Trends in Common Coral Trout Populations on the Great Barrier Reef

Report to the Queensland Fisheries Management Authority

sland
ment
t of
lustries

CRC Reef Research Centre

SEA RESEARCH

Information Series QI00063

TRENDS IN COMMON CORAL TROUT POPULATIONS ON THE GREAT BARRIER REEF

A REPORT TO THE QUEENSLAND FISH MANAGEMENT AUTHORITY

Tony Ayling
Sea Research,
Melita Samoilys
Queensland Fisheries Service,
Dan Ryan
Agricultural and Agri–Food Canada,

Queensland Fisheries Service
Department of Primary Industries, Queensland

QI00063
ISSN 0727-6273
Agdex #476\10

First Published 2000

The correct citation of this document is:
Ayling, Tony, Samoilys, Melita, and Ryan, Dan (2000). Trends in Common Coral Trout populations on the Great Barrier Reef. Information Series QI00063. Department of Primary Industries, Queensland, Brisbane.

Inquiries should be directed to:

The Manager,
DPI Publications
GPO Box 46
Brisbane Q 4001

Table of Contents

List of Tables

List of Figures

Abstract

The common coral trout *Plectropomus leopardus*, a grouper in the serranid subfamily Epinephelinae, is the primary target species in the Great Barrier Reef (GBR) commercial and recreational line fishery. Underwater visual census surveys have been used to assess coral trout populations in a number of projects on a range of reefs along the length of the GBR since 1980. We used a selection of these data from 20 reefs that have been surveyed $\geq$ 3 times over at least 10 years to look at long term changes in common coral trout populations. For our analyses, we grouped the data into 3 time periods: pre 1990; 1991–1994; 1995 to the present. We also grouped the reefs into 6 regions based on cross shelf position (Mid Shelf; Outer Shelf) and latitude (Northern; Cairns; Townsville; Southern). Other factors examined included protective zoning status within the GBR Marine Park (open/closed to fishing) and habitat (front reef/back reef).

There were no significant differences in common coral trout density between front and back reef habitats in this study, either for the total population or for adults over 38 cm TL. As has been shown previously, and for many coral reef organisms on the GBR, shelf position and latitude had a marked effect on coral trout density: more than twice as many fish were recorded on Mid Shelf reefs compared with Outer Shelf reefs, and densities were almost three times higher on Southern region reefs compared with the other three regions. Although zone was confounded with region in this study, there appeared to be no effect of protection on coral trout densities, a finding that has been reported by previous studies.

We detected highly significant differences in trends in common coral trout densities between time periods. Differences were seen primarily between the early and recent periods, in the Townsville and Southern regions, and differences were remarkably consistent between reefs. On these reefs a pattern of stable trends through the 1980s, positive trends in the early 1990s, and negative trends in the mid 1990s, was evident. There was also some indication of a similar pattern for coral trout >38cmTL on Townsville Outer Shelf reefs. The analysis of mean density changes only detected differences on the Townsville Mid Shelf reefs, confirming coral trout numbers were significantly higher in the 1980s and mid 1990s compared with recent times. Densities of coral trout in the most recent surveys were equal to or lower than densities measured in previous surveys. This pattern was not evident for the Northern (Lizard Island region) reefs, and unfortunately there were no data from the recent period for the Cairns reefs.

The fish length data from this study showed a number of patterns. Mean lengths were significantly higher on Outer Shelf reefs compared with Mid Shelf reefs but were similar in all four Mid Shelf regions. There has been a significant reduction in both mean length and length range (standard deviation) between the early and recent time periods, and the percentage of fish over 50 cm TL has reduced from 7.2% to 2.3% over this period, suggesting growth overfishing of common coral trout populations. However, mean lengths did not decrease in the Townsville Mid Shelf and Southern regions where the significant downward trends in density were recorded, and it may be argued that only very heavy fishing pressure (removal of over 50% of adults) will have a detectable effect on length of coral trout populations.

Log book data from the commercial fishery indicate that there is five times as much fishing pressure in the Townsville Mid Shelf and Southern regions compared with the other regions and this is where we have recorded recent downward trends in coral trout populations. In addition, fishing effort has increased by almost 30% since 1995. We suggest that the strong downward trends in coral trout densities in recent years, combined with present low densities and high levels of fishing effort are cause for concern

Acknowledgements

Data for this report came from a wide variety of studies and the following individuals and institutions are gratefully acknowledged: CRC Reef Research Centre; Bruce Mapstone; Campbell Davies; Australian Institute of Marine Science; Dave McB. Williams; Great Barrier Reef Marine Park Authority; Wendy Craik; John Robertson; James Cook University; Great Adventures; Sunlover Cruises; Fantasy Cruises; Fisheries Research and Development Corporation.

We wish to thank Andrew Thwaites of the QFMA for providing the commercial log book data and graphs, and Dorothée Teboul for editing and assistance with figures.

The Queensland Fisheries Management Authority and Fisheries Group, DPI, funded the preparation of this report.

Introduction

Coral trout is the name commonly applied to members of the Indo–Pacific fish genus *Plectropomus* (Heemstra and Randall 1993). They are grouped in the serranid subfamily Epinephelinae, fishes usually referred to as groupers or cod. Five species of coral trout have been recorded from the GBR region (Heemstra and Randall 1993), but the common coral trout *Plectropomus leopardus* (Lacepéde 1802) is by far the most abundant of these (Ayling and Ayling 1986a).

The biology of the common coral trout is now reasonably well understood. Most epinepheline fishes are long lived and slow growing (Manooch 1987), but coral trout grow rapidly and are relatively short lived (Goeden 1978, Ferreira and Russ 1994). Growth rate is very rapid over the first three years of life and the mean total length of 3+ year old fish is around 40 cm total length (TL) Ferreira and Russ 1994, Loubens 1980). Their study showed that growth slows after three years and reaches an asymptote after about 8 years, with a maximum age of 14 years. On average, only around 5% of the population are over 10 years of age, and the normal maximum size is about 65 cm TL (Ferreira and Russ 1994, Loubens 1980). The legal minimum size for common coral trout in the Great Barrier Reef (GBR) line fishery is 38 cm TL. The age and growth data of Ferreira and Russ (1994) suggest that about half of 2+ year old common coral trout have entered the fishery, while the majority of the 4+ cohort are 38 cm TL or over.

Groupers form the basis of important fisheries throughout the tropical and subtropical regions of the world (Heemstra and Randall 1993)., and the GBR is no exception. Coral trout are the dominant species in the commercial and recreational fisheries on the GBR. They comprise up to 60% of the demersal reef fish catches landed by commercial fishers (Turnbull 1996), contributing up to around 1,500 tonnes or over A$10 million per annum (Trainor 1991, Brown 1993, Mapstone et al 1996). They are also one of the four most targeted species by recreational anglers in north Queensland (Roy Morgan Research 1996, Cormack 1997). Various estimates of the recreational catch of coral trout have been made. These range from 2–3 times the commercial catch (Craik 1989), to approximately equal to the commercial catch (Blamey and Hundloe 1993), to considerably less than the commercial catch (J. Higgs pers comm). The trade in live reef fish to Asia (Richards 1993) has stimulated an increase in the demand for coral trout in Australia since 1995, with an increase in coral trout catch and effort in 1996–7 and 15% of the commercial coral trout catch now taken as live product (Elmer 1998). Management of the Queensland GBR line fishery is controlled jointly by the Queensland Fisheries Management Authority (QFMA) and the Great Barrier Reef Marine Park Authority (GBRMPA). QFMA have recently (July 1999) released a draft management plan which will be reviewed over the next two months.

Densities of many grouper species can be dramatically reduced by fishing effort because they are selectively targeted by fishing gears (Jennings and Lock 1996) such as hook and line. Dramatic reductions in or removal of the serranid component of multispecies fisheries has been demonstrated in Papua New Guinea (Lock 1986), Philippines (Russ and Alcala 1989) and Jamaica (Koslow et al 1988). Coral trout are fast growing compared with most groupers and are subject to more controlled fishing pressure in Australia than groupers in some other parts of the world, but there has been considerable popular concern that they are being overfished. There has been little rigorous evidence that overfishing of GBR stocks has been occurring (Trainor 1991, Ayling et al 1991, Mapstone et al 1996). However, there is some evidence that the type of commercial and recreational line fishing carried out on the GBR has the potential to have a marked effect on coral trout stocks (Ayling and Ayling 1998). These authors found that when a replenishment area on Bramble Reef was opened to fishing in 1995 fishermen removed almost 80% of adult stock in 12 months (estimated at over 12,000 fish).

A number of studies have tried to assess coral trout population status by using underwater visual census techniques. Goeden (1979) used manta tow techniques to count target fisheries species (87% of which were coral trout) on 44 GBR reefs. At that time all reefs were open to fishing and it was difficult to quantify the relative fishing pressure on each reef but he suggested that the population density of coral trout appeared to be related to the estimated level of fishing. Craik (1981) reported that coral trout densities on fished reefs in the Capricorn/Bunker Group were lower than in an unfished reference area on Heron Island. However, it has since been suggested that the reference area was in fact a spawning aggregation site (B.C. Russell personal communication), and supported unnaturally high coral trout densities. Subsequent surveys by Ayling and Ayling (1986a) and Osborne et al. (1986) in the same reef group did not find significantly higher densities of coral trout on protected reefs compared with fished reefs. Further surveys by Ayling et al. (1991) after protection had been in place on reefs in the Cairns Section of the GBR Marine park for over 7 years did not find any coral trout density differences between a large sample of fished and protected reefs. In summary there has been no good evidence presented to date that suggests that coral trout densities on the GBR have been reduced by fishing pressure.

The senior author has carried out underwater visual counts of coral trout on a range of GBR reefs since 1980 as part of a variety of studies. This has included several surveys for the Great Barrier Reef Marine Park Authority: general pre-zoning surveys (Ayling and Ayling 1983, 1984, 1985, 1986a); surveys of crown-of-thorns infested reefs (Ayling and Ayling 1989a); studies on the effect of zoning changes (Ayling and Ayling 1992a, 1994a); studies of the effects of reef zoning (Mapstone et al 1991); studies of the effects of a reef replenishment closure (Ayling and Ayling 1992b, 1993, 1994b, 1997, 1998a, 1998b); impact studies on GBR tourism operations (Ayling and Ayling 1989b, 1994c, 1994d, 1994e, 1995a, 1995b, 1998c). Recently (since 1995), visual surveys have been conducted for the CRC Reef as part of a large experiment to examine the effects of fishing on coral trout (Mapstone et al 1998). Therefore, there exists a large dataset of coral trout population densities collected at a number of reefs over a substantial period of time. Although detailed cross-shelf and latitudinal patterns in coral trout populations have been documented using these data (Ayling and Ayling 1986a) the different groups of counts have not been collated and examined collectively for any overall long-term temporal patterns. The aim of this study was to look at long-term patterns from these data to see if there is any evidence of consistent trends in coral trout population densities on the GBR and to ascertain whether this may be related to fishing.

Methods

The consultants Sea Research (A.M. Ayling and A.L. Ayling) have undertaken a number of contracts to carry out underwater visual census (UVC) surveys of coral trout in the GBR region since 1980. Most of these have been under contract to the GBRMPA but some have been instigated by other organisations or by companies using the GBR. All count data used in this study have been collected by the senior author and hence problems with observer bias between the different groups of counts have been avoided. (Might suggest saying observer bias has been reduced. Not sure it can be totally eliminated as there are changes in any observer over time. DR) However, several different count techniques were used over the years; methods were changed as new studies showed up deficiencies in those methods previously in use.

Surveys carried out between 1979 and 1982 employed hectare counts such as were instigated by the Great Barrier Reef Marine Park Authority (GBRMPA) after a series of field workshops in 1979–1980 (Craik et al 1980). These counts surveyed fish numbers in a 150 x 67 m area of reef slope, with the inner edge of the 150 m border run along the edge of the reef flat, and the count area extending 67 m down the reef slope. This often resulted in depths of over 25 m being reached along the outer edge of the count area. The count area was delineated with a 150 m rope laid along the reef edge and a 65 m line laid at right angles down the slope from one end. Because of the large area covered, and large depth range often encountered, the counts were logistically very difficult, especially in poor visibility. Comparisons of density estimates from these hectare counts to those made using smaller, logistically easier, transect counts suggested that the hectare counts were markedly underestimating coral trout densities and their use ceased in 1983.

Coral trout counts made between 1983 and 1989 used 50 x 20 m transect counts (each count surveyed in two adjacent 10 m wide paths) with 10 replicate counts made haphazardly along a

representative area of reef slope about two km in length. Each count was run down the reef slope at right angles to the reef edge to try and cover the same range of depths as the hectare counts. These counts were usually confined to the back reef habitat but on some reefs a separate group of ten counts was made on the front of the reef (Ayling and Ayling 1986a).

After dedicated methodological studies in 1991–1993 (Mapstone and Ayling 1998, Samoilys and Carlos in press) the coral trout count methods were further refined. Surveys subsequent to 1990 used mainly 50 x 5 m counts with five replicate counts made in a number of survey sites on each reef. For most studies three of these sites have been surveyed on the front of each reef and three on the back, but for some studies where extra power was required six sites were located in each reef habitat. The five 50 x 5 m transect counts at each site were run parallel to the edge of the reef at a depth of between four and eight metres, rather than at right angles to the reef edge. Each site covered a length of reef edge of about 400–500 m. For a few projects where northern Outer Shelf reefs were surveyed, the width of these transects was increased to 10 m because of the low density of coral trout in these areas (Ayling and Ayling 1993). On a few projects used in this summary the length of these transects was also varied but the techniques were otherwise identical.

Comparisons have been made between the different count techniques and their relative performance has been established (Ayling and Ayling 1983, 1986a; Mapstone and Ayling 1998). As a result it was possible to calculate conversion factors so that the different estimates of coral trout density could be standardised (Table 1). Using this approach does not account for the error associated with estimating the conversion factor in the analysis, and also assumes that this correction factor is constant in both space and time. However, these correction factors do allow direct comparison of the different data sets.

Table 1 Correction Factors for the Different Count Methods.

Correction factors are relative to the standard 50 x 5 m parallel transect method as 1.0.

Transect size	Correction factor
50 x 5 m	1.000
60 x 5 m	0.833
100 x 5 m	0.500
50 x 10	0.715
50 x 20	0.358
Hectare (150 x 66.7 m)	0.073

This study was confined to looking at density and fish size changes for the common coral trout *Plectropomus leopardus*, as this is by far the most abundant of the five species of *Plectropomus* found on the GBR (Ayling and Ayling 1986b), and is the major component of the fishery. In the majority of surveys the estimated total length of all coral trout counted was also recorded. This enabled adult coral trout numbers (over the minimum legal size of 38 cm total length, hereafter termed "adult" coral trout) to be separated from the rest of the population. Length estimation trials carried out at various times by Tony Ayling using wooden coral trout models showed that the grand mean error in length estimation was –0.76 cm or 4.6% of the model length. Absolute errors ranged from –10 to +9 but the majority of estimates were within 2 cm of the true length. All large errors were for models of more than 50 cm TL.

Of the 200 or so GBR reefs on which coral trout counts have been made over the past 20 years (Ayling and Ayling 1986b), we selected 20 reefs for which three or more separate surveys spaced over at least 10 years were available. These 20 reefs (see Table 2) include both protected ("green") and unprotected ("blue") reefs as well as some reefs that are part zoned green and part zoned blue. Some of the reefs have changed zoning status during the study, either permanently or for a period ranging from 1 to 3.5 years. The initial counts on all but one reef (Norman) were made prior to the establishment of any Marine Park zoning, when all reefs were open to fishing.

The reefs were grouped into six regions according to two criteria: cross shelf position and latitudinal position. Common coral trout density is strongly affected by cross shelf position (Ayling and Ayling 1986a), with very low numbers on inshore reefs, moderate to high numbers on Mid Shelf reefs and low numbers on Outer Shelf reefs. Cross shelf position was best defined using a cross shelf index which documented the position of each reef relative to the shoreline (cross shelf index of 0) and the 200 m depth contour (index of 1.0). In general reefs with a cross shelf index of less than 0.3 can be regarded as inner shelf, an index of 0.3–0.8 indicates Mid Shelf reefs and reefs with an index over 0.8 are Outer Shelf. We divided the study reefs into mid and Outer Shelf reefs (no inshore reefs were included in this study) (Table 2). There are also significant north–south changes in common coral trout density with a 3.7 times increase from the north to south of the GBR (Ayling and Ayling 1986a). We divided the reefs into four sectors based on their north–south position: Northern — reefs in the Lizard Island area; Cairns – reefs in the central portion of the Cairns Section of the GBR Marine Park; Townsville – reefs in the offshore Townsville region; Southern – reefs south of the Whitsunday region (Table 2).

Table 2 List of reefs where temporal series of coral trout counts are available.
Lat.=latitute; Long. = longitude; C-S = cross shelf; No. = number of surveys.

