# EFFECTS OF LIVE FISH TRADING AND TARGETING SPAWNING AGGREGATIONS ON FLEET DYNAMICS, CATCH CHARACTERISTICS, AND RESOURCE EXPLOITATION BY THE QUEENSLAND COMMERCIAL DEMERSAL REEF LINE FISHERY 

Principal Investigator

B. D. Mapstone

## Authors

B.D. Mapstone, C.R. Davies, S.J. Slade, A. Jones, K.J. Kane, A.J. Williams



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## National Library of Australia Cataloguing-Publication entry

Effects of live fish trading and targeting spawning aggregations on fleet dynamics, catch characteristics, and resource exploitation by the Queensland commercial demersal reef line fishery.

Bibliography.
Includes index.
ISBN 1876054700.

1. Fisheries - Queensland - Great Barrier Reef. 2. Fishery management - Queensland Great Barrier Reef. I. Mapstone, Bruce D. (Bruce David). II. James Cook University of North Queensland.
338.372709943

This publication should be sited as Mapstone et al. (2001).
Effects of live fish trading and targeting spawning aggregations on fleet dynamics, catch characteristics, and resource exploitation by the Queensland commercial demersal reef line fishery.
CRC Reef Research Centre
Townsville, 72pp.

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Published by the Cooperative Research Centre for the Great Barrier Reef World Heritage Area @ 2001.

## Non-Technical Summary

96/138 Effects of live fish trading and targeting spawning aggregations on fleet dynamics, catch characteristics, and resource exploitation by the Queensland commercial demersal reef line fishery

## Principal Investigator <br> Address

Dr B.D. Mapstone<br>CRC Reef Research Centre James Cook University<br>Townsville Qld 4811<br>Telephone: 0747815113 Fax: 0747814099

Authors:<br>B.D. Mapstone, C.R. Davies, S.J. Slade, A. Jones, K.J. Kane, A.J. Williams

## Objectives

I. To quantify the effects of live fishing on: a) on-site fishing dynamics and catch rates in dories; b) primary vessel fleet dynamics; c) tolerance of commercial fishing to declines in catch rates.
II. To verify the effects of live fishing on data routinely recorded in QFMA compulsory logbooks, and identify ways in which the system might be made more efficient.
III. To verify whether live fishing results in concentrated effort around major ports/reefs (e.g., inshore).
IV. To identify regional variations in fleet dynamics with respect to live fishing.
V. To verify the extent of deliberate targeting of coral trout spawning aggregations by the Great Barrier Reef commercial reef line fishery.
VI. To quantify the encounter rate of (spawning) aggregations of coral trout by commercial reef line fishers.
VII. To compare searching behaviours, dory dynamics, catch rates and total catches of coral trout during spawning and non-spawning periods.
VIII. To make direct observations of putative spawning aggregations and normal occurrences of coral trout, as encountered by commercial reef line fishers.
IX. To estimate the net change(s) in catch of coral trout by the commercial reef line fishery during spawning periods.

## Summary

The Queensland reef line fishery is comprised of three main sectors: recreational fishers operating under their own methods; charter vessels that take recreational fishers to off-shore fishing sites; and commercial fishers. All sectors have access to the same grounds and generally target the same suite of species using similar simple hook and line gears. This research is focused only on the commercial sector.

The commercial sector of the fishery has existed since at least the early 1940's and has historically been a dory fishery, with 1 to 6 dories tendered to $8-20 \mathrm{~m}$ primary vessels. The fishery targets three main species groups: coral trout (mainly Plectropomus leopardus, P. laevis, and P. maculatus), red throat emperor (Lethrinus miniatus) and spanish mackerel (Scomberomorus commersons), with over 125 species groups being taken as by-product (Mapstone et al. 1996). In most regions, coral trout comprises 40-55\% of landings (Mapstone et al. 1996). Until 1993, all commercial catch was killed and marketed both locally and internationally either as frozen fillets, frozen gilled and gutted fish or chilled whole fish.
Since 1993, some commercial reef line fishers have retained their catches of some species, especially coral trout, for sale alive to supply live food fish markets in east Asia. The practice developed slowly through 1994 and 1995, with relatively small quantities of reef fish being supplied by relatively few vessels, then grew rapidly through 1996, with up to $30 \%$ of operations in some regions supplying the live fish export trade (unpublished QFMA data). The shift to 'live fishing' was motivated by considerably greater beach prices for live fish than for dead product. Live fish of selected species generally were worth at least 1.5 -times and at times up to three-times the value of the same fish dead, provided that the live fish were in good condition and unmarked by hooking or handling injuries. Marketing reef fish live thus represented considerable value adding to the fishers, the local buyers, and the exporters, and substantially improved the value of the reef line fishery as a national export industry.
The emergence on the Great Barrier Reef (GBR) of a trade in live reef fish raised concern and uncertainty, however, about the implications for the harvest rates of key species and the potential for changes in the distribution of effort to cause local depletions, especially near to key ports. Further, concern was expressed that the development of the trade in live fish would exacerbate the (purported) targeting of spawning aggregations of some species because of the increased market price of live fish compared with dead fish. These concerns were expressed by people from most community sectors, including some commercial fishers.

