)	14 (8.2%)	7 (4.1%)	37 (21.6%)	2.3:1

3.5 *Spawning Schedule*

Spawning activity, as indicated by the presence of individuals with gonads at the ripe stage, was observed from March to November (Fig.13). The ripe ovaries were almost all found from September to November. A similar pattern was found also for mature males. These figures confirm an annual spawning season of coral trout from September to November in the central GBR.

4. DISCUSSION

4.1 *Effects of Fishing on Size and Age Structure*

Line fishing tends to select the larger individuals in a population. Thus expected effects of fishing are a reduction in the average size and age of fish populations (Russ, 1991). Significant differences between size and age structures on the closed and open reefs, however, may depend largely on the duration of closure in relation to the longevity of the species and fishing mortality. The pilot study for this project (Ferreria and Russ, in press) suggested that the short period of time for which the reefs have been closed (three to four years) in relation to the longevity of the coral trout (14+ years) may be largely responsible for the failure to detect a significant difference between either mean size or age of coral trout on the open and closed reefs. The results of the present study indicate that a longer duration of reef closure (six years) still did not result in a significant increase in either mean size or age although the mean age in the closed reefs appeared slightly higher than that of the open reefs. Even in 1993 (six years of closure) there were no significant differences in size or age structure between closed and open reefs. Therefore, some other factors may play more important roles in determining abundance of the coral trout populations, assuming that reef closures were effective.