Reef	Lat.	Long.	Region	Shelf position	C-S index	No.	Zoning	Time span
Lizard Is	14°39’	145°27’	Northern	Mid	0.61	4	Mixed	1982–1999
Eyrie	14°42’	145°23’	Northern	Mid	0.44	9	Green	1983–1998
MacGillivrays	14°39’	145°29’	Northern	Mid	0.68	9	Green	1983–1998
Escape	15°51’	145°49’	Cairns	Outer	0.92	4	Green → Blue	1980–1993
St. Crispins	16°05’	145°51’	Cairns	Outer	0.88	4	Blue	1983–1993
Norman	16°26’	146°00’	Cairns	Outer	0.84	6	Blue → Green	1987–1993
Channel	16°57’	146°27’	Cairns	Outer	0.88	4	Green → Blue	1983–1993
Hastings	16°31’	146°01’	Cairns	Mid	0.74	3	Mixed	1983–1994
Arlington	16°40’	146°03’	Cairns	Mid	0.64	5	Blue	1983–1993
Wardle	17°26’	146°32’	Cairns	Mid	0.75	4	Green → Blue	1983–1993
John Brewer	18°37’	147°03’	Townsville	Mid	0.56	11	Blue	1983–1997
Lodestone	18°42’	147°06’	Townsville	Mid	0.53	11	Blue	1983–1997
Davies	18°50’	147°38’	Townsville	Mid	0.57	10	Blue	1983–1997
Bramble	18°26’	146°43’	Townsville	Mid	0.43	8	Blue	1984–1997
Yankee	18°34’	147°30’	Townsville	Mid	0.78	8	Green	1984–1998
Dip	18°25’	147°27’	Townsville	Outer	0.91	9	Green	1984–1998
Faraday	18°26’	147°21’	Townsville	Outer	0.88	8	Green	1984–1998
Hardy	19°49’	149°14’	Southern	Mid	0.51	8	Green	1983–1994
21–131	21°23’	151°22’	Southern	Mid	0.64	8	Green	1985–1998
21–132	21°24’	151°20’	Southern	Mid	0.62	8	Green	1985–1998

Survey time was not consistent between years but this was not considered problematic because coral trout are relatively sedentary and there is no evidence of seasonal movements except to spawning aggregations (Davies 1996, Samoilys 1997b Samoilys 1997a, Zeller 1998). None of the surveys reported here were carried out during the new moon period in spring when coral trout aggregate to spawn.

To simplify analysis of temporal patterns we grouped survey times into three periods: ‘early’ included all surveys prior to 1990; ‘middle’ included surveys carried out between 1990 and the end of 1994; ‘recent’ included surveys from beginning 1995 to the present (Table 3). This grouping was an arbitrary break up which seemed reasonable based upon the distribution of the data. Note that

surveys were not made on any of the Cairns region reefs in the recent period and there were no middle period surveys in the Outer Shelf Townsville region.
Plots of total coral trout and adult coral trout density changes were made to document the temporal patterns for the different regions (Figures 1–6). Reefs within the same region were grouped on the same graph. To improve clarity years were offset slightly if reefs on the same graph had been surveyed at the same time. Line graphs have been used, again to improve clarity, but note that lines joining points some distance apart in time do not necessarily represent the path of real density changes. In obvious cases (more than 5 years between surveys) a question mark has been inserted on the line in the graphs.

Analysis

Underwater visual census data

The data (corrected for collection method) were analysed on the square root scale to satisfy the assumptions of the mixed linear model and all results were back transformed for presentation. A mixed linear model was used to describe the change in the density of all coral trout and for legal sized coral trout over time, accounting for the factors presented in Table 3.

It should be noted that an extremely large fluctuation was noted in coral trout counts on Dip and Faraday reefs in the recent period, with a short-lived, almost order of magnitude, increase in juvenile densities. This fluctuation was obviously a real effect, also noted on some other reefs in this region, and was accounted for in the model. The reason for adjusting the model for this fluctuation was the potential for it to hide other effects as the variation due to this marked change would automatically be included in the error term otherwise. Further, the difference between the two apparent slopes (the marked increase and subsequent rapid decline) within the Recent period on the Townsville Outer Shelf was also modelled (TO slope in Table 5) to examine the unusual change at Dip and Faraday reefs.

Comparisons of slopes within periods and period averages were carried out within regions at the 5% level of significance, as these were attributes of the data that were of interest.

Analysis of Size Distribution Data

The distribution of the size of fish at each reef was characterised by three measures:
(1) Overall mean length: this describes the average size of the fish
(2) Standard deviation: this describes the variability of the distribution around the mean. Small values suggests that the fish are all of uniform size, while large values indicate a population with many different size classes
(3) Skewness: this quantifies the symmetry of the distribution. Values of zero indicate that there are equal numbers of fish larger than and smaller than the mean. A positive values suggests the population is made up of proportionally more small fish with few, but much larger big fish. Similarly a negative value suggests many fish are larger than the mean, but with a smaller number of fish which are less than the mean.

These three values were calculated for fish sampled from each reef in each year surveyed. A mixed linear model was then used to describe the change over time of these components accounting for the factors in Table 3, (excluding habitat as this was not recoverable from the data). Contrasts were used to estimate the effects of interest.

Table 3. Factors used in the analytical design

Factor	Levels
Townsville Outer (TO) Change	This factor represents the change that took place in the Townsville Outer region (see text)
Habitat	1. Front reef slope 2. Back reef slope
Region	1. Northern: reefs in the Lizard Island area 2. Cairns Mid: Mid Shelf Cairns area reefs 3. Cairns Outer: Outer Shelf Cairns area reefs 4. Townsville Mid: Mid Shelf Townsville area reefs 5. Townsville Outer: Outer Shelf Townsville area reefs 6. Southern: reefs south of the Whitsunday Islands
Period	1. Early: surveys between 1980 and 1989 inclusive 2. Middle: surveys between 1991 and 1994 inclusive 3. Recent: surveys between 1995 and 1999 inclusive
Zone	1. Green: reefs protected from fishing 2. Blue: reefs open to fishing 3. Mixed: reefs zoned part green and part blue

Commercial catch and effort data

Total catch, effort and catch rate for the commercial reef line fishery were calculated from the QFMA/DPI logbook data (CFISH). Data were extracted from those 30' grids (Table 4) that corresponded to the six regions being analysed (see above). Thirty degrees is the smallest resolution at which the commercial data is recorded.

Table 4. Commercial logbook data grids selected to represent the reefs and regions.

Region	Reefs	30' Grids
Northern	Lizard	G12
	Eyrie	G12
	MacGillivray	G12
Cairns Mid Shelf	Hastings	I16
	Arlington	I16
	Wardle	J17
Cairns Outer Shelf	Escape	H14 & J14
	St Crispins	H15
	Norman	I15
	Channel	(I16)*
Townsville Mid Shelf	John Brewer	K20
	Lodestone	K20
	Davies	L20
	Yankee	L20
	Bramble	J19
Townsville Outer Shelf	Dip	K19
	Faraday	K19
Southern	21–131	S25
	21–132	S25
	Hardy	O22

* Grid I16 was not included in the Cairns Outer Shelf group because two of the Cairns Mid Shelf reefs were in the same grid, Hastings and Arlington, and it was therefore used for that region.

Results

Habitat Differences

Total coral trout densities

Densities of common coral trout were not significantly different (F=3.79, p=0.09) between the exposed front reef habitat and the more sheltered back reef habitat (Table 5). Interactions of habitat with other factors such as region, period and linear trend were also non-significant. Overall mean density from front reef surveys was 49.2 fish per ha, while mean density on the back reef was 47.7 fish per ha (Table 6). Although the significance level was not over the 0.2 generally accepted as necessary for pooling, data from both habitats were pooled for further analyses. This was done because many of the early surveys were confined to the back reef habitat.

Adult coral trout densities

For adult coral trout (fish >38cmTL), overall densities were also not significantly different between habitats, but the habitat x period interaction was significant (Table 5). There were significantly more adults on the back reef compared to the front reef in the middle time period, but no habitat differences were detected in the early or recent time periods. The habitat differences in the middle time period were not great (densities on the front reef were 70% of those on the back), and the adult density data from both habitats were pooled for further analyses.

Fish lengths

Mean length of coral trout was not significantly different between the two habitats (p=0.387, Overall mean TL was 34.2 cm in the front reef habitat, and 34.9 cm. in the back reef habitat.

Table 5. Results of mixed linear model: tests of fixed effects on coral trout density. Trend represents the average linear trend in density within each period. TO = Townsville Outer region (see Table 3). Statistically significant (p<0.05) results are italicised.

Source of variation	Num. df	Denom. df	F	probability
TOTAL CORAL TROUT				
TO	1	3983	19.79	*<0.001*
Zone	2	3983	1.38	0.252
Region	5	7	9.39	*0.005*
Zone (region)	4	3983	1.92	0.105
Period	2	7	0.37	0.703
Region x period	4	7	3.86	0.058
TO slope (region x period)	1	3983	0.68	0.408
Trend (period)	3	17	10.60	*<0.001*
Trend x region (period)	11	17	5.92	*<0.001*
Habitat	1	7	3.79	0.093
Region x habitat	5	7	1.71	0.250
Habitat x period	2	7	3.88	0.074
Region x habitat x period	1	7	0.32	0.587
Trend x habitat (period)	3	3983	1.55	0.200
Trend x region x habitat (period)	6	3983	1.18	0.313
ADULT CORAL TROUT				
TO	1	4032	31.29	*<0.001*
Zone	2	4032	1.00	0.370
Region	5	19	8.37	*<0.001*
Zone (region)	4	4032	1.59	0.174
Period	2	88	0.62	0.541
Region x period	4	88	3.85	*0.006*
Trend (period)	3	31	18.99	*<0.001*
Trend x region (period)	11	31	5.05	*<0.001*
Habitat	1	19	3.66	0.071
Habitat x period	2	4032	14.50	*<0.001*

Table 6. Coral trout densities (mean no fish ha^{-1}, and standard errors) among habitats

Habitat	Total coral trout		Adult coral trout	
	mean	**se**	**mean**	**se**
Front reef slope	49.2	1.43	16.1	0.64
Back reef slope	47.7	1.19	17.8	0.58

Temporal Patterns

Total coral trout densities

Mean coral trout densities between early, middle and recent time periods within each of the six regions (Figures 1–6) did not differ significantly except on the Townsville Mid Shelf reefs (Figure 4). At these reefs, the mean densities in recent years were significantly different (p<0.001) from early and middle years (Table 7). The results suggest that densities on the Townsville Mid Shelf reefs over the past few years have been on average lower than during any of the surveys conducted prior to 1995. All five Townsville Mid Shelf reefs showed similar patterns in density changes (Figure 4). Densities were relatively stable and high through the 1980s, low in the early 1990s,

increased rapidly from 1991 to 1995, and then underwent a rapid decline to levels in the latest surveys that are lower than, or approximately equal to, the lowest recorded in the past 15 years.

Table 7 Comparison of mean coral trout densities between periods for given regions . Statistically significant (p<0.05) results are italicised.

Region	Shelf position	Period comparison	Num. df	Denom. df	F	probability
TOTAL CORAL TROUT						
Northern	Mid	Early vs Recent	1	181	0.37	0.543
Cairns	Mid	Early vs Middle	1	181	0.55	0.461
Cairns	Outer	Early vs Middle	1	181	0.03	0.872
Townsville	Mid	Early vs Middle	1	181	2.13	0.146
Townsville	Mid	Early vs Recent	1	181	13.38	*<0.001*
Townsville	Mid	Middle vs Recent	1	181	16.63	*<0.001*
Townsville	Outer	Early vs Recent	1	181	0.37	0.545
Southern	Mid	Early vs Middle	1	181	0.74	0.390
Southern	Mid	Early vs Recent	1	181	1.00	0.320
Southern	Mid	Middle vs Recent	1	181	2.61	0.108
ADULT CORAL TROUT						
Northern	Mid	Early vs Recent	1	4032	0.58	0.448
Cairns	Mid	Early vs Middle	1	4032	0.78	0.377
Cairns	Outer	Early vs Middle	1	4032	1.73	0.188
Townsville	Mid	Early vs Middle	1	4032	3.42	0.065
Townsville	Mid	Early vs Recent	1	4032	16.91	*<0.001*
Townsville	Mid	Middle vs Recent	1	4032	18.16	*<0.001*
Townsville	Outer	Early vs Recent	1	4032	3.99	*0.046*
Southern	Mid	Early vs Recent	1	4032	1.38	0.241

Mean coral trout densities on the three northern Lizard Mid Shelf reefs have not changed significantly (p=0.54, Table 7) over the past 15 years, with densities in recent surveys similar to those during the early surveys (Figure 1). Although we have no recent surveys from Cairns region reefs, no change in mean density between early and middle time periods, for either Mid Shelf or Outer Shelf reefs was apparent (Figures 2, 3, Table 7). On Townsville Outer Shelf reefs, no surveys were available from the middle period. There were rapid density fluctuations during the recent time period of more than an order of magnitude (Figure 5A). Large numbers of coral trout between 27–37 cm TL appeared on these reefs in early 1997 at densities of around 40 per ha. Over the following 18 months densities of these young coral trout dropped rapidly to around 10 per ha, a change that could not be attributed to fishing mortality as these reefs were closed to fishing and the fish were below the minimum legal length. As discussed in the Analysis section above, this change was so large it accounted for a significant component of the variance in the mixed linear model (TO, Table 5). However, if mean densities are compared, those from the recent period were not significantly different from those during the early time period (Table 7). Similarly, there were marked changes in total coral trout density over the past 15 years on the three Southern Mid Shelf reefs (Figure 6), although mean densities between the three time periods did not differ significantly (Table 7). Densities on Hardy Reef were relatively stable through the 1980s, reached a low point in the early 1990s, before a rapid increase to a peak in 1996 (the other two reefs only had a single survey in the early time period). Since that peak in abundance, densities on all three reefs have declined rapidly (by 73%) over a 2.5 year period. These patterns were similar to those seen on Townsville Mid Shelf reefs (Figure 4) but were delayed by around 12 months.

Adult coral trout densities

The temporal patterns of adult coral trout density changes in the six regions were generally similar to those for total coral trout populations (Figures 1–6, Tables 5 & 7), with the exception of the

Townsville Outer Shelf region. The influx of small common coral trout in early 1997 mentioned above did not affect adult densities on these reefs. The peak densities of small fish decreased rapidly over the following 18 months before they could cause an increase in adult numbers due to normal growth. Adult densities were in fact significantly lower during the recent time period than in the early period (Table 7, Figure 5B).

Table 8 Results of mixed linear model:
Tests of fixed effects on the mean length of coral trout and the standard deviation of the mean lengths. Only significant factors (p<0.05) are shown.

Source of variation	Num. df	Denom. df	F	probability
MEAN LENGTHS				
Region	5	14	14.15	<0.001
Period	2	35	6.08	0.005
Trend (period)	3	46	7.76	<0.001
STANDARD DEVIATION				
Region	5	74	11.15	<0.001
Period	2	74	19.50	<0.001
Trend (period)	3	93	8.88	<0.001
Trend (period x region)	13	93	2.44	0.007
Habitat	1	74	7.74	0.007

Table 9 Comparison of means and standard deviations of fish lengths between time periods
Statistically significant results (p<0.05) are italicised.

Period comparison	difference	se	df	t	probability
MEAN LENGTHS					
Early vs Middle	2.15	0.87	35	2.48	*0.018*
Early vs Recent	3.19	1.11	35	2.87	*0.007*
Middle vs Recent	1.04	1.03	35	1.01	0.319
STANDARD DEVIATION					
Early vs Middle	1.06	0.61	74	1.73	0.087
Early vs Recent	3.77	0.69	74	5.42	*<0.001*
Middle vs Recent	2.71	0.63	74	4.30	*<0.001*

Fish lengths

There were significant differences in the mean length and standard deviation of common coral trout populations between time periods and regions (Table 8). Significant decreases in mean length were detected between the early and middle periods and between the early and recent periods (Table 9, Figure 7). Overall adjusted mean length was 37.9 cm in the early time period, 35.8 cm in the middle time period and 34.7 in the recent time period. (Note: the adjusted mean, is the mean one would expect to see when the covariates are held constant. Because surveys were carried out at different times in a period, the variability in the observed mean is larger than one would expect had the reefs been surveyed at the same time. This adjusted mean removes some of this variability and thus gives a better estimate of the mean.) There was also a significant reduction in the standard deviation of the mean length between the early and the recent time periods and the middle and recent periods, suggesting that variability or spread of fish length had also decreased (Table 9). The standard deviation decreased from 10.3 cm in the early time period to 6.5 cm in the recent time period. This implies a reduction of fish in the small and/or large size classes. The length frequency plots indicate that this decrease can be attributed mainly to a decline in the number of large fish (Figure 7).

Although there were notable declines in mean length between early and recent surveys, these were not apparent in the Townsville Mid Shelf and Southern Mid Shelf reefs (Table 10), the two regions where significant declines in density over the 15 years covered by this study have been detected (see above).

While means and standard deviations of coral trout lengths have decreased significantly over time, this is not clearly reflected in the length frequency distributions. Modal size class and the rapid fall off of both large and small size classes remained relatively stable over the course of the study (Figure 7). Length distributions were not significantly skewed from a normal distribution (p>0.05), with the exception of Townsville Mid Shelf reefs in the recent time period where the distribution was significantly skewed towards smaller length classes (t=-2.06; p=0.041). Size classes below 30 cm TL were strongly represented in the middle period on Northern reefs (Figure 7), though skewness toward smaller size classes was not significant (t= -1.68; p=0.09). A strong recruitment peak of 0+ fish (juveniles) was recorded on these reefs during the one survey made in this region during this time period. This survey was made during February when juvenile coral trout are between 5–15 cm TL (Doherty et al 1994, Brown et al 1994, Light and Jones 1997).