This research was done over two years (1996-98) in the early development of the trade in live reef fish from the GBR to clarify the implications of the switch in market for fishing practices, harvest rates, and effort distribution. The research was based on four sources of information: i) Direct observations of fishing activities by on-board observers; ii) Analysis of research logbooks filled out voluntarily by skippers of commercial fishing operations; iii) Analysis of compulsory logbook data provided to the Queensland Fisheries Management Authority (QFMA); and iv) Interviews with skippers.
The intended market (live or dead) for catch affected the characteristics of movements by main vessels, fishing behaviours of dory fishers, realised catch rates and the species mix harvested. In many cases these effects varied with year, season, and time of day. Nevertheless, some general patterns were apparent.
Early in the development of the trade in live reef fish from the GBR, live fishing effort tended to be concentrated in the vicinity of Cairns, the location of the main international airport for export of live food fish. In recent years, however this concentration of effort has diminished, with live fish now being taken from most regions of the GBR.
When keeping catch alive, operations tended to make shorter trips, remain closer to ports during those trips, and spend shorter periods at fishing sites than they or their counterparts did when killing their catch. There tended to be fewer live trips than dead trips per operation at certain times of year. In other respects, such as periods in port between trips and distances travelled between fishing locations, fishing dynamics generally were not affected by the change in handling and market strategy.

Changes in fishing dynamics were apparent also at the level of individual fishers. Those fishers targeting fish for live markets tend to fish for shorter periods per hang (fishing location) and per session (period in the dory), make more returns to their mother boat, move more often, and spend more time searching for fishing sites than fishers killing their catch. Further, fishers supplying the live markets tended to be more selective in their fishing, often apparently avoiding (possibly through the use of underwater 'view buckets') or releasing fish that were not marketable alive. This selectivity was most likely motivated by the higher prices paid to fishers for live fish and / or a reluctance to process (gill and gut or fillet) byproduct species at night when there was an option to avoid processing altogether.

Catch rates of most species groups tended to be less when fish were being kept alive for market than when they were being killed. This was most conspicuous for by-product species and when average maximum daily catch rates of live target species were considered.
Though these effects were at times considerable (e.g., catch rates of coral trout on live trips were at times up to $30 \%$ less than on dead trips), they varied with year and season and at times were slight and not statistically significant. Notably, however, catch rates during live trips were never significantly greater than those during dead trips.
The intended market for the catch also affected the composition of the catch landed. Operations selling their catch alive generally landed up to half as much demersal by-product as operations killing their catch. The sizes of coral trout taken also varied with the intended market but patterns varied through time and were often contrary to the speculation that live operations harvest significantly more small coral trout than do dead operations.

We found little evidence in this study of the consistent targeting of spawning aggregations of coral trout by commercial reef line fishers. Indeed, one of the difficulties we encountered during the observer program was being able to timetable trips with fishers to coincide with specific moon phases when coral trout were expected to be spawning. This problem arose because the fishers we contacted were not structuring their trips around lunar phase, suggesting either that they were unaware of the timing of spawning by coral trout or that they were not targeting their fishing at spawning fish. Although there were occasional significant effects of season on a variety of variables, including trip length, searching \& fishing patterns by dory fishers, and the size composition of catches, these varied among years and with the intended market of the catch and the effort class of vessels. The most consistent effects of season were on catch rates of demersal by-product species, which were typically elevated in the spawning season of coral trout. We conclude, therefore, that the targeting of spawning aggregations of common coral trout is not common practice in the reef line fishery, but the possibility that other species are being targeted when spawning is worth further investigation.

The emergence of the export trade in live food fish from the GBR represents considerable value adding to an existing commercial line fishing industry. Accordingly, the live fish trade has considerable potential benefit to commercial fishers and associated local communities. The changes in fishing practices, especially in respect of lowered catch rates and reduced harvest of by-product species, also represents significant potential benefit to target stocks and non-target species. The trade in live fish has not resulted in increased per-capita catch rates or fishing practices that are intrinsically worse than those which have characterised the traditional reef line fishery for decades.

On the other hand, the tendency of live operations to fish nearer to ports and initial concentration of live effort nearer to areas of high population probably precipitated some of the controversy about the live fish trade because of the increased visibility of commercial fishers to recreational fishers and short-haul charter operations. Further, the increased beach prices for live product are likely to have provided at least part of the incentive for real increases in total commercial effort in the fishery since 1994. This increase included a number of latent line fishing endorsements re-entering the fishery. The potential benefits of the live fish trade may be off-set by such increased overall effort in the commercial fishery and / or increased competition between recreational and commercial fishers in some areas. Prudent management action is advisable to control effort adequately and avoid real or perceived stock depletions in areas closer to key ports and population centres.

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## Acknowledgments

This project was funded by the Fisheries Research and Development Corporation (Project 96/138). Salaries for principal investigator, co-investigators, and liaison officer were provided by the Cooperative Research Centre for the Ecologically Sustainable Development of the Great Barrier Reef.

James Cook University (Department of Tropical Environmental Studies and Geography) provided the administrative, infrastructure and operational support for the project.
The compulsory logbook data from which much of this report stems was provided by the Queensland Fisheries Management Authority. We thank the QFMA for permission to use these data and Andrew Thwaites and StJohn Kettle for assistance with those data.