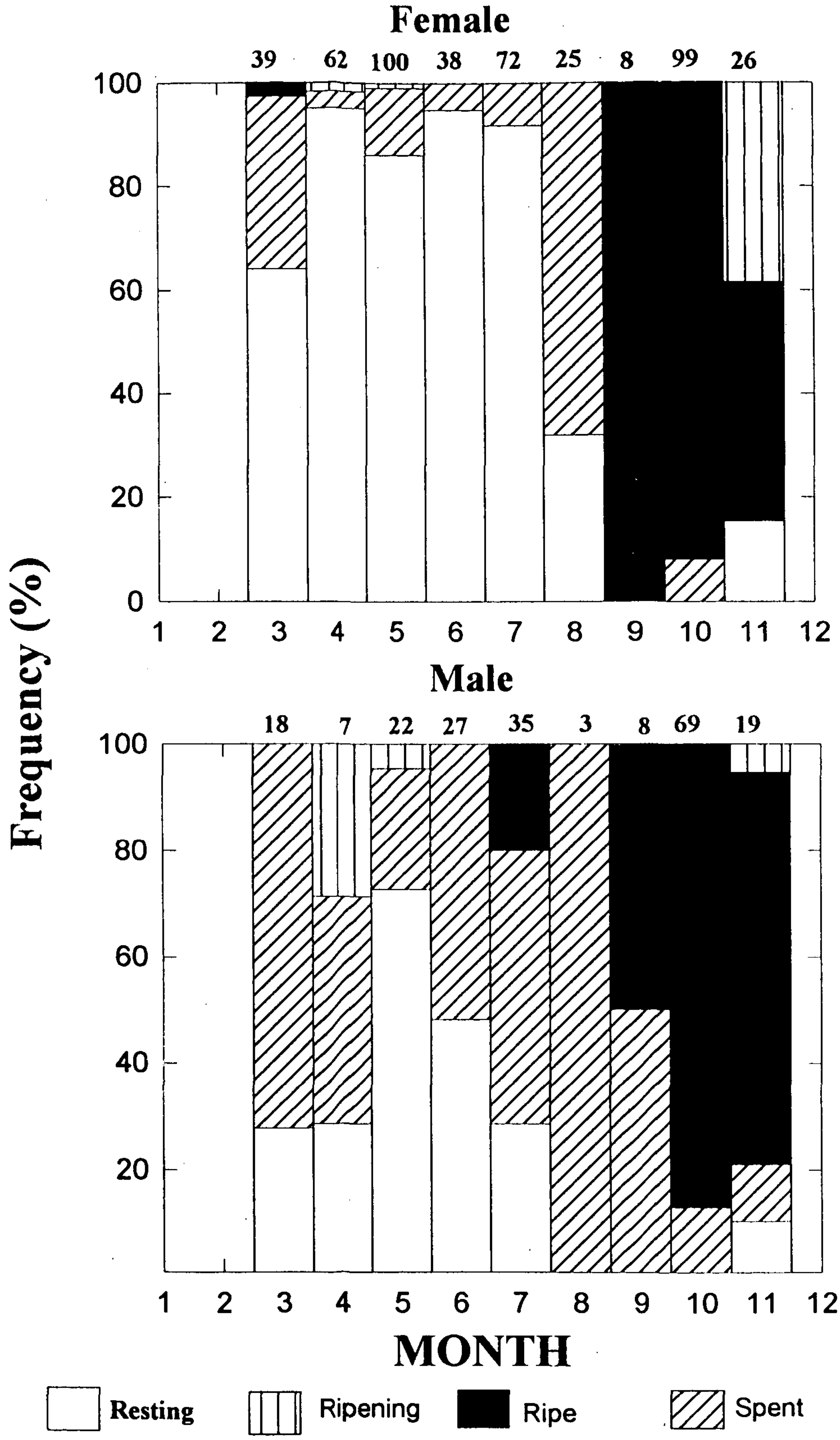

Fig.13 Overall distributions of mature status in male and female coral trout from all 4 reefs. sample sizes are indicated at the top of each bar.

A large variability in the mean size and age between replicate reefs was observed in the present study. If only Glow (closed) and Grub (open) had been compared, the result would reveal a classic effect of fishing scenario, with a larger range of sizes and ages and significantly larger mean sizes and ages observed on the reef closed to fishing. In contrast, if only Yankee (closed) and Hopkinson (open) had been compared, no effect of fishing would have been detected on the population structure. These results emphasise the importance of replicates (ie, more reefs per fishing status). Replicates increase the degrees of freedom and thus the power of the anova.

One possible reason for the differences between the two open reefs is the fact that they are apparently not subject to the same fishing pressure. Grub is renowned for its excellent anchorage (Townsville Coast Guard, pers. comm.), and therefore is a favourite site for recreational and commercial fishing vessels. Aerial surveys conducted by the Great Barrier Reef Marine Park Authority between 1989 and 1992 (GBRMPA, data base, 1992), indicated that Grub was frequented by boats 2.2 times more than Hopkinson and that commercial fishing vessels were sighted three times more frequently at Grub than at Hopkinson. Also, on the closed reefs some illegal fishing might have occurred. Such factors would compromise the results and should be taken into account in designing future sampling and experimental programs on the effects of fishing on the GBR.

Nevertheless, there was a major and consistent difference between the open and closed reefs analysed. For the two closed reefs, the population structure was dominated by the presence of a strong year class which settled in early 1984. A similar pattern was not observed on the open reefs, although there was a suggestion of this strong year class at Hopkinson. Sample sizes at the open reefs were so small that a clear indication of the strong year class was difficult to detect, even if it was present. Occurrence of strong year-classes is a well documented phenomenon in commercial catches of temperate species (Sissenwine, 1984; Rothschild and Mullen, 1985). For temperate species, year-class strength has been linked to early life history processes since the beginning of this century. However, for populations of coral reef fish, the importance of recruitment in temporal variability of abundance has been recognised only recently (Williams, 1980; Doherty, 1981; Doherty and Williams, 1988).

There is evidence for the possibility of strong recruitment pulses of reef fishes occurring concurrently on midshelf reefs off Townsville which are separated by distances of up to 10-30 km (Doherty and Williams, 1988; Williams, 1991). The age structure data for the two closed reefs provides circumstantial evidence in support of pulses of recruitment being synchronous on reefs at least 10 km apart. If one assumes that the four reefs received a similar pulse of recruitment in 1984, then fishing mortality may have operated to largely decrease the relative abundance of this year class. This would however require the unlikely scenario of increased catchability of the strong year class relative to all other year classes. On the closed reefs, this strong year class was protected from fishing for almost its entire life and as a result had its strength maintained. On open reefs, the same year class was probably supporting the fisheries in a disproportionate way in relation to the other age classes based simply on it's greater relative abundance. An alternative hypothesis is that the settlement pulse occurred only on the two closed reefs due to some process independent of fishing. This latter hypothesis seems unlikely as all four study reefs are closely located in the same midshelf region and under a similar physical environment. Another explanation would be that sample sizes on the open reefs were too small to detect the strong year class.

By examining age structure within the closed reefs this project provides a useful technique that perhaps could reveal the temporal distribution of recruitment of coral trout. Such a technique would have important implications for the zoning strategy of GBRMP. Furthermore, abundance of coral trout populations can be dominated by a strong age class (35% - 55% in the present study).