Table 10. Mean lengths of common coral trout in the different regions.
Mean (estimated TL in cm) is shown for each time period within each region.

Region	Shelf position	Period	Mean TL (cm)	sd	se
Northern	Mid	Early	37.1	12.2	0.88
		Middle	28.5	14.6	1.32
		Recent	33.5	10.1	1.32
Cairns	Mid	Early	37.1	12.6	1.17
		Middle	34.0	11.0	0.71
Cairns	Outer	Early	43.4	7.8	1.63
		Middle	39.9	9.1	0.53
Townsville	Mid	Early	33.8	10.1	0.37
		Middle	34.9	10.2	0.30
		Recent	35.1	8.9	0.30
Townsville	Outer	Early	45.5	9.1	1.30
		Recent	36.7	6.6	0.44
Southern	Mid	Early	33.3	10.8	0.60
		Recent	33.7	8.0	0.22

Total coral trout trends

Since differences in coral trout densities were attributed to linear trends in density within periods and this varied between regions (Trend (period) and Trend x region (period) in Table 5), we compared separately the mean linear trends in density of the three periods, in each of the six regions, to look at rates and directions of density change. These results revealed significant differences between the early and middle periods compared with recent surveys in two regions (Table 11). In both the Townsville and Southern Mid Shelf regions recent trends were strongly downward, whereas trends in the early and middle time periods were either steady or positive (Figures 4, 6). Note that there were no surveys done in the middle period on two of the three Southern reefs. Trends were not highly variable within a region (eg linear trend(region x reef x period): Z=0.28; p = 0.778), i.e. trends were relatively consistent between reefs within periods and regions. Note that the model compared the trend in density on Townsville Outer Shelf reefs in the recent period before and after the large increase in numbers (Figure 5A; TO slope, Table 5) and found that the trends were not significantly different (p=0.408).

Adult coral trout trends

Linear trends in adults densities within the different time periods for the different regions showed similar patterns to those described for total coral trout. There were significant differences between the early/middle periods and the recent period in the Townsville and Southern Mid Shelf regions. There was also some suggestion (p=0.056) of a difference between early and recent periods for Townsville Outer Shelf reefs (Table 11, Figures 4,5,6), although there are very little data from the early period. In this region the mean trend in adult fish in the recent period was negative (Figure 5B) and this was no doubt masked in the total numbers analysis by the unexpected influx of small fish in 1997 (Figure 5A), as discussed above.

Zoning Effects on Density

Although there was no significant effect of zone within regions for either total or adult coral trout densities (Table 5), suggesting that protection from fishing resulting from marine park zoning has had no effect since its introduction in the early 1980s, confounding factors render this result of little consequence. The effect of zone was confounded with region, as there were no blue (or part blue) reefs in the Townsville Outer Shelf or Southern regions, and only a single part blue reef in the Northern region. In addition, the Southern region reefs (all green) have higher densities than all other reefs in this study due to their north–south position (see below). However, if these Southern reefs are excluded the overall mean adult densities were 15.6 per ha on blue reefs and 14.2 per ha on green reefs, providing some evidence that zone is having no effect on coral trout densities.

Table 11. Comparisons between trends (slopes) within periods for given regions. Statistically significant (p<0.05) results are italicised. NB. Data are missing for adults >38cm TL on Southern reefs in middle years because lengths were not estimated.

Region	Shelf position	Period comparison	Num. df	Denom. df	F	probability
TOTAL CORAL TROUT						
Northern	Mid	Early vs Recent	1	3998	1.43	0.233
Cairns	Mid	Early vs Middle	1	3998	2.88	0.090
Cairns	Outer	Early vs Middle	1	3998	0.50	0.479
Townsville	Mid	Early vs Middle	1	3998	*8.4*	*0.004*
Townsville	Mid	Early vs Recent	1	3998	*13.66*	*<0.001*
Townsville	Mid	Middle vs Recent	1	3998	*33.56*	*<0.001*
Townsville	Outer	Early vs Recent	1	3998	1.87	0.172
Southern	Mid	Early vs Middle	1	3998	2.43	0.119
Southern	Mid	Early vs Recent	1	3998	*24.99*	*<0.001*
Southern	Mid	Middle vs Recent	1	3998	*10.72*	*<0.001*
ADULT CORAL TROUT						
Northern	Mid	Early vs Recent	1	31	2.66	0.113
Cairns	Mid	Early vs Middle	1	31	0.61	0.440
Cairns	Outer	Early vs Middle	1	31	0.29	0.591
Townsville	Mid	Early vs Middle	1	31	*7.46*	*0.010*
Townsville	Mid	Early vs Recent	1	31	*13.45*	*<0.001*
Townsville	Mid	Middle vs Recent	1	31	*38.6*	*<0.001*
Townsville	Outer	Early vs Recent	1	31	3.95	0.056
Southern	Mid	Early vs Recent	1	31	*25.13*	*<0.001*

Regional Differences

Coral trout densities

There were significant regional differences in density (Table 5, p=0.005), and an understanding of these differences is important for interpreting the temporal changes in density described above. In general there were lower densities of common coral trout on Outer Shelf reefs than on Mid Shelf reefs (Table 12). Overall densities on Outer Shelf reefs were less than half of those recorded on Mid Shelf reefs in the same latitude range (19.0 vs. 44.5 per ha). In addition, common coral trout densities were higher in the southern region than in the Northern, Cairns and Townsville regions (Table 12). These patterns were similar for adult coral trout.

Fish lengths

Strong regional differences in fish length were also apparent (Table 8). The mean size of coral trout was larger on Outer Shelf reefs compared with Mid Shelf reefs (Table 10). Mean length was similar for all Mid Shelf regions with an overall mean of around 34 cm TL, but was almost 7 cm longer on Outer Shelf reefs (Table 10). This difference is also seen in the length frequency distributions (Figure 7) with a strong peak in the 31–40 cm length class apparent on Mid Shelf reefs, and a peak in the 41–50cm length class on the Outer Shelf reefs, in most time periods. An exception to this was on Townsville Outer Shelf reefs in the recent time period where the length frequency was very similar to those from Mid Shelf reefs. This was due to the influx of smaller fish onto these reefs in early 1997, as discussed above (Temporal Patterns section).

Further regional differences were seen in the standard deviations of the mean lengths. These were significantly smaller on Cairns Outer Shelf reefs compared with Cairns Mid Shelf reefs (t=4.55, p<0.0005), and smaller on Townsville Outer Shelf reefs compared with Townsville Mid Shelf reefs (t=4.26, p<0.0008). On Outer Shelf reefs most fish counted were large adults and there were fewer small fish (Figure 7). An exception to this was in the recent time period on Townsville Outer Shelf reefs where the influx of sub-adults (see above) reduced mean length and increased the standard deviation.

The standard deviation was greater (12.1 cm) on northern Mid Shelf reefs than in all other regions (6.2 to 9.3 cm). This was probably due to the large number of juvenile fish recorded during the only survey made in this region during the middle time period (Figure 7).

Table 12. Coral trout density (mean no fish ha^{-1}, and standard errors) patterns among regions and shelf positions.
nr = not recorded.

Region	Total coral trout				Adult coral trout			
	Mid Shelf		Outer Shelf		Mid Shelf		Outer Shelf	
	mean	se	mean	se	mean	se	mean	se
Northern	43.3	1.96	nr		14.9	1.01	nr	
Cairns	42.6	2.61	15.8	1.48	16.4	1.58	8.2	0.87
Townsville	44.7	0.94	21.6	1.49	17.5	0.60	8.8	0.87
Southern	117.8	4.55	nr		31.1	1.78	nr	

Commercial catch and effort data

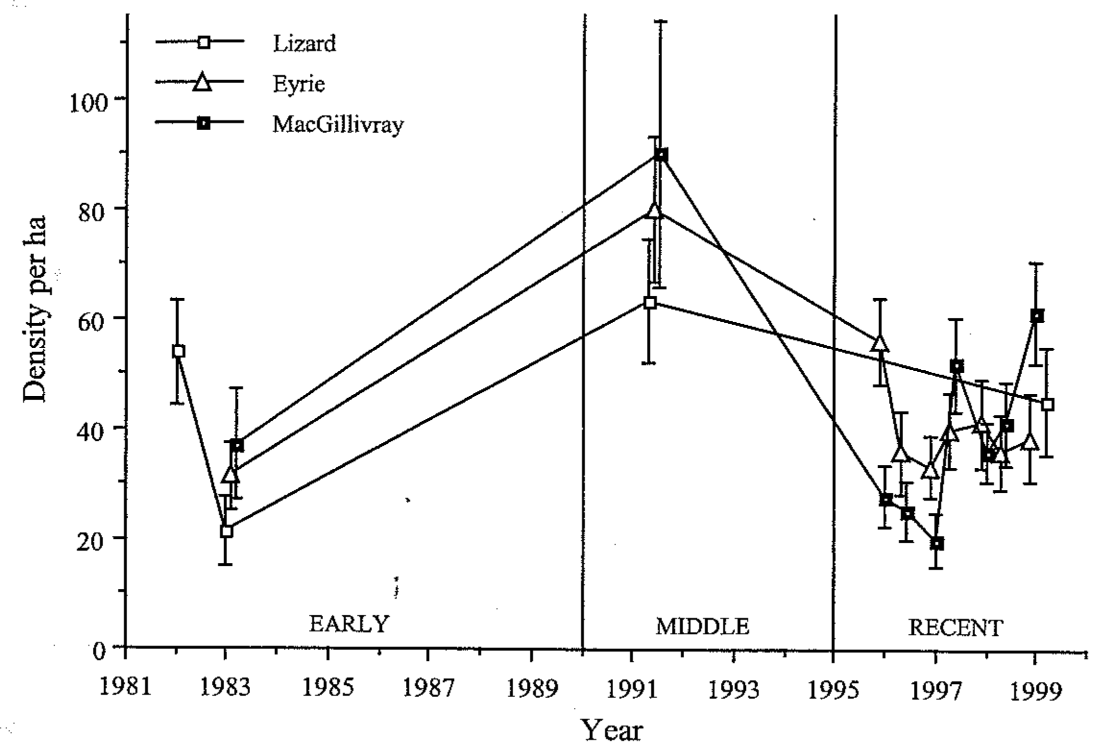
Since commercial log book data was first collected in 1988, fishing effort in the Townsville Mid Shelf and Southern regions has been consistently much higher, at around 1,000–2,000 boat days per year, than in other regions where the number of boat days is mostly less than 400 (Figures 8–13). An exception to this is the Cairns Outer Shelf region where over 1,000 boat days were reported in both 1997 and 1998. Note that the 1998 data is not quite complete, though most of the log book data has been entered.

In the Northern region there has been a steady rise in effort since 1993 to around 150 boat days in 1997–1998. Catch has almost trebled since 1993 with peak catches of 8–9 t in 1995–1996; but catch rates have declined since 1995 (Figure 8). On Cairns Mid Shelf reefs effort has risen steadily since the late 1980s with a peak in 1995–1996 of around 300 boat days (Figure 9). Catch has been relatively consistent at around 10–14 t, but catch rates have changed from around 70 kg/day in 1992 to 40 kg/day in 1997–98. Fishing effort on Cairns Outer Shelf reefs has been considerably higher in recent years at around 1,500 boat days in 1997 (Figure 10). Again effort has increased steadily in this region since 1989, with concomitant increases in catch from just over 20 t in 1989 to over 60 t in 1998. Catch rate changes over years were similar to those seen on Cairns Mid Shelf reefs. On the Townsville Mid Shelf reefs fishing effort ranged from 1,000 to 2,000 boat days between 1989 and 1996, and then increased substantially in 1997 to over 2,500 boat days (Figure 11). Catch has been consistent at around 100–140 t since 1993. Catch rates were high (around 70 kg/day) until 1997–98 where they have dropped slightly to 50–60 kg/day. On Townsville Outer Shelf reefs there has been a 75% increase in effort since 1996 to 350–400 boats days, giving the greatest catches in the same years, though catch rate declined (Figure 12). Fishing effort in the Southern region was relatively steady from 1989 to 1993 at 1200 to 1600 boat days. It has declined since 1996 with a similar drop in catch for the same years (Figure 13). Catch rates in this region were notably higher than the other regions, with peak rates of 115 kg/day in 1992, dropping to around 90 kg/day in 1995–96, and a further drop to 60 kg/day in 1997–98.

Figure 1. Coral Trout Density Changes: Northern Mid Shelf Reefs.

Densities are means per ha from varying numbers of sites for each survey time. Error bars are standard errors. Vertical lines separate analysis time periods.

A. Total Coral Trout



B. Adult Coral Trout

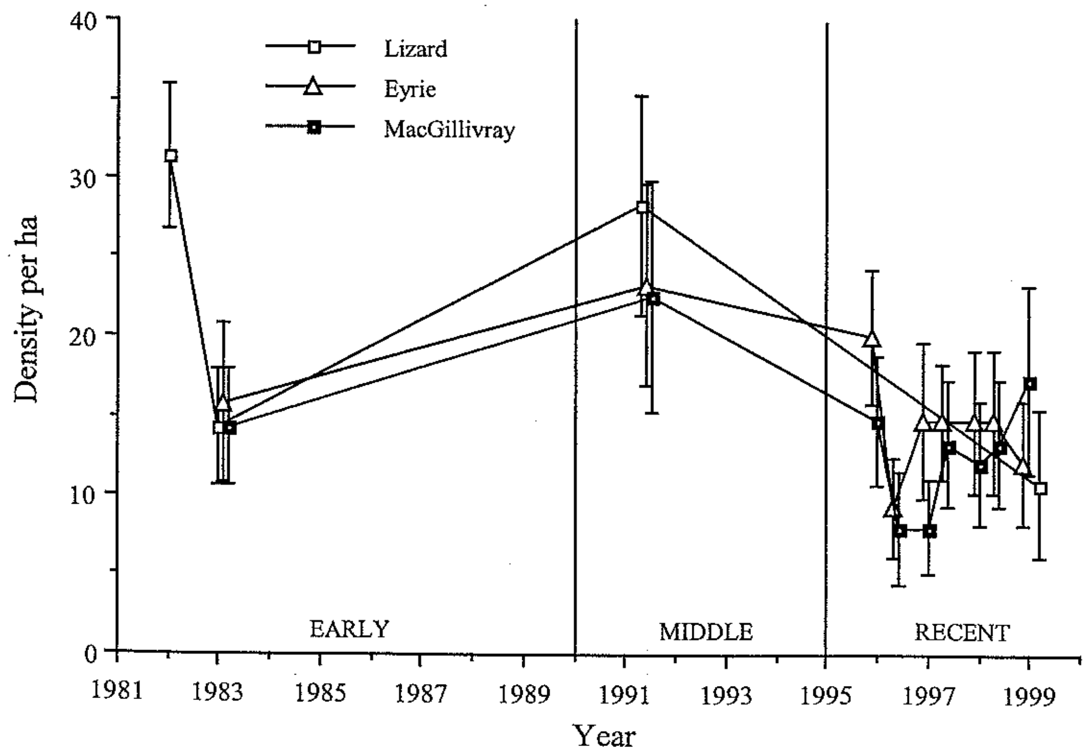
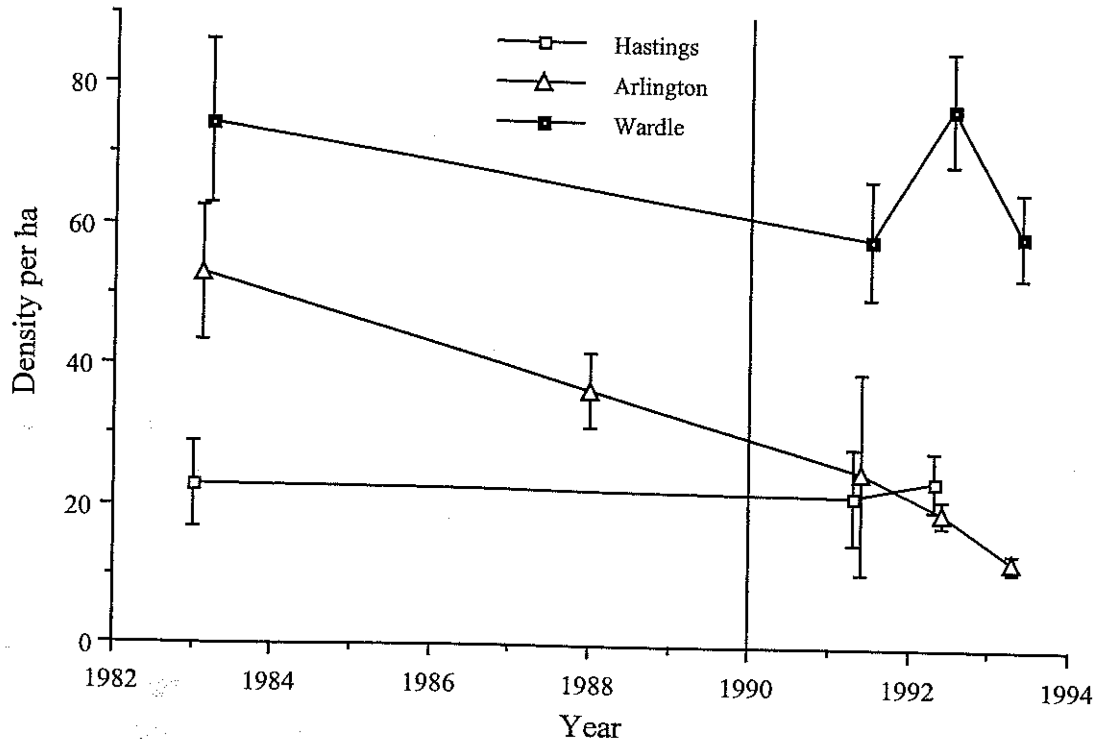


Figure 2. Coral Trout Density Changes: Cairns Mid Shelf Reefs.