The project would not have been successful without the cooperation and considerable assistance of many commercial reef line fishers, who gave us time, information, berths on their vessels, and encouragement. We thank them all.
We thank the many observers who diligently collected observer data under often difficult conditions at sea. Various members of the Effects of Line Fishing Team provided useful comment, assistance and encouragement throughout the project. We thank the anonymous reviewer nominated by the FRDC who provided useful suggestions that improved the clarity of the final report. Finally, we thank our families for their support, especially during the writing of this report.

## Background

## Preamble

This research addressed two contemporary issues related directly to the Queensland tropical reef line fishery:
i) The commencement and growth of an export trade from Australia of live reef fish for food markets in South East Asia; and
ii) Concern that commercial line fishers may be actively targeting spawning aggregations of reef fish.
Both issues were raised at public and industry meetings as high priorities for research for management of the reef line fishery during consultation for a broader research project.
Although in many respects separate issues, key aspects of both could be addressed by common research methods. Thus, we sought to address both issues in one project, rather than duplicating research effort and cost over separate projects.

As background, we first provide a synopsis of the reef line fishery, the perceived need for the research, and comment on the achievement of the objectives. This is followed by detailed descriptions of our investigations into the implications of the development of the live fish trade and the our assessment of the available evidence about the potential targeting of spawning aggregations of reef fish by commercial line fishers

## The Queensland Demersal Reef Line Fishery

The reef line fishery is comprised of three main sectors: recreational fishers operating under their own methods; charter vessels that take recreational fishers to off-shore fishing sites; and commercial fishers (Gwynne 1990). All sectors have access to the same grounds and generally target the same suite of species using similar simple hook and line gears. This research is focused only on the commercial sector, predominantly in the GBR region (Fig. 1).

Figure 1: Map of the Great Barrier Reef Marine Park (GBRMP). This report is focussed mainly on the commercial reef line fishery in the GBRMP, but we include also data from the Eastern Torres Strait, immediately to the north of the GBRMP (see also Fig. 2)


The commercial sector of the fishery has existed since at least the early 1940's and has historically been a dory fishery (Gwynne 1990, Trainor 1991). Fishing is done from small (typically $<6 \mathrm{~m}$ long) aluminium, fibreglass or (historically) timber boats powered by outboard motors, which are tendered to a larger ( $8-20 \mathrm{~m}$ ) primary vessel (Mapstone et al. 1996). Fishing is by $50-130 \mathrm{lb}$ breaking strain handlines, usually with one line per fisher and one bait per line. Both locally caught fin fish and frozen packaged pilchards are used for bait. Although historically an artificial lure, such as a skirted jig ("wog"), often was trolled slowly over shallow reef habitats, fishers now fish mainly at anchor using mainly demersal gear.
Fishing generally occurs in two 'sessions' (AM and PM) per day, with dories moving among several 'hangs' on a reef or shoal throughout the session. Dories work independently at varying distances from the primary vessel during each session. Fish captured in each session are kept in the dory and transferred to the primary vessels at the completion of the session, where they are weighed and processed. Until 1993, all commercial catch was killed and marketed locally and internationally either as frozen fillets, frozen gilled and gutted fish or chilled whole fish. Increasing amounts of the catch of some species have been sold alive for export since 1993.
The catch and effort characteristics of the reef line fishery from1988 to 1995 have been described by Mapstone et al. (1996) based on the available QFMA compulsory commercial logbook data. Total annual effort and catch of demersal reef fish are given in Table 1. Both total effort and total catch were relatively stable prior to 1995, but have increased considerably since. This period of increase corresponds with the development of the export in live food fish from the reef line fishery, with a review of management arrangements for all fisheries in Queensland, and with increased regulation of some of those fisheries ${ }^{1}$.

Table 1: Catch of tropical demersal reef species from the Great Barrier Reef and Eastern Torres Strait by the reef line fishery between 1989 and 1998 and the effort from which that catch came, as reported in the QFMA compulsory logbooks

| Year | Catch $(\mathbf{t})$ | $\mathbf{N}^{0 .}$ Operations $^{\mathbf{1}}$ | Operation Days | Line Days $^{2}$ |
| :---: | :---: | :---: | :---: | :---: |
| 1989 | $1,938.1$ | 344 | 16,799 | 53,075 |
| 1990 | $2,402.3$ | 373 | 17,422 | 57,772 |
| 1991 | $2,682.4$ | 342 | 15,879 | 53,555 |
| 1992 | $2,761.8$ | 325 | 15,221 | 54,045 |
| 1993 | $2,640.5$ | 376 | 17,689 | 65,630 |
| 1994 | $2,647.7$ | 388 | 19,201 | 73,087 |
| 1995 | $2,761.2$ | 423 | 19,821 | 72,750 |
| 1996 | $3,269.9$ | 534 | 24,933 | 86,170 |
| 1997 | $3,339.2$ | 593 | 27,518 | 93,569 |
| 1998 | $3,599.8$ | 554 | 27,314 | 88,575 |

${ }^{1}$ An operation is a primary vessel plus whatever dories it has tendered to it.
${ }^{2}$ Line days are estimated from incomplete logbook data.