One very practical aspect of these results to the management of coral trout populations should be noted. A very large settlement of coral trout in any particular year (detected by say visual surveys of newly settled juveniles) is likely to be followed three years later by a very large recruitment to the fishery. If stocks ever reached the stage where concern existed about low levels of spawning stock biomass, a management agency would have three years' lead time to close a larger than average number of reefs to allow a build up of spawning stock biomass. Additional reefs to be closed may be selected on the basis of oceanographic data which suggests that they are likely to be good sources of larvae in the future. It could also be argued that closure of a smaller percentage of reefs, with closures timed to maximise build up of spawning stock biomass, may be more beneficial than closures of a greater percentage of reefs. A paucity of good data and models of larval sources and sinks on the GBR limit the usefulness of such a suggestion at the moment.

4.2 *Effects of Fishing on Sex Structure*

Sequential hermaphroditism is common among coral reef fishes (Thresher, 1984). Bannerot *et al.* (1987) modelled the resilience of protogynous populations to exploitation and concluded that a definite risk existed in managing these stocks by traditional Yield-per-Recruit models under high fishing pressure. The effects of selective removal of larger individuals (presumably mostly males) on the sex-ratio of a population, however, will depend on the mechanisms controlling sex-reversal. For protogynous populations, for example, if female to male sex-change is determined by size or age, a decline in the proportion of males will be expected. Such effects have been reported by Thompson and Munro (1983), comparing populations of serranids subjected to different levels of fishing pressure in the Caribbean. In contrast, no fishing related effects were detected by Reeson (1983) on populations of scarids. Social induction of sex-change is known or claimed for many species of fish (Shapiro, 1987). If social induction applies, selective removal of larger individuals would induce earlier female to male sex-change, compensating for the effects of fishing on the sex-ratio. Consequently, a reduction in the average size and age of sex-change may be expected.

A common question regarding the effects of fishing on protogynous hermaphrodite fishes is how the sex-structure of the population would respond to fishing mortality. If sex-change is determined by age or size, the selective removal of larger and older individuals would result in a decrease in the proportion of males in the population. However, if sex-change is behaviourally induced, the population is expected to compensate for the selective removal of males by female to male sex-change, ie., by changing sex at smaller ages and sizes. For the coral trout populations examined in this study a general decrease in the proportion of males was observed on the open reefs. There was no significant difference in either the mean size or age of males between the closed and open reefs. However, as there is such a broad range of size or age of sex-change it is more likely that sex-change in the coral trout is determined by a combination of the developmental process, in which individuals are more susceptible to sex-change as they grow larger and older, and a social process through behaviourally induced stimuli. Therefore, increasing fishing pressure would produce a potential danger to such a stock when the proportion of males decreases below the minimal level at which the stock can be successfully sustained.

The spawning activity observed for *P.leopardus* between early September and November in the central GBR coincides with the spawning period observed by Goeden (1978) for the southern region. The spawning season during this period has also been observed for the congeneric species *P.maculatus* from the Townsville region (Ferreira, 1993). Early spring and summer (September-November) spawning seems to be the pattern for species of groupers in low latitudes (Shapiro, 1987). It is possible that small latitudinal differences may exist in terms of exact time of the beginning and end of the spawning season. In spite of the fact that the sampling design did not allow effective comparisons between locations in terms of the exact time of spawning, it seems reasonable to infer that the spawning season for coral trout in the GBR occurs generally in the same period, ie,. from early spring to early summer.

4.3 *Conclusions*

Based on the results of this project the following conclusions were obtained:

1. No significant differences were detected between the mean size and age of coral trout on open and closed reefs (up to 6 years of closure), a result that could have been a consequence of variability among replicate reefs.

2. A very strong year class dominated the 2 closed reefs (6, 7, 8 and 9 year olds in 1990, 1991, 1992 and 1993 respectively). This strong year class was not obvious on fished reefs close by although this may have been due to small sample sizes from these reefs. The strong year class accounted for 35-55% of experimental catches on closed reefs, suggesting that strong year classes may contribute disproportionately to catches.

3. The age composition on closed reefs can possibly give insights into the temporal distribution of coral trout recruitment.

4. Fishing by selective removal of larger individuals appeared to reduce the proportion of males in coral trout populations.

5. Histological examination of gonads confirms an annual spawning season of coral trout in the central GBR from early spring to early summer, which may be useful information for the management of coral trout fisheries.

6. It is suggested from this project that age structure is more useful than size structure in detecting effects of fishing. Therefore age determination should be a routine component in the management of coral trout populations.

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