Densities are means per ha from varying numbers of sites for each survey time. Error bars are standard errors. Vertical lines separate analysis time periods.

A. Total Coral Trout



B. Adult Coral Trout

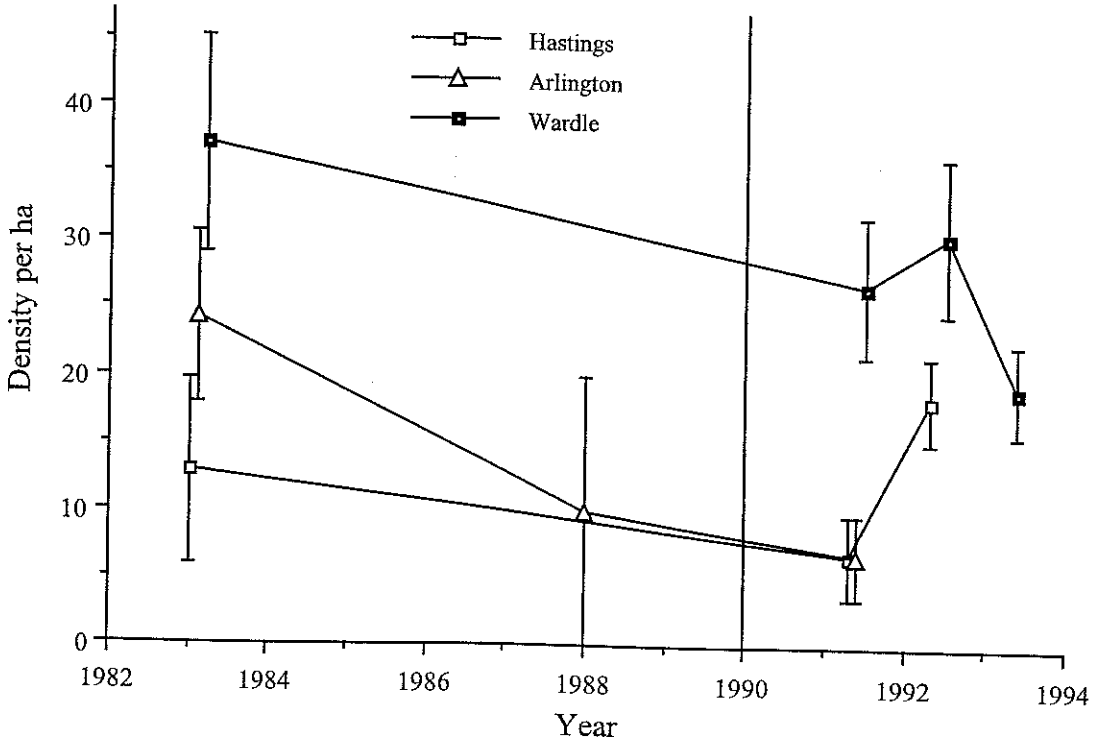
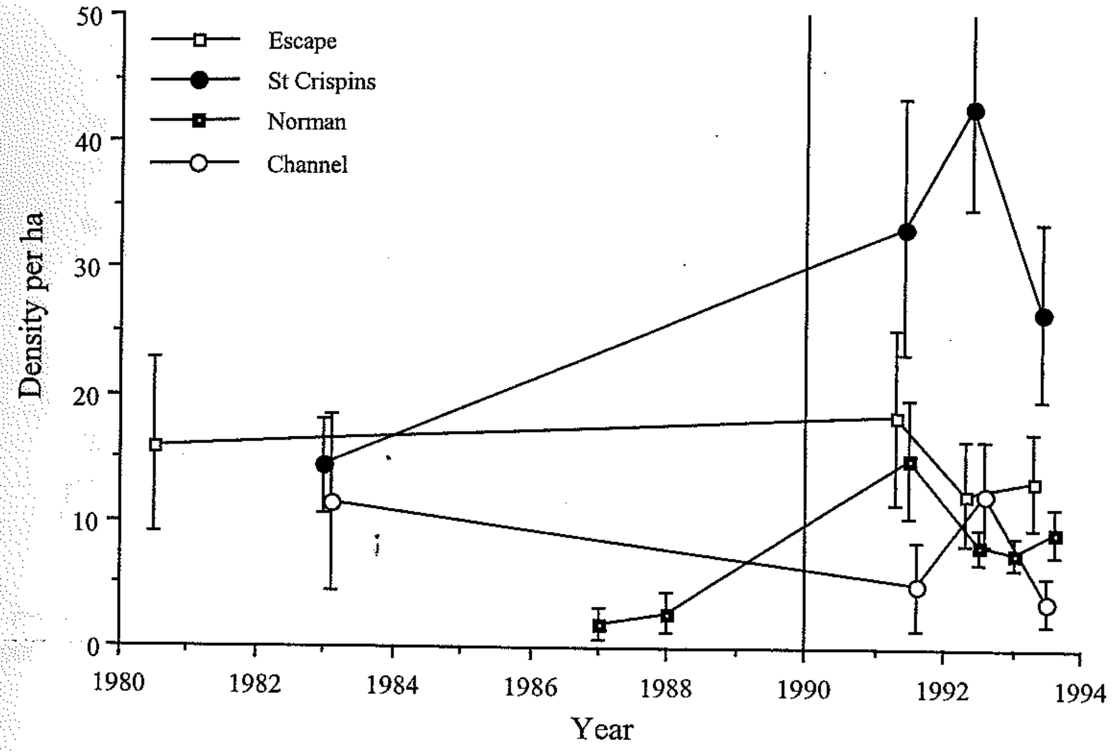


Figure 3. Coral Trout Density Changes: Cairns Outer Shelf Reefs.

Densities are means per ha from varying numbers of sites for each survey time. Error bars are standard errors. Vertical lines separate analysis time periods.

A. Total Coral Trout



B. Adult Coral Trout

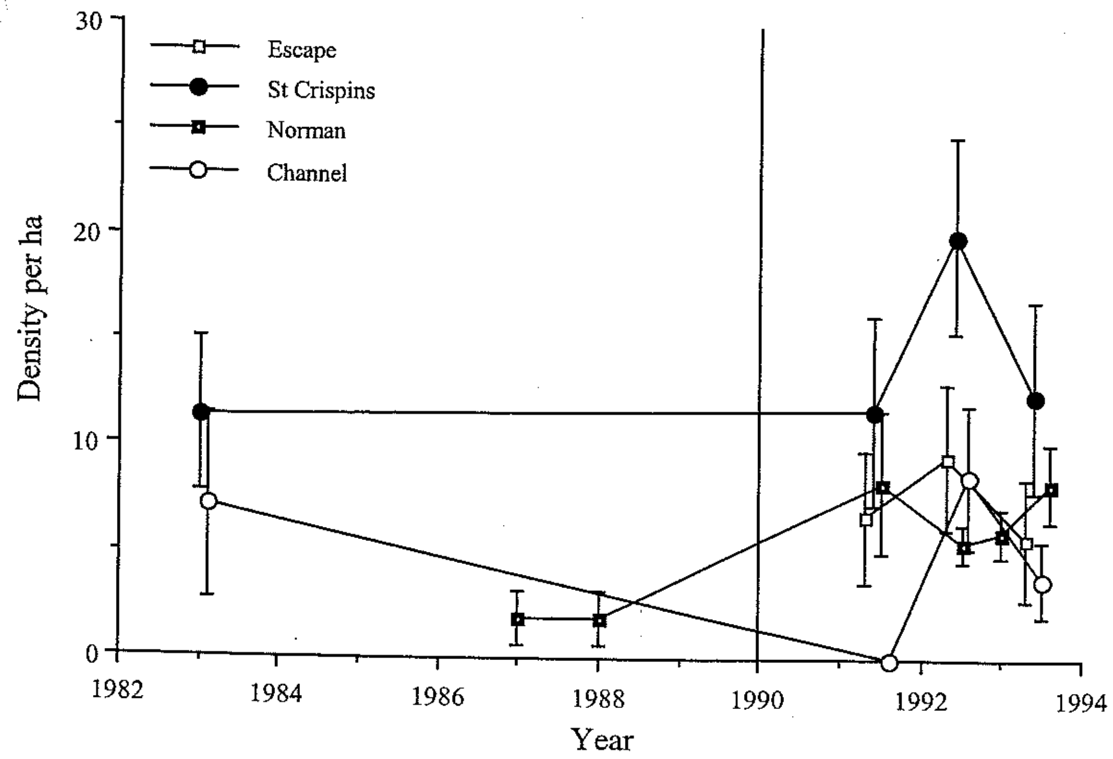
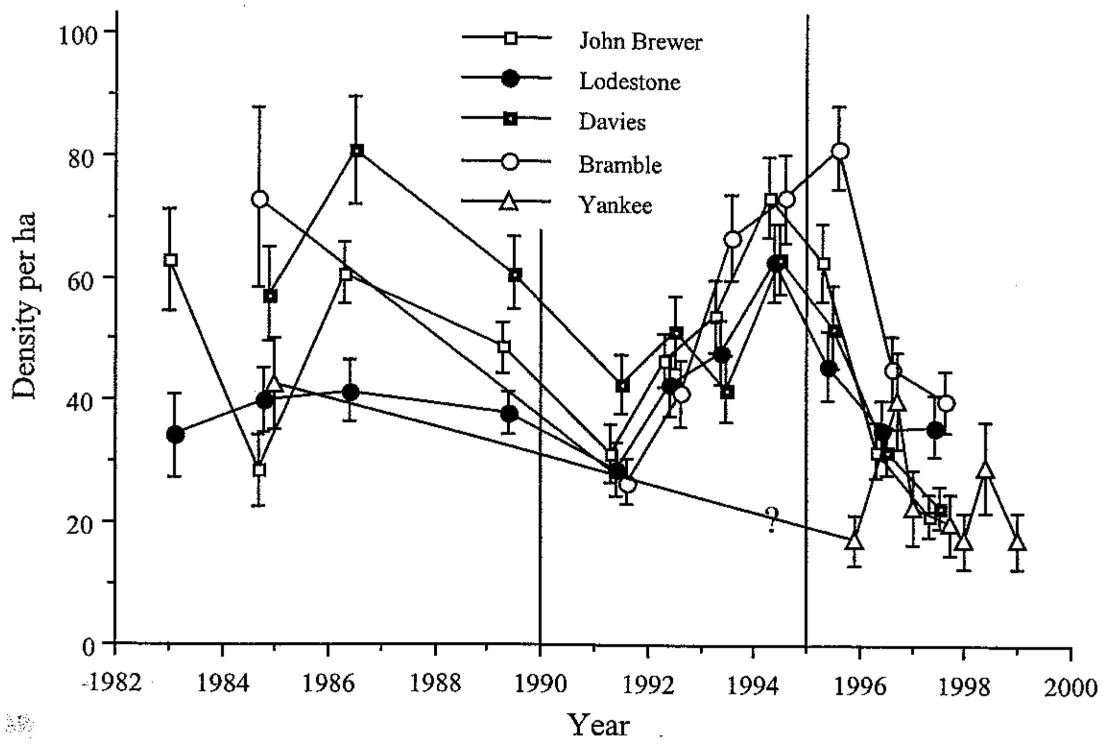


Figure 4. Coral Trout Density Changes: Townsville Mid Shelf Reefs.

Densities are means per ha from varying numbers of sites for each survey time. Error bars are standard errors. Vertical lines separate analysis time periods.

A. Total Coral Trout



B. Adult Coral Trout

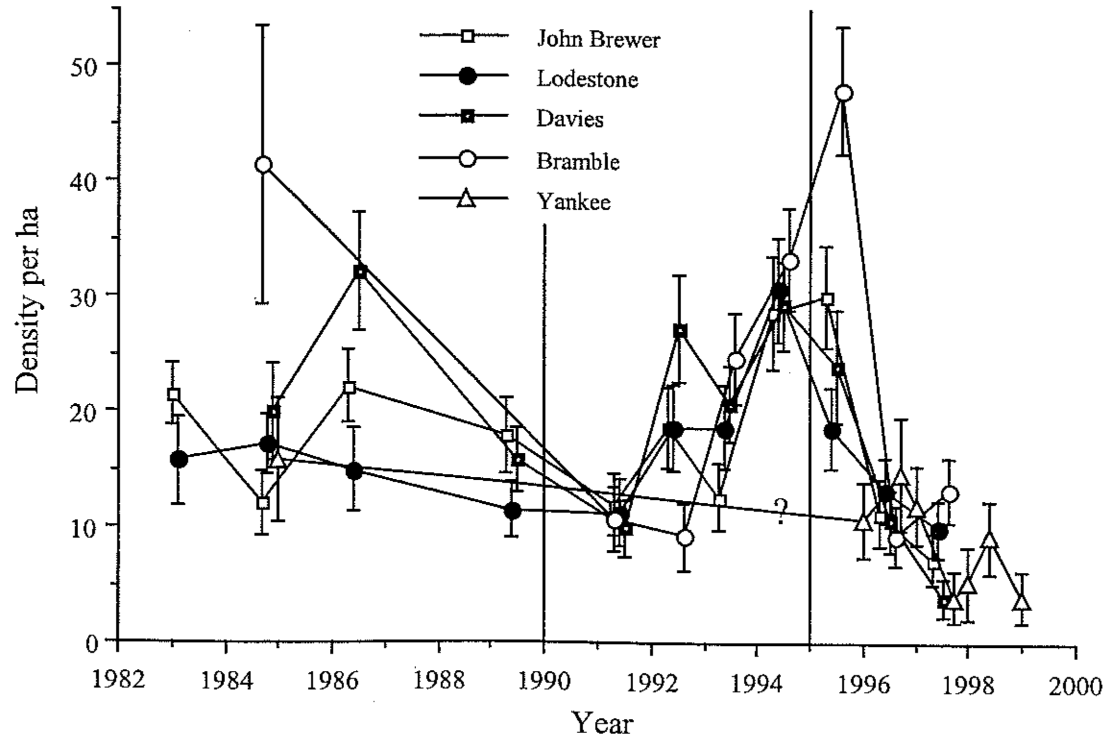
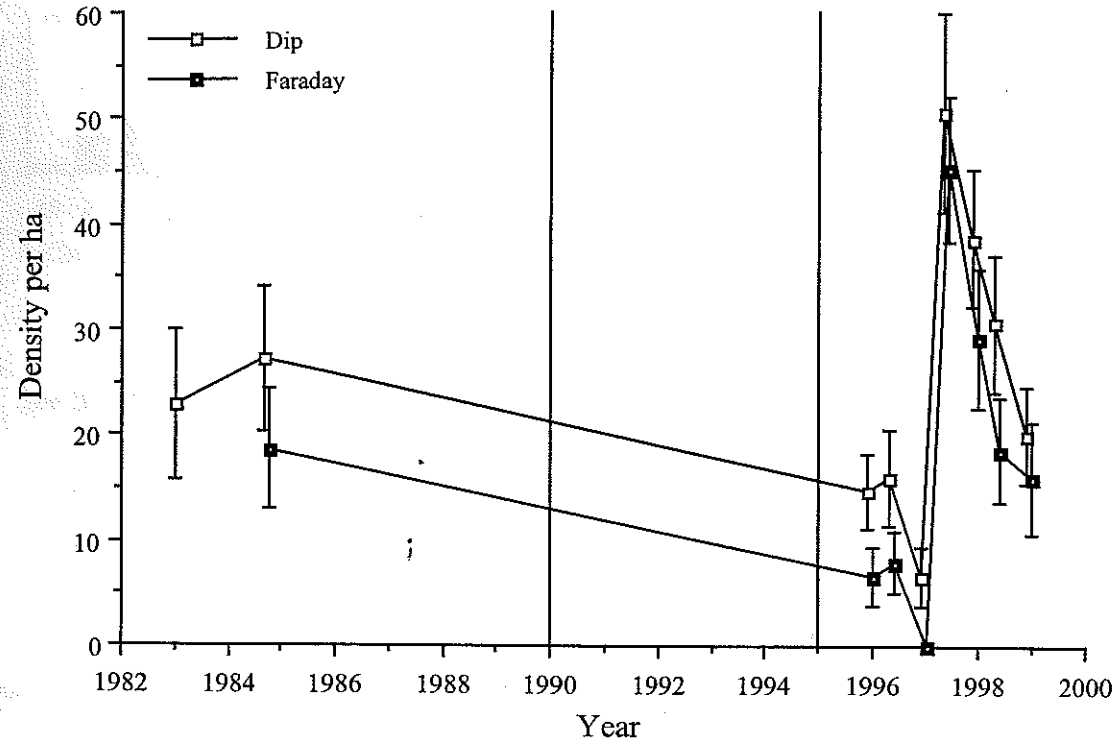


Figure 5. Coral Trout Density Changes: Townsville Outer Shelf Reefs.