Mapstone et al.'s (1996) analyses showed that the spatial distribution of effort and catch was uneven along the tropical Queensland coast but remained relatively stable from the late 1980's until the mid 1990's. The majority of effort occurred in, and catch was taken from, the Townsville, Mackay and Swains regions (Fig. 2). Effort and catch have been consistently lower in the regions to the north of Townville (Cairns, Far North, Eastern Torres Strait, Gulf of Carpentaria) and to the south of the Swains region (Capricorn-Bunkers, Sub-Tropical). This distribution of effort is consistent with the anecdotal history of the reef line fishery that Bowen, Mackay and Gladstone represent the major reef line fishing ports with the progression of the fishery into the areas to the north of Cairns being more recent.

[^0]Figure 2: Annual total effort and total catch of all line-caught species as reported in the QFMA compulsory logbooks in each region in 1990, 1992 and 1994. Region boundaries are shown in the figure at bottom right, with the key to region abbreviations in the table below the map. (Adapted from Mapstone et al. 1996)





|  | Key to Regions Indicated on Map |  |  |
| :--- | :--- | :--- | :--- |
| GC | Gulf of Carpentaria | MKY | Mackay |
| WTS | Western Torres Straits | SWN | Swains |
| ETS | Eastern Torres Straits | C-B | Capricorn Bunkers |
| FN | Far Northern | OCS | Offshore Coral Sea |
| CNS | Cairns | STROP | Sub-tropical |
| TVL | Townsville |  |  |

Effort and catch traditionally also have been distributed unevenly within years, being lowest in the late summer and greatest in late winter and spring (Mapstone et al. 1996) (Fig. 3).

Figure 3: Monthly effort and catch for coral trout from the Townsville region (see Fig. 2) between 1988 and 1995. Grey portions of the bars represent the 60 most active and productive operations in each year, white sections represent the next 90 most active and productive operations, and the black sections the remainder of the operations. Figure reproduced from Mapstone et al. (1996).


Historically, the fishery has targeted three main species groups: coral trout ${ }^{2}$ (mainly Plectropomus leopardus, P. laevis, and P. maculatus), red throat emperor (Lethrinus miniatus) and spanish mackerel (Scomberomorus commersons), with over 125 species groups being taken as by-product (Mapstone et al. 1996) (Fig. 4). Anecdotally, the relative degree to which the three major species have been targeted has varied according to the market price and relative availability. During the period over which logbook data are available for the fishery (1988-1997), however, coral trout has been the dominant species group in the commercial catch (Fig. 4, Mapstone et al. 1996), has attracted the highest market price and, as such, is the species of principal concern to management (QFMA 1996).
Management arrangements for the fishery are complex as the fishery operates within the GBR Marine Park and World Heritage Area. As a result, it is subject to direct or indirect regulation by both state and commonwealth acts. Direct fisheries regulation under the Queensland Fisheries Act (1994) is administered by the QFMA, a Queensland Statutory Authority. Indirect regulation occurs under the commonwealth Great Barrier Reef Marine Park Act (1975), administered for the conservation and wise use of the GBR Marine Park by the GBR Marine Park Authority (GBRMPA), a Commonwealth Statutory Authority. The fisheries management measures for the fishery include a cap on the total number of commercial licences, recreational bag limits, and minimum and maximum size limits for a range of species, which apply to all sectors of the fishery (QFMA 1996). At the time of writing, these measures were under review by the QFMA. The main conservation management measure is system of spatial zoning which excludes line fishing from approximately $16-23 \%$ of coral reef habitats of the main target species within the GBRMP.

[^1]Figure 4: Composition of the total catch reported from the reef line fishery between 1988 and 1995. Figure reproduced from Mapstone et al. (1996). Note that data for 1995 were not complete at the time this figure was prepared.

1988


1989


1993


1990


1994

1995

|  | YEAR |  |  |  |  |  |  |  |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | :---: |
|  | Species Group | $\mathbf{1 9 8 8}$ | $\mathbf{1 9 8 9}$ | $\mathbf{1 9 9 0}$ | $\mathbf{1 9 9 1}$ | $\mathbf{1 9 9 2}$ | $\mathbf{1 9 9 3}$ | $\mathbf{1 9 9 4}$ |  |
| Red Emperor | 22.7 | 33.3 | 38.7 | 51.5 | 35.3 | 23.1 | 22.1 | 11.9 |  |
| Other Pelagics | 69.4 | 40.5 | 64.7 | 48.0 | 33.3 | 53.7 | 138.0 | 62.6 |  |

A total of 1806 licences exist for commercial line fishing in the GBR region. These licences fall into two endorsement categories: L2 endorsements, of which there were with 251 allocated in 1993, allows fishing from 2 or more dories in addition to the primary vessel; and L3 endorsements, comprising the remaining licences, that restrict fishers to no more than one dory in addition to their primary vessel. There are presently no restrictions on total catch by the commercial fishery or on the movement of appropriately endorsed vessels within the GBRMP (Mapstone et al. 1996).

## Need

As part of another project (the Effects of Line Fishing (ELF) Project), in March \& April, 1995 we held two series of meetings with commercial and recreational fishers and other stakeholders at major regional centres along the tropical Queensland coast. In eight of the ten meetings, concern or uncertainty was expressed about the implications of the emergence on the GBR of a trade in live reef fish. A second recurrent issue was the perception that the commercial reef line fishery was actively targeting aggregations of spawning reef fish, especially common coral trout. Further, concern was expressed that the development of the trade in live fish would exacerbate the (purported) targeting of spawning aggregations because the increased market price of live fish compared with dead fish would increase incentives to invest in the fishery and maximise catches.
Although controversy over the development of a live fish trade arose mainly from recreational fishers and conservation groups, concerns were expressed also by some commercial fishers. In particular, recreational fishers raised concerns that landing fish alive would result in increases in commercial fishing effort because of the higher beach prices paid for live fish, concentration of commercial effort close to ports from which live fish could be delivered to international airports, and increased (commercial) fishing mortality because higher market prices would increase the tolerance of declining catch rates by commercial fishers. Liaison with commercial fishers and direct observations on commercial fishing vessels following these meetings indicated that supplying live fish markets had resulted in several changes to fishing practices, but the details and implications of those changes for management of the fishery were unknown.
In addition to the above issues local to the GBR line fishery, there existed considerable apprehension about the live fish trade because of its association with destructive fishing practices on some western Pacific and South East Asian reefs. The appearance in GBR waters of live fish transport vessels and off-shore holding pens (now banned) further exacerbated controversy about the industry, resulting in considerable media attention and debate in state and federal parliaments.

This project was needed, therefore, to clarify some of the above ambiguities and uncertainties around the live fish trade and the harvesting of fish from spawning aggregations. Consultation with the peak fishing organisations (Queensland Commercial Fishermen's Organisation (QCFO), SUNFISH), Queensland charter boat operators and management agencies (QFMA, GBRMPA) consolidated support for this research.

## Objectives

## Effects of the Live Fish Export Trade

I. To quantify the effects of live fishing on: a) on-site fishing dynamics and catch rates in dories; b) primary vessel fleet dynamics; c) tolerance of commercial fishing to declines in catch rates.
II. To verify the effects of live fishing on data routinely recorded in QFMA compulsory logbooks, and identify ways in which the system might be made more efficient.
III. To verify whether live fishing results in concentrated effort around major ports/reefs (e.g., inshore).
IV. To identify regional variations in fleet dynamics with respect to live fishing.

## Targeting of Spawning Aggregations of Coral Trout

V. To verify the extent of deliberate targeting of coral trout spawning aggregations by the Great Barrier Reef commercial line fishery.
VI. To quantify the encounter rate of (spawning) aggregations of coral trout by commercial reef line fishers.
VII. To compare searching behaviours, dory dynamics, catch rates and total catches of coral trout during spawning and non-spawning periods.
VIII. To make direct observations of putative spawning aggregations and normal occurrences of coral trout, as encountered by commercial reef line fishers.
IX. To estimate the net change(s) in catch of coral trout by the commercial reef line fishery during spawning periods.

## Achievement of Objectives

The objectives of the project were to be fulfilled via an observer program and analysis of information provided by commercial fishers, through interview and completion of voluntary and compulsory logbooks.
The observer program completed successfully, with two alterations. First, we planned to structure trips to sea by observers around lunar phase, to maximise the potential to observe encounters with, and/or targeting by reef line fishers of, spawning aggregations of coral trout. This stratification proved impossible because the fishers with whom we worked were not structuring their trips to coincide with known or expected spawning behaviour of the target species. This phenomenon, however, indicated that fishers were on the whole not specifically targeting spawning fish at the expense of other operational considerations. The result was that the timing of trips by observers was effectively random within the spawning and off-spawning seasons. This impacted on objective VI but did not affect substantially the achievement of the other objectives of the project.
Second, we planned to make direct observations of apparent spawning aggregations (if encountered) whilst they were being fished. This proved unfeasible because a) few apparent aggregations were encountered, judging from the condition of the fish as they were caught, and b) observations either from the dory or in the water were not acceptable to fishers because of disruption of their fishing practices. Since the primary objectives of the observer program were to observe fishing behaviours as near as possible to 'normal' practice, we ceased attempting direct observations of the fish being targeted (whether obviously spawning or not). Accordingly, objectives VI and VIII were not met.

The implementation of a voluntary logbook program worked well and the resultant information allowed us to address several objectives with greater detail than would have been possible on the basis of compulsory logbook data alone.
The use of multiple sources of data in this project has provided the most complete analysis to date of the dynamics and fishing practices of the commercial reef line fishery on the Great Barrier Reef. The general consistency of results among the data from different sources also provides some comfort that the most comprehensive data, those from the compulsory logbooks, probably provide a relatively reliable record of the fishery, though there is need to quantify formally and more completely than was intended here the uncertainties in those data.