Densities are means per ha from varying numbers of sites for each survey time. Error bars are standard errors. Vertical lines separate analysis time periods.

A. Total Coral Trout



B. Adult Coral Trout

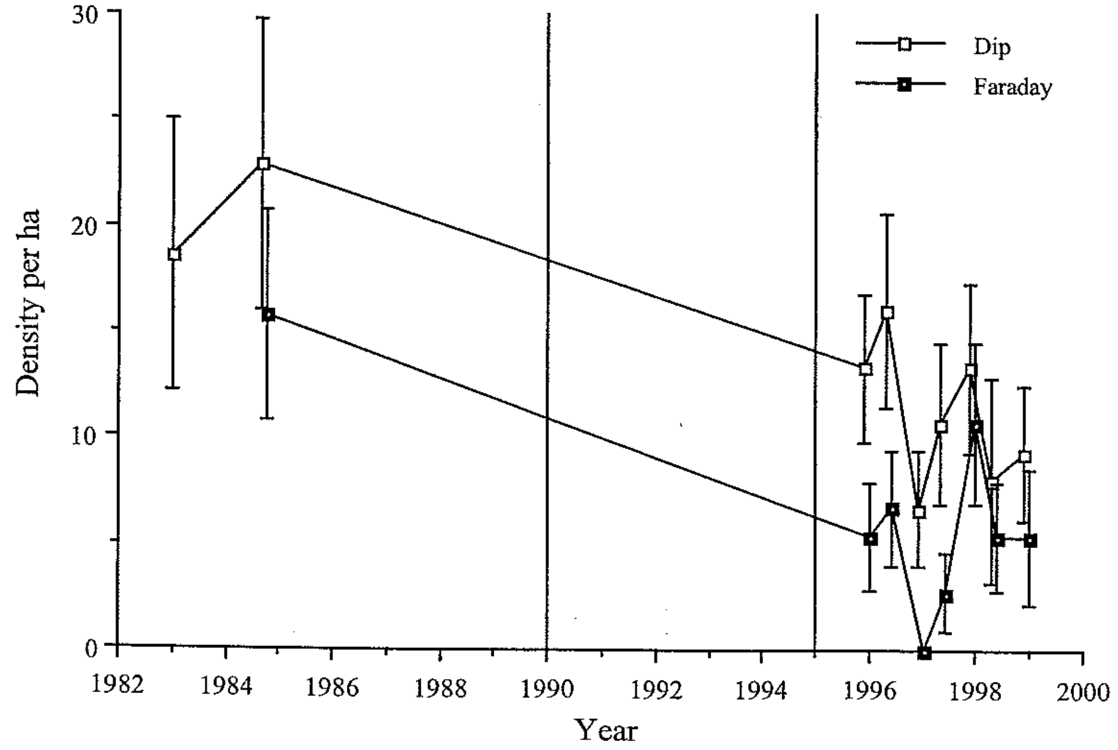
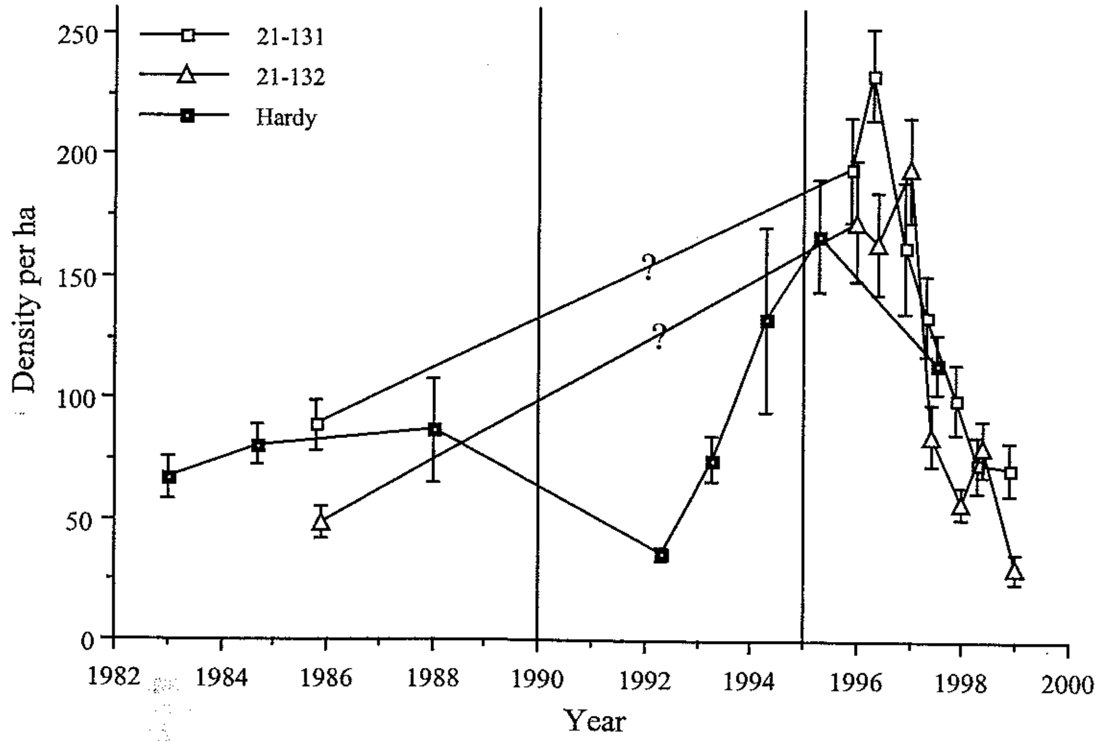


Figure 6. Coral Trout Density Changes: Southern Mid Shelf Reefs.

Densities are means per ha from varying numbers of sites for each survey time. Error bars are standard errors. Vertical dashed lines separate analysis time periods.

A. Total Coral Trout



B. Adult Coral Trout

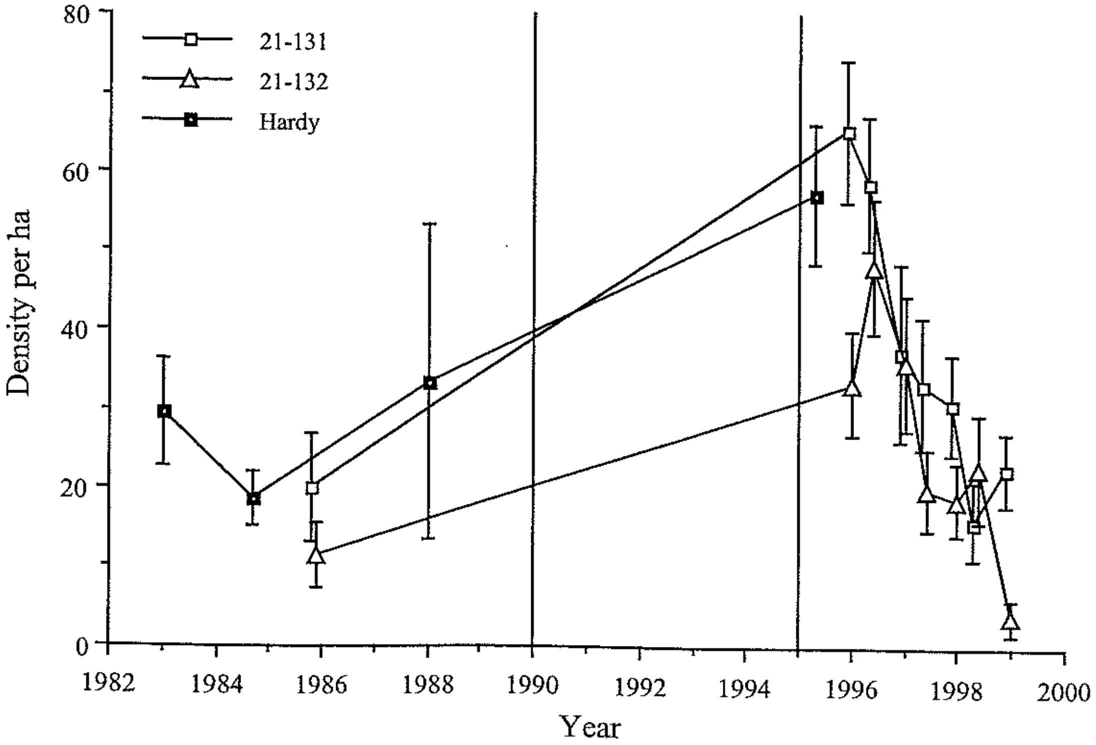


Figure 7. Coral Trout Length Frequency Comparisons.

Frequency (number) on the vertical axis against TL in cm. Length categories: 10=1–10 cm; 20=11–20 etc. Nth = Northern region; CM = Cairns Mid Shelf region; CO = Cairns Outer Shelf region; TM = Townsville Mid Shelf region; TO = Townsville Outer Shelf region; Sth = Southern region;

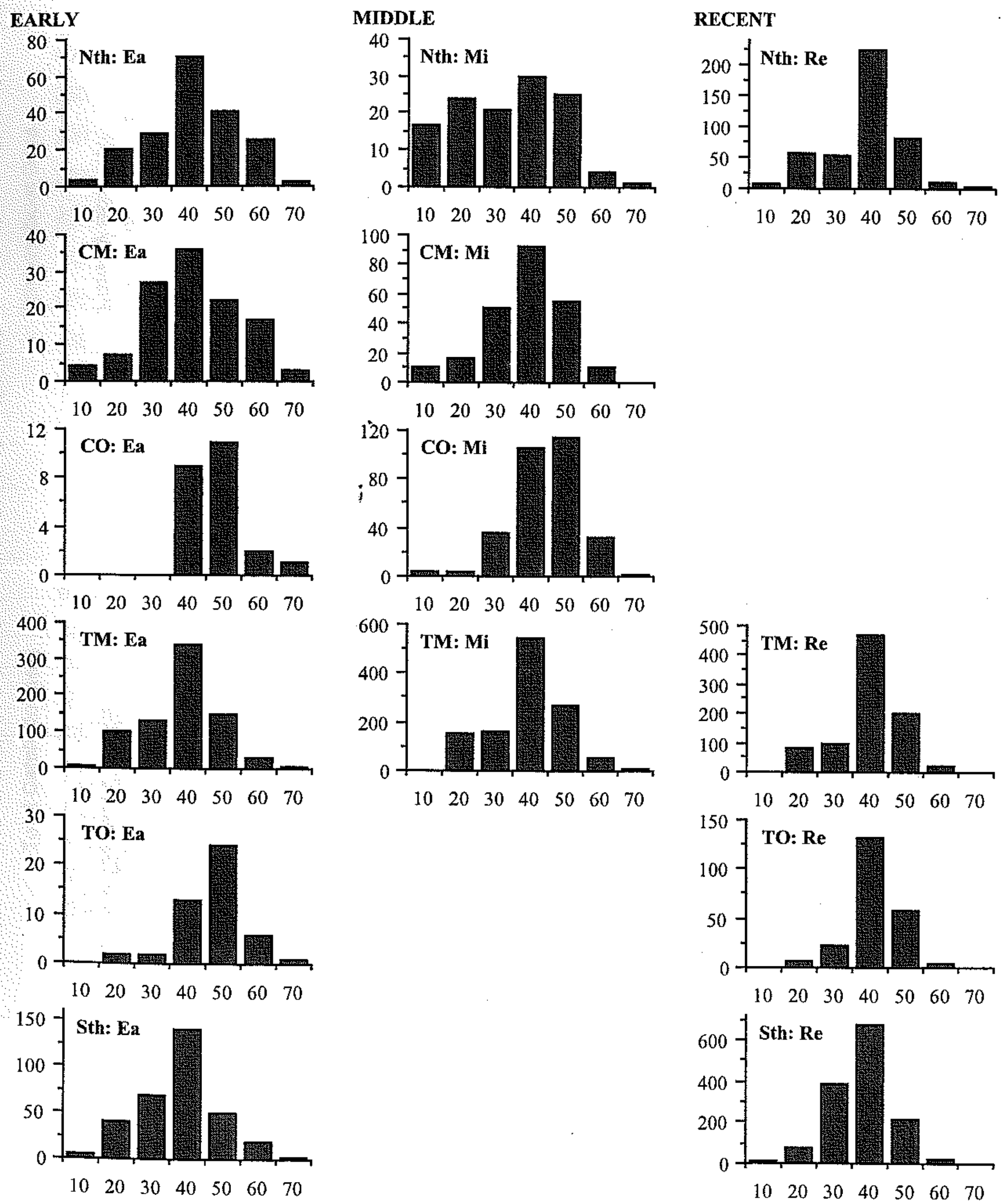
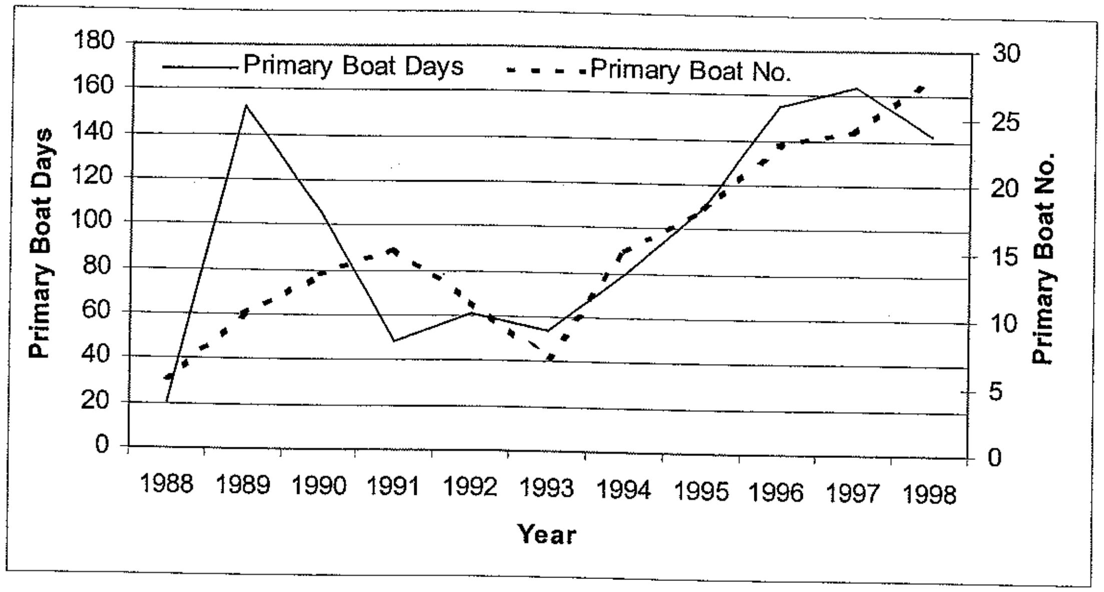


Figure 8. Northern Mid Shelf reefs.

A. Commercial line fishing effort: number of primary boats and number of fishing days per primary boat. B. Commercial line fishing catch and catch rate (catch per unit effort, CPUE). Primary boat = mother vessel with between 0 and 7 tender vessels (usually 4).

A.



B.

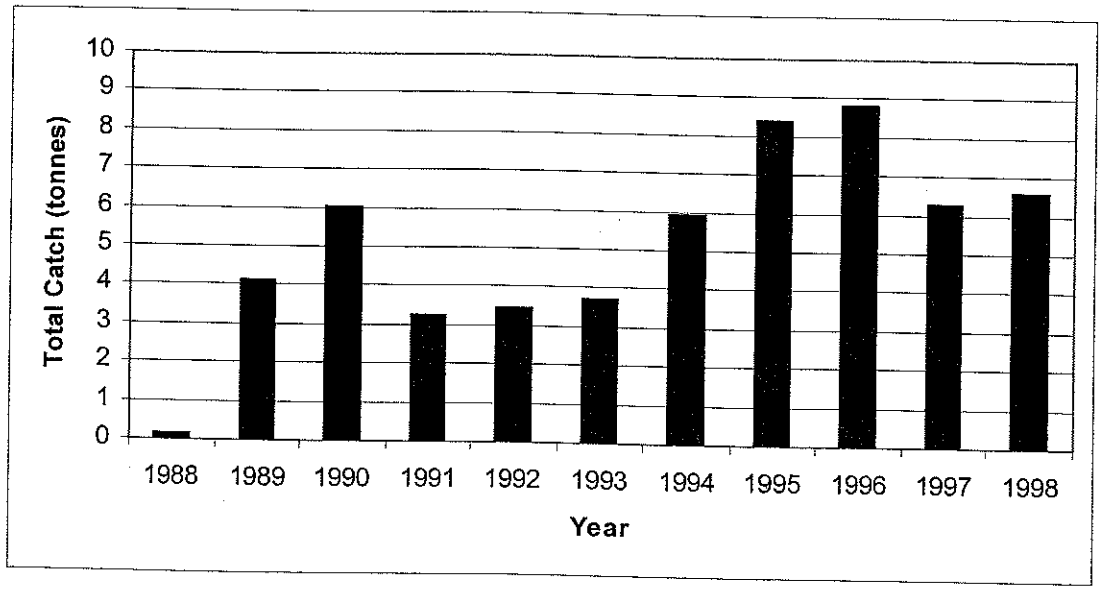
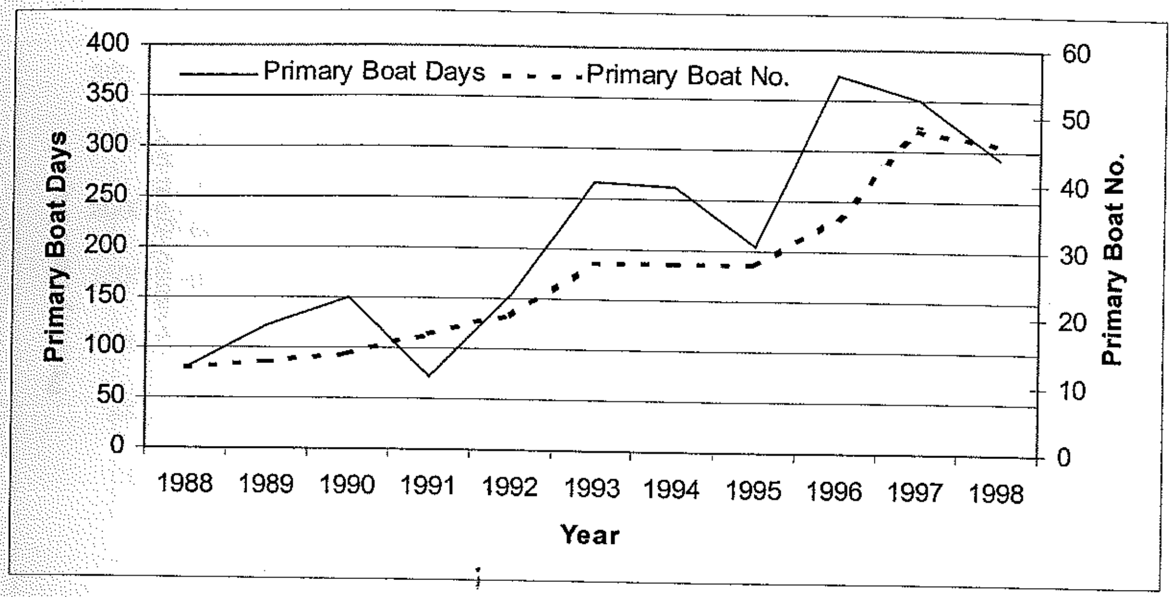


Figure 9. Cairns Mid Shelf reefs.

A. Commercial line fishing effort: number of primary boats and number of fishing days per primary boat. B. Commercial line fishing catch and catch rate (catch per unit effort, CPUE). Primary boat = mother vessel with between 0 and 7 tender vessels (usually 4).



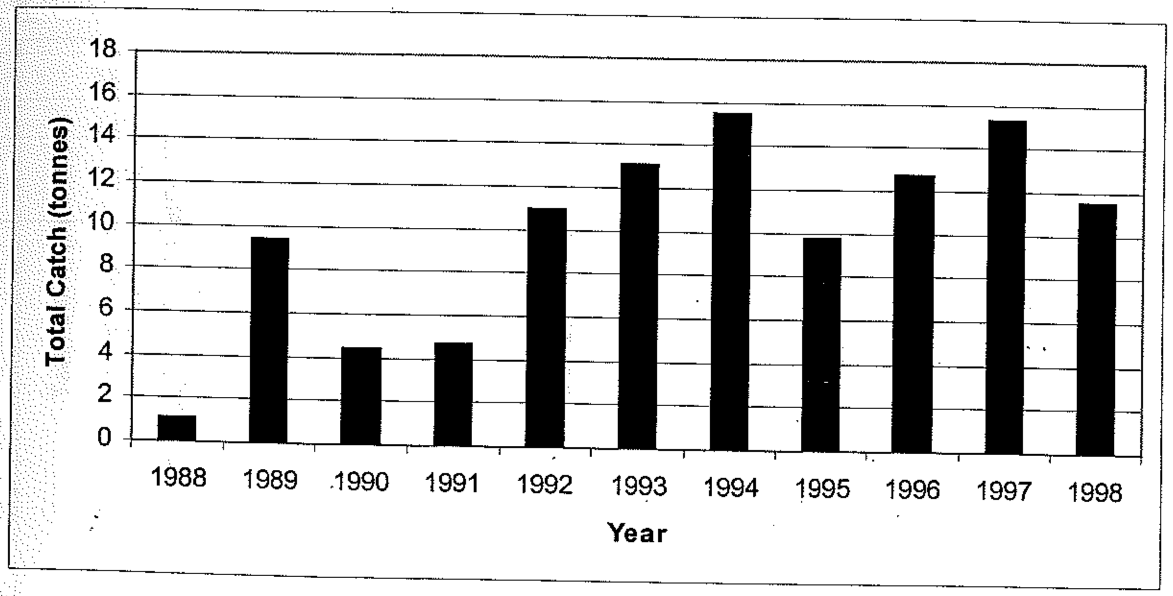
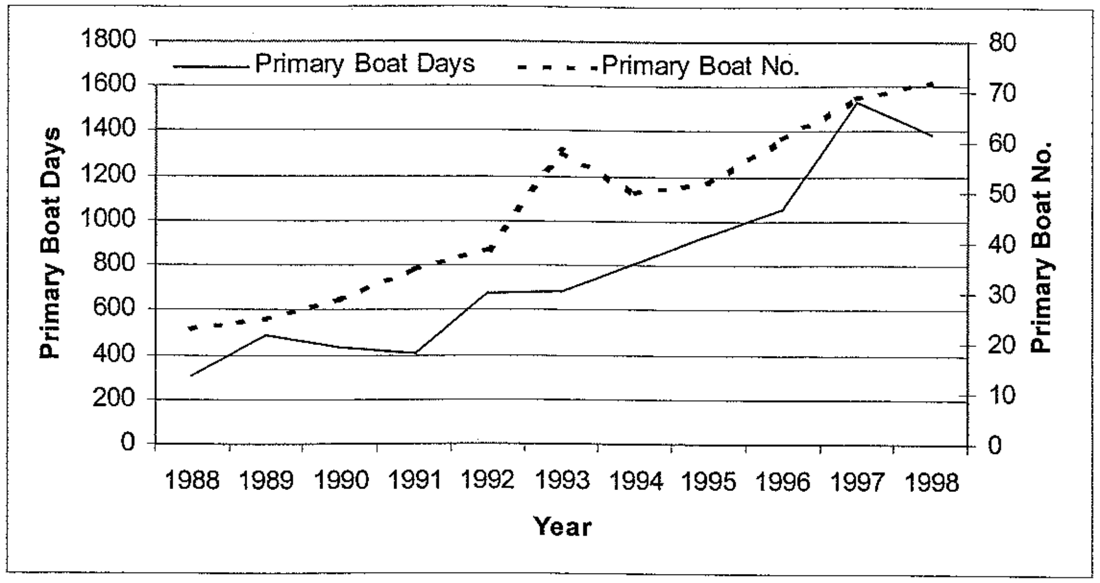


Figure 10. Cairns Outer Shelf reefs.

A. Commercial line fishing effort: number of primary boats and number of fishing days per primary boat. B. Commercial line fishing catch and catch rate (catch per unit effort, CPUE). Primary boat = mother vessel with between 0 and 7 tender vessels (usually 4).

A.



B.

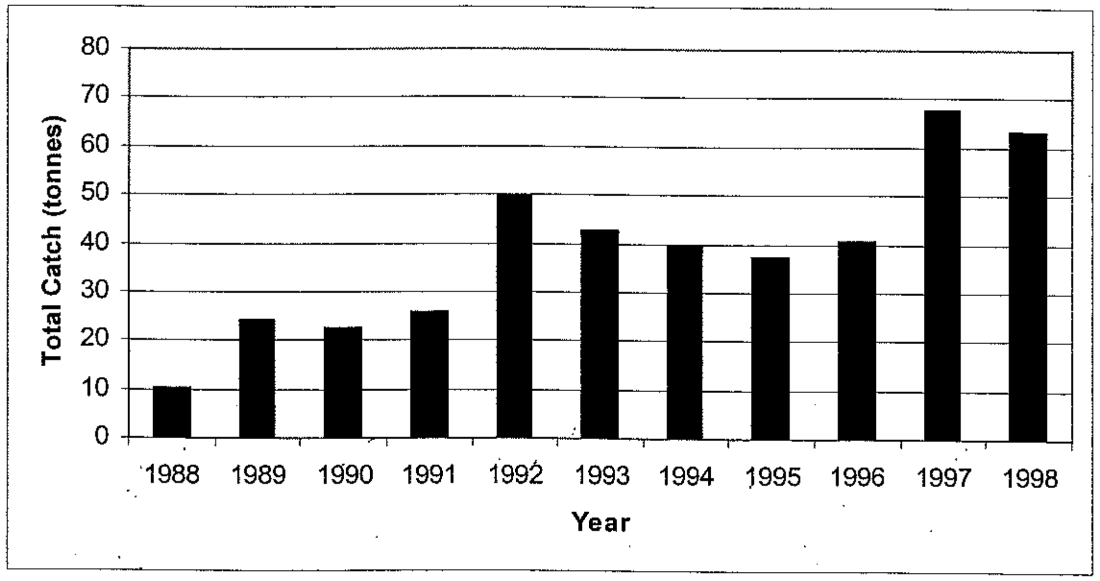
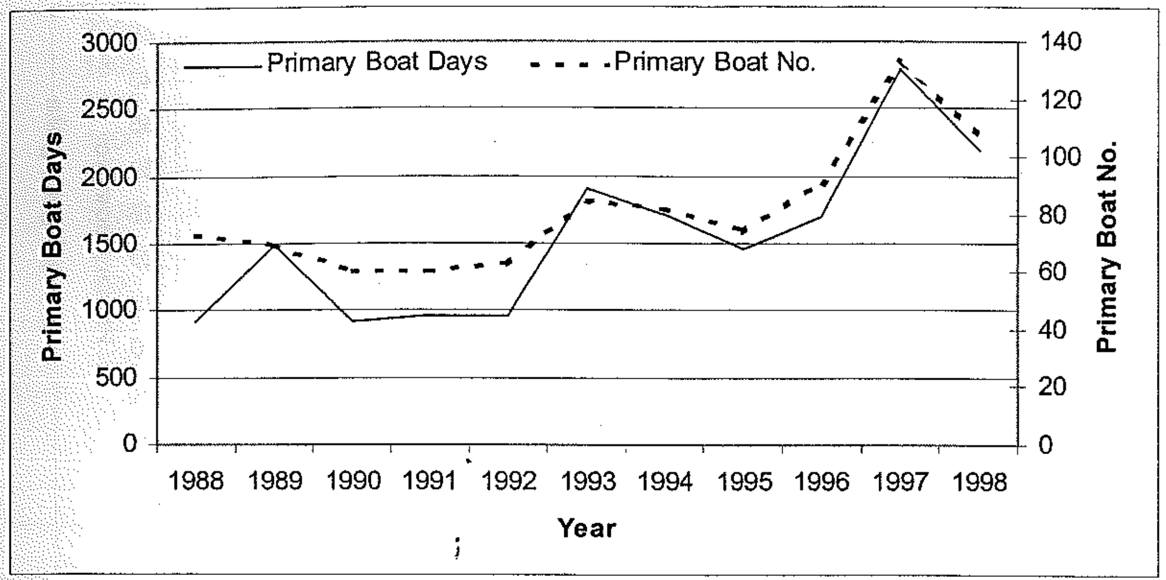


Figure 11. Townsville Mid Shelf reefs.

A. Commercial line fishing effort: number of primary boats and number of fishing days per primary boat. B. Commercial line fishing catch and catch rate (catch per unit effort, CPUE). Primary boat = mother vessel with between 0 and 7 tender vessels (usually 4).

A.



B.

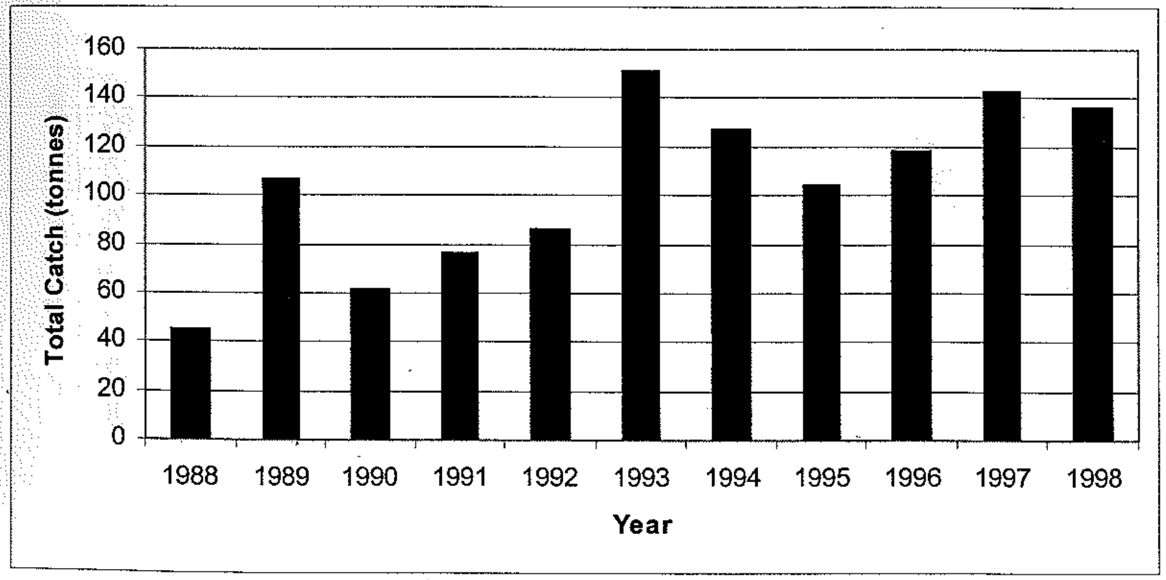
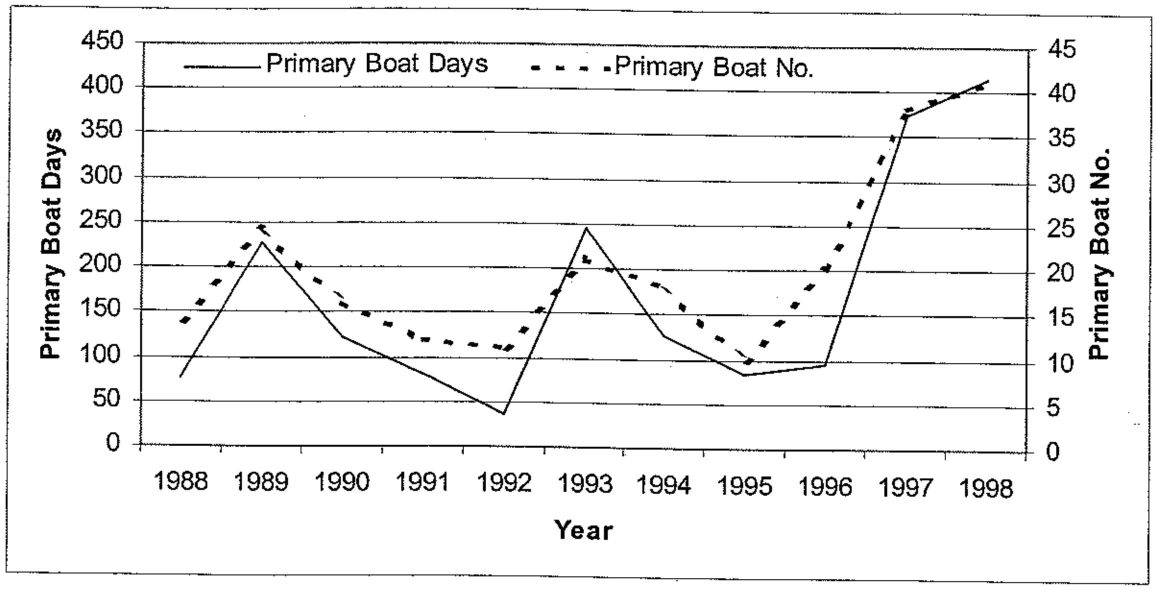


Figure 12. Townsville Outer Shelf reefs.

A. Commercial line fishing effort: number of primary boats and number of fishing days per primary boat. B. Commercial line fishing catch and catch rate (catch per unit effort, CPUE). Primary boat = mother vessel with between 0 and 7 tender vessels (usually 4).

A.