# Effects of trade in live fish on fleet dynamics and catch characteristics by the Queensland commercial reef line fishery 

## Introduction

Management of fishery systems historically has been based mainly on assessments of stock status and predictions of stock responses to changes in fishing mortality (Hilborn \& Ledbetter 1979; Hilborn 1985). Catch per unit of effort (CPUE) remains one of the key variables used for the assessment of impacts of fishing and responses of stocks to harvest. At its simplest, CPUE is accepted as an indicator of relative abundance and changes in CPUE interpreted as indicating (relative) changes in stock biomass. Under a suite of assumptions about the distribution of fishing effort, constancy in availability of the target stocks and selectivity of fishing gears, declines in CPUE typically would signal concern that stocks were at risk of over-exploitation. Implicit in such inferences also is the assumption that fishing practices have remained relatively constant over the period of change in CPUE. Because of these assumptions of constancy, changes in gear, distribution of effort, or fishing practice could substantially undermine the utility of CPUE as an indicator of stock status.

Conventionally, the fishing dynamic has been weighted lightly, if at all, in the interpretation of fishery data (especially CPUE) or in the prediction of effects of management strategies or changed market forces on fishing mortality (Hilborn 1985). More recently, several authors have recognised the importance of fishers and their behaviours in mediating the links between operational constraints, such as management strategies and market conditions, and fishing mortality (Hilborn \& Walters 1992, Watson et al. 1993, Seijo et al. 1998, Holland \& Sutinen 1999). There is now an increasing recognition of the need to understand better the responses of fishers to changing regulatory and economic conditions when interpreting fishery data and considering future management strategies (Holland \& Sutinen 1999).
Change in the characteristics of fishing effort, such as spatial and temporal distribution and targeting behaviour, is likely to be one manifestation of fishers' responses to changing operating conditions (Allen \& McGlade 1986). Other changes might include adoption of new technologies and changes in gear. Examination of changes in effort characteristics of a fishery is likely to serve as a useful surrogate for more direct process studies of changes in motivation and psychology and provide a useful aid to the interpretation of indexes of the fishery system derived from basic catch and effort data. Where operating conditions are subject to known changes, such as changed market forces or regulations, effort information is likely to provide useful explanation of the responses seen in subsequent catch and effort data (Hilborn 1985). Where operating conditions are believed to be relatively constant, effort information may prove useful as an early indicator of changes in stock status, CPUE, or unexpected changes in market places. In this context, effort dynamics may provide more sensitive and immediate indications of changes in stock status and/or CPUE than the posterior analysis of fleet or research catch rate data. Further, where conflicts arise over access to resources and perceived impacts of different fishing sectors on stocks, understanding of effort distribution and dynamics is likely to clarify the basis of conflict, the degree of overlap in use of resources, and the most productive management strategies to reduce conflict.

Uncertainty about the interpretation of trends in CPUE usually involves concerns that improved gear, exploitation of new grounds, or 'smarter' fishing practice will result in hyperstability in CPUE, with the attendant risk that real declines in stocks will be obscured (Hilborn \& Walters 1992). This would be analogous to a Type II error in statistical inference, with the main risk being inadvertent and unrecognised over-exploitation of target stocks and continued (over) capitalisation of the fishery. The longer term consequence, when the error is recognised, is either drastic management action and hardship in the fishery or a fishery collapse.

A less common issue is that of changes in fishing practice resulting in declines in CPUE unrelated to declines in stocks. In most cases this would seem contrary to the presumed
motivation of fishers to maximise their profit by taking whatever steps possible to maintain or increase CPUE. A change in market that entails significant value-adding to the catch, however, is one motivator of change in fishing practice that might be consistent with both profit maximisation and lowered CPUE. Such a change clearly involves a trade-off between lowered CPUE and increased value of the catch. Provided that the increase in value exceeds the drop in CPUE (and any costs of change in operation), the net result for fishers favours the change, with attendant drop in CPUE.
If an operational cause of a decline in CPUE is unrecognised, the drop in CPUE would likely be taken as a strong indicator of declining stocks. This might result in tightening of management provisions, in this case possibly unnecessarily. Such a scenario would be analogous to a Type I statistical error, with action being taken inappropriately on the basis of an erroneous inference of declining stocks, possibly leading to unnecessary hardship in the fishery. The potential for the latter case arose in the mid 1990s in the GBR commercial reef line fishery with the development of export markets of live reef fish.

## Development of a market for live reef fish

Trade in live tropical fin fish for consumption has been widespread throughout South East Asia for some time, driven by high value markets. Hong Kong has developed as the major importer, consumer and secondary marketer of live reef fish (Johannes \& Riepen 1995; Sadovy 1998), with imports ranging from 38,204 to 54,141 tonnes between 1989 and 1994 (McDonald \& Jones 1998). Imports of live reef fish to Hong Kong were estimated to be around 45,000 t in 1997, of which approximately 840 t was coral trout, Plectropomus spp (Lau \& Parry-Jones 1999, Parry-Jones \& Lau 1999). Destructive fishing practices and inadequate regulation, however, threaten the viability of supplies of live fish from several countries (Johannes \& Riepen 1995, Johannes \& Lam 1999),
The market for live reef fish is a recent development on the GBR, however, with the first fish exported live in 1993 (McDonald \& Jones 1998, Mapstone et al. 1996, Squire 1994). The market developed slowly through 1994 and 1995, with relatively small quantities being supplied by relatively few vessels, then grew rapidly through 1996. The shift to 'live fishing' has been motivated by considerably greater beach prices for live fish than for dead product. Live fish of selected species generally are worth at least 1.5 -times and at times up to threetimes the value of the same fish dead, provided that the fish are in good condition and unmarked by hooking or handling injuries. Marketing reef fish live thus represents considerable value adding to the fishermen, the local buyers, and the exporters, and substantially improves the value of the reef line fishery as a national export industry. Accordingly, the development of a live fish trade from the reef line fishery has been supported enthusiastically by a number of industry and management sectors.

## Implications of development of a live fish trade from the Great Barrier

The primary impacts of the shift in marketplace on the reef line fishery were likely to be manifest in four areas: fleet infrastructure \& capitalisation; effort distribution; fishing practices and catch rates; and inferences about the status of the fishery.

## Infrastructure

Infrastructural response by the commercial fleet to the development of live fish export markets has taken two main forms: i) Substantial capital investment in modification of existing primary vessels or construction of new primary vessels specifically for holding live fish. ii) Minor modification of existing vessels to allow holding of live product, without substantially reducing the vessels original holding capacity for frozen or chilled product. The former group fished principally for common coral trout to be marketed live and is the group for which the development of the market for live product was most likely to have resulted in significant, inflexible changes in fishing practices. In many instances this group included the most active and productive operations in the fleet prior to the development of the market for live product (Mapstone et al. 1996; pers. obs.). Those operations that retained their frozen
product capacity also were likely to exhibit changed fishing practices, but would be less tied to them in the event of market fluctuations for live fish. In most cases new entrants to the fishery have made substantial capital investments, in both vessels and endorsements, on the expectation of realising high returns from elevated high beach prices paid for live product in comparison to the traditional frozen and chilled forms. Fishers have flagged, however, that there is greater financial risk associated with the live fish trade because of considerable and rapid price fluctuations and the risk of death or damage of fish before sale.
The increased interest in the fishery resulted in a substantial increase in market value of endorsements for the line fishery. Prices of L2 endorsement packages (allowing the use of 2 or more dories) had been consistently around $\$ 20,000-\$ 25,000$ until 1992 , rose to $\$ 35,00$ $\$ 40,000$ in 1994-95, and were over \$60,000 in 1996-99 (unpublished licence brokers' data).

## Effort

Effort responses to the trade in live fish have been speculated in two categories. First, if the prices paid for live fish remain substantially above those for dead product, increased participation in the fishery has been predicted. Because licences are currently capped in the reef line fishery, this could occur only through mobilisation of currently inactive endorsements. Second, concentration of effort might be expected in areas within easy reach of road transport to major airports, resulting in shifts in the distribution of effort.

## Fishing Practices

Commercial fishers have argued that retaining their catch alive involves several changes in fishing practices. These include: i) reductions in catch rates because of increased handling time for each fish; ii) shallower fishing to avoid the risk of embolism that occurs when taking fish from deeper water; and iii) shorter fishing trips with reduced effective fishing time, because of the lower holding capacities for live fish than for dead fish.

## Inferences about the Reef Line Fishery

It would be expected also that data provided from the fishery to management, via the QFMA compulsory logbook scheme (1988-present), might reflect any drops in catch rates or changes in distribution of effort. The status of the fishery normally would be assessed from analyses of these catch and effort records (QFMA 1996, 1999). Signals of declining catch rates, taken at face value, might give the impression of a declining stock biomass, whereas they simply had arisen because of changes in the operational characteristics of the fishery.

Compulsory logbook records only coarsely reflect the underlying dynamics of the fishery, however, because: a) the reporting time frame for line fishing is typically 'catch per day' (by species or group of species); b) the reported unit of effort is the primary vessel, with no individual catch information recorded for the effective unit of effort - a fishing dory; and c) the obligatory spatial scale of reporting is by 30 grid ( $\sim 3600 \mathrm{sqr} \mathrm{km}$ ), whereas the fishery typically operates at the scale of individual coral reefs or deep shoals (typically $<50 \mathrm{sqr} \mathrm{km}$ ).
There is currently no empirical description of the fleet or dory dynamics of the reef line fishery at scales less than the compulsory reporting scale, or in relation to the form of product landed. Further, there was no requirement prior to 1997 in the QFMA compulsory logbooks to indicate when product was being kept alive. This was of particular concern during the development of the live fishery because there was no requirement to discriminate between live product and other forms of product (whole (dead), gutted, trunk, and fillet).
Consequently, for many operations live product would appear in logbook records as whole (dead) product, and an inference of 'dead' fishing practices would follow.
In this project we sought to clarify in detail some of the realised consequences for fishing effort dynamics and catch rates of a shift to live fishing, and to provide an empirical basis for discussion of the implications of the live fishery for the shared fishery resources.

## Methods

## General Methods

The research was done over two years (1996-98) in the early development of the trade in live reef fish from the Great Barrier Reef, Australia. We used four methodological approaches:
i) Direct observations of fishing activities by on-board observers;
ii) Analysis of research logbooks filled out voluntarily by skippers;
iii) Analysis of compulsory logbook data provided to the QFMA; and
iv) Interviews with skippers.

The first two approaches provided contemporary data for comparison of live and dead fishing operations, whilst approaches iii) and iv) allowed us to examine more completely the development of the live fishery in relation to previous and concurrent dead fishing practices.