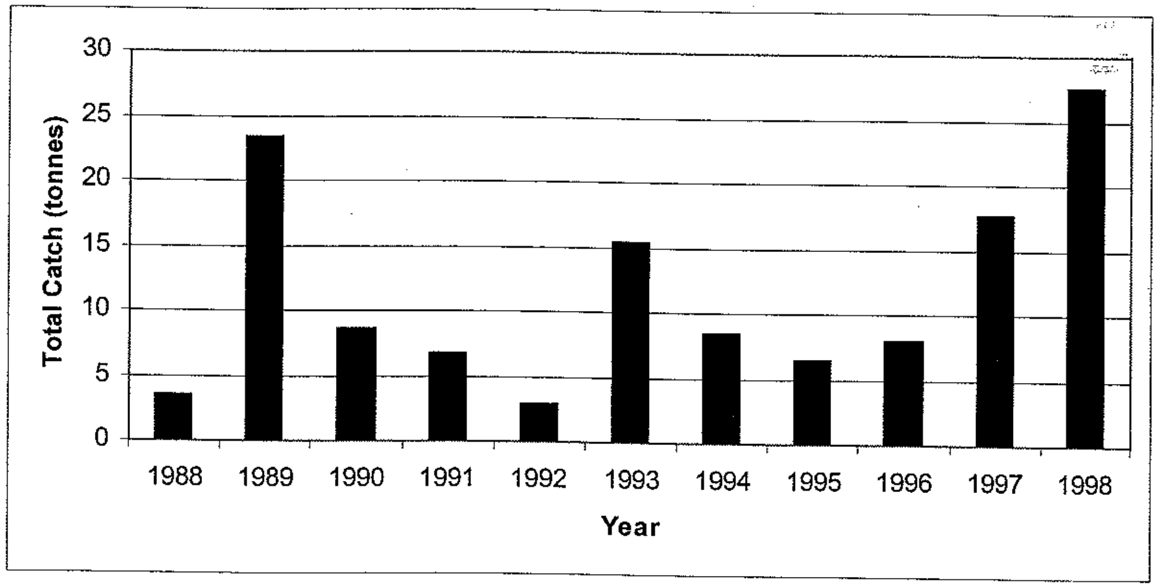
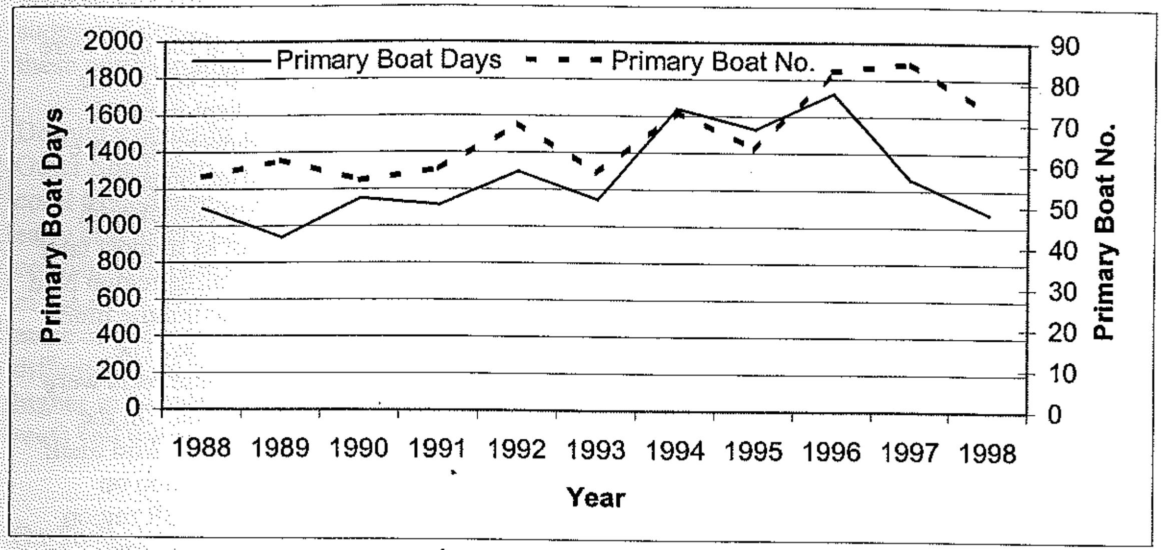


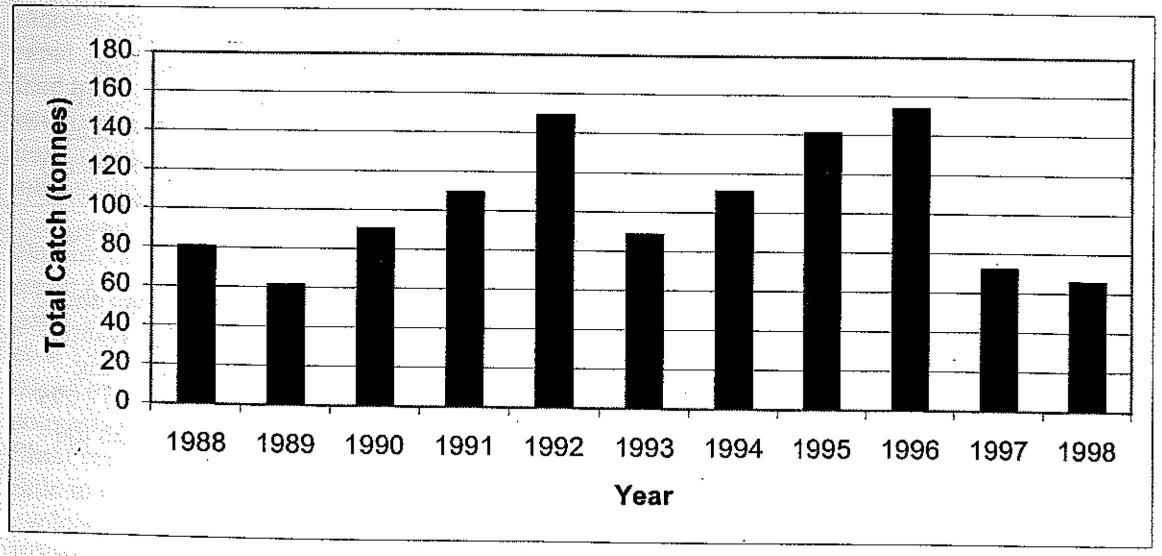
Figure 13. Southern Mid Shelf reefs.

A. Commercial line fishing effort: number of primary boats and number of fishing days per primary boat. B. Commercial line fishing catch and catch rate (catch per unit effort, CPUE). Primary boat = mother vessel with between 0 and 7 tender vessels (usually 4).

A.



B.



Discussion

The primary purpose of this study was to use fishery independent indicators of the coral trout population to assess changes in stock status. We were fortunate that a fishery–independent technique, underwater visual census, has been used on the Great Barrier Reef to collect density and length–frequency data of coral trout over at least a 15 year period, providing us with an ideal opportunity to examine the stock fluctuations independently from fishery catch and effort data.

Although this study covers twenty reefs and a time period of over 15 years, much of the data were not collected with a view to making long term comparisons, especially that from the early time period. As a result there are a number of limitations in the dataset that should be kept in mind. Although the majority of the data comes from 50 x 5 m transects, six different transect sizes are represented in the dataset. Conversion factors have been determined but these differences are bound to affect the rigour of the analyses. Many of the early studies surveyed only part of each reef, rather than having smaller sites spaced around the entire perimeter of the reef as in most later surveys. There is also a problem with missing periods: there were no surveys on Cairns region Mid or Outer Shelf reefs during the recent period, and there were few surveys during the middle time period for the Northern and Southern regions, or for the Townsville Outer Shelf region. The distribution of blue and green reefs among the regions was also less than ideal: no blue reefs were included in the Northern or Southern regions, nor in the Townsville Outer Shelf region. On the other hand, only a single green reef was included in the otherwise excellent Townsville Mid Shelf dataset. However, despite these problems the data represent the best available information on changes in common coral trout density over the entire period that line fishing in the GBR region has been under management. The Fisheries Act (1976) and Regulations (1977) were the first management regulations to affect coral reef fish. Then in 1984 Fisheries regulations specific to the reef line fishery were introduced and the Great Barrier Reef Marine Park Authority introduced zoning or area closures in 1984–86.

Although the primary focus of this study was to examine trends in coral trout populations over time, we consider it important to describe the spatial patterns in coral trout densities on the GBR illustrated by this dataset, to put the temporal changes into context. There were no overall habitat effects in the data used in this study: densities of common coral trout on exposed front (windward) reef slopes and more sheltered back (leeward) reef slopes were similar. Previous studies have shown some significant habitat effects for this species but these have not been consistent. During the early GBR wide surveys in the mid 1980s (Ayling and Ayling 1986a) densities were significantly higher in the back reef habitat, with densities on the front reef being on average about 70% of those in the back reef habitat. On Townsville Mid Shelf reefs there were also significantly higher densities on the back reef compared with the front in the early 1990s (Ayling and Ayling 1993). However, there were no differences between habitats on these reefs between 1993 and 1995 (Ayling and Ayling 1997), and significantly higher densities on the front reefs compared with the back reefs in 1996 and 1997 (Ayling and Ayling 1998).

Previous studies have suggested that there are marked cross shelf patterns in the distribution of most coral reef fishes (Williams 1982, Russ 1984), and that these patterns are more important than much larger scale north–south geographic effects. All *Plectropomus* species show significant cross shelf distribution patterns (Ayling and Ayling 1986a). Common coral trout are more or less absent on coastal inner shelf reefs and peak in abundance on Mid Shelf reefs. They decrease rapidly in abundance toward the outer edge of the shelf and are almost absent from the front of outer barrier type reefs that are situated right on the edge of the shelf. Hence common coral trout densities on Outer Shelf reefs in this study were only 34% of those from Mid Shelf reefs. The reasons for these strong cross shelf patterns are not well understood but may relate to larval distribution patterns (Williams 1982). Recruit (0+ fish, <15cm FL) densities for common coral trout are much lower on Outer Shelf reefs than on Mid Shelf reefs (Ayling et al 1991), suggesting larval recruitment rates are lower on Outer Shelf reefs.

Four north–south regions were recognised in this study, spread over a 7° latitudinal range, a length of some 800 km of the GBR. Common coral trout densities were similar in the Northern, Cairns and Townsville regions, but were much higher in the Southern region. On Southern Mid Shelf reefs densities were almost three times those on Mid Shelf reefs in the other regions. This is similar to the patterns previously documented for common coral trout over the entire length of the GBR (Ayling and Ayling 1986a). These authors suggested that densities on reefs north of the Whitsunday Group of islands (20°S) averaged about 35 per ha, while reefs to the south of this area supported common coral trout densities of around 90 per ha. Again, it is not known what drives these north–south density changes, but they are possibly related to tidal regime differences.

Despite a complex spatial pattern in the distribution of coral trout from north to south and Mid to Outer Shelf reefs, and a less than perfect dataset, we detected significant differences in common coral trout densities between time periods. Differences in trends were seen primarily between the early and recent periods, in the Townsville and Southern regions, and differences were remarkably consistent between reefs. On these reefs a pattern of stable trends through the 1980s, positive trends in the early 1990s, and negative trends since 1995, was evident. The analysis of trends provided more useful information compared with the analysis of mean densities. The latter only detected differences on the Townsville Mid Shelf reefs, confirming coral trout numbers were significantly higher in the 1980s compared with recent times. This may reflect that the Townsville Mid Shelf reefs had the most comprehensive and rigorous data set of all the regions.

On Townsville Mid Shelf reefs densities increased prior to 1995 from a low point in 1991, giving peak densities in 1995. This may be due to a highly successful recruitment episode in early 1992, relatively high recruitment in the following few years, and low recruitment rates since 1995 (Ayling and Ayling 1997). In 1992 the Townsville Mid Shelf reefs supported densities of new recruits of between 15–20 per ha, accounting for 30–50% of total coral trout numbers. Given the rapid growth rate of young coral trout (Ferreira and Russ (1994) this level of recruitment would lead to an increase in adult numbers 2–3 years later . There is a suggestion that a similar increase occurred in the Southern region over this period, probably also due to good recruitment episodes, but lack of surveys on several of these reefs during the early 1990s leaves an element of speculation in this statement.

Natural fluctuations in coral trout populations are not uncommon. A strong recruitment year can result in a dominant age class which persists for years in unfished *Plectropomus leopardus* populations (Russ et al 1996). Such dominant cohorts tend to disappear in fished populations (Russ et al 1996). If the peak in densities in 1995 was caused by unusually high recruitment in, say 1992, based on Russ and colleagues' findings, the lack of persistence in numbers through 1996–1998 suggests removal of adults from fishing. The sharp decreases on both Townsville and Southern Mid Shelf reefs since the mid 1990s have been well documented (Ayling and Ayling 1997). The sharp falls in both total and adult densities on Southern reefs began about the time of the impact of cyclone Justin in this area in March 1997. This huge storm system affected the area south of the Whitsunday Islands for over a week and caused some structural and coral damage on the front face of all the reefs in this region (A.M. Ayling personal observations). Although this event did not cause any changes in densities of other fishes being counted on these reefs coral trout densities declined sharply at about this time and it has been suggested that this may have been due to the impact of the cyclone. However, it should be noted that the decline has continued in the two years since the cyclonic episode, and this cyclone effect would not explain the decline on Townsville Mid Shelf reefs.

We suggest that the present negative trend in coral trout densities in Townsville and Southern regions is cause for concern. Current densities on Townsville reefs are lower than they have ever been in previous surveys conducted during the last 15 years. It may be that the high densities in the mid 1990s were unusual, at least in the Southern region, and densities are now falling to previous "more normal" levels. However, early 1980s densities on at least some of the Townsville Mid Shelf reefs were in the same range as the mid 1990s peak, and densities on a number of other Southern region reefs surveyed once in the mid 1980s were in the same 200 per ha range recorded in 1995 (Ayling and Ayling 1986). It seems probable that the recent declines may be attributed to fishing. Commercial fishing pressure in the Townsville and Southern Mid Shelf regions is much higher than it is the Cairns and Northern Mid Shelf regions. Further, fishing effort, measured as fishing days of primary vessels, has increased by almost 30% from 1995 to 1997 (QFMA 1999). The concern is whether common coral trout densities on these reefs will stay at these low levels, or perhaps drop even lower, in the face of sustained high fishing effort. The only post–1997 data for the Townsville Mid Shelf region is from Yankee, which shows a considerable drop in densities since this green reef was opened to fishing in 1997 and was showing no signs of recovery by the end of 1999.

The overall reduction in both mean length and standard deviation of length distribution that has occurred since 1980 also suggests that fishing pressure may be responsible for the recent decline in common coral trout density in Townsville and Southern regions. Growth overfishing is typically the first effect of high fishing pressure (Russ 1991, Polunin and Roberts 1996). When the Bramble Reef replenishment area was opened to fishing and adult coral trout densities dropped 80% in 12 months the mean length reduced from 36.5 cm to 32.3 cm (Ayling and Ayling 1998b). Although growth overfishing has been demonstrated in a number of coral reef fisheries (Samoilys 1988, Russ 1991), studies have not shown any fishing effect on the lengths of coral trout (Ayling et al 1991, Ayling and Ayling 1992, 1993). Although the overall mean length decreased since 1980, this was caused by length changes in the Northern, Cairns and Townsville Outer regions, and mean lengths have not decreased in the Townsville Mid Shelf and Southern regions where the declines in coral trout numbers were significant. The decrease in the variability of length could be an indication that fishing pressure has reduced the spread of lengths by removing large fish from the population. The reduction in variability may have been partly due to the lower than normal recruitment since 1995, leading to a reduction in small length classes, rather than just to a reduction in larger length classes. However, size frequency data do not support this. On Mid Shelf Reefs the combined percentage of the population of common coral trout less than 30 cm TL was 31% in the early time period, 29% in the middle time period and 29% in the recent time period, whereas the percentage of fish over 50 cm TL reduced from 7.2% in the early time period, to 5.3% in the middle time period, to 2.3% in the recent time period. In the recent time period the population on Townsville Mid Shelf reefs was skewed toward smaller size classes, again suggesting higher fishing pressures in this region since 1995.

However, a number of factors in the life history of coral trout argue against there being a significant length reduction from fishing pressure. Growth rates and natural mortality rates are high (Ferreira and Russ 1994), and this high turnover may be expected to minimise the fishing effect. In addition, on average only about 37% of the population are available to fishermen (>38 cm TL), assuming that our data are representative. Previous studies have suggested that adult trout are removed from the population by fishing roughly in proportion to their abundance (Ayling and Ayling 1997). If this is the case then the effect of fishery removal of a varying percentage of adults on mean size is represented in Table 11. Hence it would require the removal of over 50% of adults to reduce the mean length significantly and this would be possible only in cases of extreme fishing pressure such as was experienced following the opening of Bramble Reef mentioned above (Ayling and Ayling 1998b)

Table 13. Effect of adult removal on mean length of coral trout populations.
Based on entire dataset of 5630 fish. Significance calculated using mean square from table 7 analyses.

Percentage of adults removed	Mean length after removal (cm)	Reduction in mean length (cm)	Significant change?
0%	34.6	0	no
10%	34.3	0.3	no
20%	33.9	0.7	no
30%	33.5	1.1	no
40%	33.0	1.6	no
50%	32.5	2.1	no
60%	32.0	2.6	yes

The unusual changes observed on the two Townsville Outer Shelf reefs (Dip and Faraday) are noteworthy. There was a large influx of sub-adults onto these two reefs, and other Outer Shelf reefs in the area, in early 1997 (A.M. Ayling personal observations). These fishes were not seen on the reefs as juveniles in the previous 18 months and it is possible that they resulted from a migration of coral trout originating elsewhere. However, although it is known that coral trout can migrate between reefs, it is normally rare (Davies 1996, Samoilys 1997a), and this is the first time such large unexplained increases that may be due to migration have been observed. Since this influx, densities have declined rapidly, and as the fishes were well below the legal size limit, and were on protected reefs this is unlikely to be due to fishing pressure. The peak has not translated into increased adult numbers and this suggests that the fish have either slowly gone back to where they came from, or have been unable to cope with conditions on Outer Shelf reefs, where common coral trout densities are normally low, and have suffered high mortality.

A major question over the past two decades has been whether coral trout densities are declining in a non-sustainable way due to increasing fishing pressure. As long ago as 1979 Goeden (1979) suggested that fishing pressure was affecting coral trout densities. Craik (1981) also concluded that common coral trout densities were being reduced by fishing pressure in the Capricorn/Bunker Group. However, more detailed studies looking at density differences between fished and protected reefs within the GBR Marine Park have failed to find any significant fishing effect on densities of coral trout (Osborne et al 1986, Ayling and Ayling 1986a, 1992a, 1994a, Ayling et al. 1991, Ferreira and Russ 1995). The present study, also failed to find any effect of zoning on common coral trout density, though the comparisons were not robust, being confounded by region and time. This failure to find any zoning effect on coral trout density leads to several conflicting hypotheses. Either coral trout are very resistant to fishing pressure and can cope easily with present levels of fishing, or else protected reefs are being illegally fished on a regular basis. It is also possible that spatio-temporal variability in common coral trout numbers makes it difficult to detect a fishing effect over other natural sources of mortality.

The results of this study are particularly relevant to the performance indicators listed in the QFMA's Draft Management Plan and Regulatory Statement (QFMA 1999), which are designed to review the effectiveness of the Plan in managing the coral reef fin fishery. If these performance indicators, or review events, are not satisfied, the plan may be repealed or amended. Notably, the review event: "estimated abundance of coral trout has decreased consistently over the last three or more years" is relevant here. We suggest that the results of our study provide strong evidence for such a decline in coral trout for some regions and this would be sufficient to trigger a review of the Plan.

The results also demonstrate the utility of independent surveys of stocks, as done here using underwater visual census surveys. Such data, in conjunction with fishery log book data, could provide an invaluable source of data for more formal assessment of the state of coral trout stocks.

DPI Fisheries have initiated a new long term monitoring programme for the reef fishery this year (1999) using underwater visual census surveys to build on the dataset reported here (Samoilys and Lunow in prep). Thus annual surveys will be continued on most of the reefs listed in Table 2 to continue monitoring coral trout populations in the long term. The design of this program could be optimised to meet the data needs of stock assessment modellers.

In summary, coral trout populations in the Northern region near Lizard island, have remained relatively stable over the last 15 years suggesting that *Plectropomus leopardus* populations in the northern GBR have not yet been impacted by high fishing levels. While it is possible that in recent years recruitment has been unusually low (Ayling and Ayling 1998a), the evidence borne out by this study points to a decrease in densities, and a decrease in large fish in the population and mean length over the recent time period, which coincide with a notable increase in fishing pressure since 1995. The present low levels of both adult and total common coral trout in the Townsville and Southern regions possibly reflect both high fishing levels (commercial fishing is considerably higher in these regions), and lower levels of recruitment. We would suggest that current densities in the Townsville and Southern regions, that are substantially lower than they have ever been in the last 15 years, are cause for concern. It would be appropriate for stock assessment modellers and management to consider whether the concerns raised by these data require a management response. It should be noted that the CRC Effects of Line Fishing program will also be addressing these issues in the near future based on a much more rigorous dataset, although one that does not extend back beyond 1995.

References

Ayling, A.M. and Ayling, A.L. (1983). Distribution and abundance of coral trout species (*Plectropomus* spp.) in the Cairns Section of the Great Barrier Reef Marine Park. Unpublished report to the Great Barrier Reef Marine Park Authority. 32 p.

Ayling, A.M. and Ayling, A.L. (1984). Far–North Section of the Great Barrier Reef Marine Park: Survey Report. Unpublished report to the Great Barrier Reef Marine Park Authority. 23 p.

Ayling, A.M. and Ayling, A.L. (1985). A biological survey of selected reefs in the Central Section of the Great Barrier Reef Marine Park. Unpublished report to the Great Barrier Reef Marine Park Authority. 53 p.

Ayling, A.M. and Ayling, A.L. (1986a). A biological survey of selected reefs in the Capricorn and Capricornia Sections of the Great Barrier Reef Marine Park. Unpublished report to the Great Barrier Reef Marine Park Authority. 61 p.

Ayling, A.M. and Ayling, A.L. (1986b). Coral trout survey data. Unpublished report to the Great Barrier Reef Marine Park Authority. 212 p.

Ayling, A.M. and Ayling, A.L. (1989a). Crown of thorns and coral trout density on three Central Section reefs: 1983–1989. Great Barrier Reef Marine Park Authority Research Publication No. 15. 54 p.

Ayling, A.M. and Ayling, A.L. (1989b). Norman Reef environmental monitoring project. Great Barrier Reef Marine Park Authority Research Publication No. 19. 54 p.

Ayling, A.M. and Ayling, A.L. (1992a). Effects of fishing pilot study: visual surveys on Cairns cluster reefs and closed reefs that will be opened under the new zoning plan. Unpublished report to the Great Barrier Reef Marine Park Authority. 45 p.

Ayling, A.M. and Ayling, A.L. (1992b). Bramble Reef replenishment area — baseline survey. Unpublished report to the Great Barrier Reef Marine Park Authority. 44 p.

Ayling, A.M. and Ayling, A.L. (1993). Bramble Reef replenishment area — first post–closure survey. Unpublished report to the Great Barrier Reef Marine Park Authority. 40 p.

Ayling, A.M. and Ayling, A.L. (1994a). Effects of fishing: effects of fishing resumption on a group of previously protected reefs in the Cairns Section. Unpublished report to the Great Barrier Reef Marine Park Authority. 55 p.

Ayling, A.M. and Ayling, A.L. (1994b). Bramble Reef replenishment area — 1993 and 1994 surveys. Unpublished report to the Great Barrier Reef Marine Park Authority. 52 p.

Ayling, A.M. and Ayling, A.L. (1994c). Norman Reef environmental monitoring project — 1992–93 survey. Unpublished report to the Great Barrier Reef Marine Park Authority. 58 p.

Ayling, A.M. and Ayling, A.L. (1994d). Hardy Reef — monitoring of the impact of the new Fantasea Cruises pontoon. Unpublished report to the Great Barrier Reef Marine Park Authority. 50 p.

Ayling, A.M. and Ayling, A.L. (1994e). Moore Reef — monitoring of the effects of the new Great Adventures pontoon. Unpublished report to the Great Barrier Reef Marine Park Authority. 38 p.

Ayling, A.M. and Ayling, A.L. (1995a). Moore Reef — monitoring of the effects of the Sunlover Cruises pontoon. Unpublished report to the Great Barrier Reef Marine Park Authority. 37 p.

Ayling, A.M. and Ayling, A.L. (1995b). Arlington Reef — monitoring of the impact of the Sunlover Cruises pontoon. Unpublished report to the Great Barrier Reef Marine Park Authority. 45 p.

Ayling, A.M. and Ayling, A.L. (1997). Bramble Reef replenishment area: pre– and post–opening surveys. Unpublished report to the Great Barrier Reef Marine Park Authority. 63p.

Ayling, A.M. and Ayling, A.L. (1998a). Bramble Reef replenishment area: third post–opening survey. Unpublished report to the Great Barrier Reef Marine Park Authority. 52 p.

Ayling, A.M. and Ayling, A.L. (1998b). Bramble Reef replenishment area: second post–opening survey – May 1996. Unpublished report to the Great Barrier Reef Marine Park Authority. 51 p.

Ayling, A.M. and Ayling, A.L. (1998c). Hardy Reef – monitoring of the impact of the relocation of the Fantasea Cruises pontoon. Unpublished report to the Great Barrier Reef Marine Park Authority. 35 p.

Ayling, A.M., Ayling, A.L. and Mapstone, B.D. (1991). Possible effects of protection from fishing pressure on recruitment rates of the coral trout (*Plectropomus leopardus*: Serranidae). Proceedings of the 1991 Recruitment Workshop of the Australian Society for Fish Biology.

Blamey, R.K. and Hundloe, T.J. (1993). Characteristics of recreational boat fishing in the Great Barrier Reef region. A report to the Great Barrier Reef Marine Park Authority. Institute of Applied Environmental Research, Griffith University.

Brown, I.W. (1993). Fish and Fisheries of Queensland. In: Australian Bureau of Statistics Queensland Year Book 1994, vol. No. 52., Brisbane. pp.20–26

Brown, I.W., Doherty, P., Ferreira, B., McPherson, G., Russ, G., Samoilys, M., and Sumpton, W. (1994). Growth, reproduction and recruitment of Great Barrier Reef food fish stocks. Final Project Report. Fisheries Research and Development Corporation. Project No. 90/18. Department of Primary Industries. 154 p.

Cormack, S. (1997). Recreational fishing telephone survey. Recreational Fishing Information System Newsletter 4: 1–4

Craik, G.J.S. (1981). Underwater survey of coral trout *Plectropomus leopardus* (Serranidae) populations in the Capricornia Section of the GBR Marine Park. Proceedings of the 4th International Coral Reef Symposium, Manila. Vol 1: 53–58.

Craik, G.J.S. (1989). Management of Recreational Fishing in the Great Barrier Marine Park. Great Barrier Reef Marine Park Authority, Technical Memorandum— 23.

Craik, G.J.S, Pollard, D.A., Russell, B. and Bell, J.D. (1980). Surveying demersal reef fish populations in the Great Barrier Reef Marine Park. I. Development of the technique. II. Surveys of *Plectropomus leopardus* (Lacepede) in the Capricornia Section. Unpublished report to GBRMPA.

Davies, CR. (1996). Inter-reef movement of the common coral trout, *Plectropomus leopardus*. Report to the Great Barrier Reef Marine Park Authority, Effects of Fishing program. 59 p.

Doherty, P.J., Fowler, A.J., Samoilys, M.A. and Harris, D.A. (1994). Monitoring the replenishment of coral trout (Pisces: Serranidae) populations. Bull. Mar. Sci. 54(1): 343–355.

Elmer, M. (1998). The facts on the live reef fish debate. Queensland Fisheries News Issue 2 (June): 4–5.

Ferreira B.P. and Russ G.R. (1994). Age validation and estimation of growth rate of the coral trout *Plectropomus leopardus* (Lacepede 1802) from Lizard Island, Northern Great Barrier Reef. Fishery Bulletin 92: 46–57.

Ferreira, B.P. and Russ, G.R. (1995). Population structure of the leopard coral grouper, *Plectropomus leopardus*, on fished and unfished reefs off Townsville, central Great Barrier Reef, Australia. Fishery Bulletin 93: 629–642.

Goeden, G.B. (1978). A monograph of the coral trout *Plectropomus leopardus* (Lacepede). Queensland Fisheries Service Research Bulletin 1: 1–42.

Goeden, G.B. (1979). Is the Great Barrier Reef being overfished? Australian Fisheries September 1979: 18–20.

Heemstra, P.C., and Randall, J.E. (1993). FAO Species Catalogue: Groupers of the World. Vol. 16. Food and Agriculture Organisation of the United Nations, Rome.

Higgs, J. (1999). Experimental recreational catch estimates for Queensland residents. RFISH Technical Report #2. Results from the 1997 Diary Round. QFMA. Assessment and Monitoring Section. 55 p.

Jennings, S., and Lock, J. (1996). Population and ecosystem effects of fishing. In: Polunin, N.V.C., Roberts, C.M. (eds.) Reef Fisheries. Chapman and Hall, London.

Koslow, J.A., Hanley, F., and Wicklund, R. (1988). Effects of fishing on reef fish communities at Pedro Bank and Port Royal Cays, Jamaica.. Mar. Ecol. Prog. Ser. 43: 201–212.

Light, PR and Jones GP (1997). Habitat preference in newly settled coral trout (*Plectropomus leopardus*, Serranidae). Coral Reefs 16:117–126.

Lock, J.M. (1986). Effects of fishing pressure on the fish resources of the Port Moresby barrier and fringing reefs. Technical Report 86/3. Department of Primary Industries, Port Moresby. 31 p.

Loubens, G. (1980). Biologie de quelques espéces de Poissons du lagon néo–caledonien. Cahiers de L'Indo–Pacific 2: 101–153.

Manooch, III C.S. (1987). Age and growth of snappers and groupers. In. J.J. Polovina and S. Ralston (eds.) Tropical snappers and groupers. Biology and Fisheries Management. Westview Press Inc., Boulder. pp. 329–374.

Mapstone, B.D. and Ayling, A.M. (1998). An investigation of optimum methods and unit sizes for the visual estimation of abundances of some coral reef organisms. Great Barrier Reef Marine Park Authority Research Publication No. 47. 70 p.

Mapstone, B.D., Choat, J.H. and Ayling, A.M. (1991). A visual survey of demersal biota in the Cairns Section of the Great Barrier Reef Marine Park. Proposal for funding from Great Barrier Reef Marine Park Authority and COTS REC.

Mapstone, B.D., McKinlay, J.P., Davies, C.R. (1996). A description of the commercial reef line fishery logbook data held by the Queensland Fisheries Management Authority. Report to the QFMA from the CRC Reef Research Centre and the Department of Tropical Environment Studies and Geography, James Cook University, Townsville, Australia. 480 p.

Mapstone, B.D., Davies, C.R., Lou, D.C., Punt, A.E., Russ, G.R., Ryan, D.A.J., Smith, A.D.M., Williams, D.McB. (1998). Effects of line fishing experiment 1995–97: Progress report. CRC Reef Research Centre. Effects of Line Fishing Project.

Osborne, S., Dunning, M., Dinesen, Z. and Crimp, O. (1986). The status of coral trout populations on thirteen reefs within the Capricornia Section of the GBR Marine Park. Unpublished report prepared for the Queensland National Parks and Wildlife Service. 31p.

Polunin, N.V.C., Roberts, C.M. (eds.) (1996). Reef Fisheries. Chapman and Hall, London.

QFMA (1999). Draft Management Plan and Regulatory Statement. Queensland coral reef fin fish fishery. Prepared by the Queensland Fisheries Management Authority with the Reef Fishery Management Advisory Committee.

Richards, A.H. (1993). Live reef fish exports to South–East Asia from the South Pacific. SPC Fisheries Newsletter 67: 34–36.

Roy Morgan Research. (1996). Recreational fishing in Queensland — a survey of Queensland residents. Report prepared for Queensland Fisheries Management Authority. 40 p. + appendices.

Russ, G.R. (1984). Distribution and abundance of herbivorous grazing fishes in the central Great Barrier Reef. I. Levels of variability across the entire continental shelf. II. Patterns of zonation of mid shelf and outer shelf reefs. Marine Ecology Progress Series 20: 23–44.

Russ, G.R. (1991). Coral reef fisheries: Effects and yields. In: Sale, P.F. (ed.) The Ecology of Fishes on Coral Reefs. Academic Press, San Diego.

Russ, G.R. and Alcala, A.C. (1989). Effects of intense fishing pressure on an assemblage of coral reef fishes. Marine Ecology Progress Series 56: 13–27.

Russ, G.R., Lou, D.C., Ferreira, B.P. (1996). Temporal tracking of a strong cohort in the population of a coral reef fish, the coral trout, *Plectropomus leopardus* (Serranidae: Epinephelinae), in the central Great Barrier Reef, Australia. Can. J. Fish. Aquat. Sci. 53: 2745–2751

Samoilys, MA (1997a). Movement in a large predatory fish: coral trout *Plectropomus leopardus* (Pisces: Serranidae) at Heron Island, Australia. Coral Reefs 16, 151–158.

Samoilys, M.A. (1997b). Periodicity of spawning aggregations of coral *trout Plectropomus leopardus* (Pisces: Serranidae) on the northern Great Barrier Reef. Mar. Ecol. Prog. Ser. 160: 149–159

Samoilys, M.A. and Carlos, G. (2000) Determining methods of underwater visual census for estimating the abundance of coral reef fishes. Env. Biol. Fish. 57: 289–304

Samoilys, M.A. and Lunow, C. (in prep.) DPI Fisheries manual for long term monitoring of reef fish. QDPI Publication.

Turnbull, C. (1996). Domestic reef fishing industry assessment. Report from Northern Fisheries Centre, Cairns. QDPI Information Series QI96106.14 p.

Trainor N. (1991). Commercial line fishing. The Queensland Fisherman. March 1991:

17–24.

Williams, D. McB. (1982). Patterns in the distribution of fish communities across the central Great Barrier Reef. Coral Reefs 1: 35–43.

Zeller, D.C. (1998). Spawning aggregations: Patterns of movement of the coral grouper *Plectropomus leopardus* (Serranidae) as determined by ultrasonic telemetry. Mar. Ecol. Prog. Ser. 162: 253–263.

Authors' Current Addresses

Tony Ayling
Sea Research,
PO Box 810, Mossman, Qld 4873

Melita Samoilys
Department of Biology
McGill University
1205 Ave Docteur Penfileld, Montreal
Quebec, H3A 1B1, Canada

Dan Ryan
Agricultural and Agri–Food Canada,
32 Main St, Kentville,
Nova Scotia, B4N1J5 Canada