In most cases we were interested in tests of the (null) hypotheses that the shift to live marketing of reef fish did not result in significant changes to various characteristics of fishing effort, catch or catch rate. We wished to test also whether apparent market effects were influenced by other factors such as season, year or the effort class (fishing capacity) of operations. Our data frequently included multiple nested random effects and crossed fixed effects and repeated observations on fishers or vessels. Accordingly, most of our analyses were by multi-factorial split-plot (or repeated measures) analysis of variance (ANOVA).
The basic model for most ANOVAs included the fixed effects of Market (live, dead), Season (spawning, off-spawning), and Year (values vary with data set), and sometimes Session (mostly AM, PM, and occasionally AD, All Day). In some analyses the nested factors trips, primary vessels, or fishers were also present. These nested factors were considered random variables. Definitions of the levels in these common factors are given in Table 2. Model details are given in the following sections relevant to each data source, as are definitions of factors other than those above that were specific to particular analyses.

Table 2: Main factors (sources of variation) considered in analyses of catch and effort data, the levels of those factors, and definitions of those levels. All references to these factors are based on these definitions unless otherwise specified.

| Factor | Level | Definition |
| :---: | :---: | :---: |
| Market | Live Dead | $\geq 60 \%$ of coral trout catch sold alive, usually assessed by trip $\leq 40 \%$ of coral trout catch sold alive, usually assessed by trip |
| Season | Spawning Off-Spawning | 3 months each year in which $P$. leopardus expected to spawn 9 months each year when $P$. leopardus not expected to spawn |
| Session | $\begin{aligned} & \text { AM } \\ & \text { PM } \\ & \text { AD } \end{aligned}$ | Continuous interval in a dory that was mostly in the morning Continuous interval in a dory that was mostly in the afternoon All day spent in a dory, without return to primary vessel |
| Effort Class | $\begin{aligned} & \mathrm{A} \\ & \mathrm{~B} \\ & \mathrm{C} \end{aligned}$ | Operation typically used 1-2 lines per day Operation typically used 3-4 lines per day Operation typically used 5-7 lines per day |
| Year | Various | 12 month period, either from January to December (199x) or July to June (199x-9y), depending on data set. |
| Vessel | Many | Primary vessel at the centre of an operation |
| Trip | Many | Period from leaving port to return to port and/or period involving no more than 2 consecutive non-fishing days |
| Fisher | Many | An individual fisher working from a dory or the primary vessel |

Two additional points should be noted with respect to Table 2. First, a third market category, Mixed, representing operations that landed $>40 \%$ and $<60 \%$ of their catch of coral trout alive
was defined but not analysed because it included very few operations. Second, the boundaries between spawning and non-spawning seasons varied by 1-2 months depending on where the catch was reported, but were constant for each region over years. Common coral trout are considered to be stimulated to spawn by post-winter increases in water temperature beyond about $26^{\circ} \mathrm{C}$ (Samoilys 1997). This and observations from commercial fishers indicate that spawning usually commences in August in the northern GBR, September south of about Cairns, and October in the southern extremity of the GBR. Spawning is believed to span three lunar months and is correlated with the major seasonality in the fishery, spawning of several other reef species, and with prevailing weather (Mapstone et al. 1996).

We tested all data for homoscedasticity prior to analysis but found in all cases that data sets had homogeneous error variances. This possibly arose because for most of our analyses the error variances were derived from means of many values, which were themselves either means or maxima of several observations (usually within trips). This approach also ensured normality of the analysed variables and data from which error variances were calculated (Central Limit Theorem). We used a relatively liberal significance criterion for all tests ( $\mathrm{p} \leq 0.1$ ) to reduce the potential for Type II errors. We adopted this strategy because we considered the inferences that would arise from failure to reject null hypotheses would be important as well as inferences based on rejection of null hypotheses.
In general we simplified analytical models wherever possible by pooling effects that were demonstrably unimportant. Sums of squares and degrees of freedom of effects were pooled sequentially from the highest-order interactions to the main effects. An effect was pooled with the source of variation in the denominator of the relevant $F$-ratio if a) $F<=1$, indicating that the effect being considered accounted for no variation in the data, and $b$ ) the effect was not involved in higher-order interactions that had not been pooled already. We did not explored effects only at the highest order of interaction where the test was statistically significant ( $p<0.1$ ), and present main effects without qualification only where they were not involved in any interactions with other factors. Throughout this report we focus mainly on those effects of interest to the objectives of this project and/or their significant interactions with other factors. Accordingly, we do not present exhaustive explorations of all significant effects in the often complex analyses and generally ignore effects that are not directly pertinent to the project objectives (e.g., effects of year or session alone).

## Direct Observations by On-board Observers

We placed single researchers on board commercial fishing vessels for routine fishing trips, typically one to three weeks, when vessels were fishing predominantly for the frozen market or selling most of their catch alive. Trips were distributed approximately evenly through the spawning and off-spawning seasons for common coral trout. Trips were concentrated mainly in the central and southern GBR between $12^{\circ} 90$ S and $22^{\circ} 00 \mathrm{~S}$ (Fig. 2), where the growth of the trade in live fish has been focused.
Observers were placed on a total of 29 trips, which included 16 trips when the catch was kept alive (live trips) and 13 trips on which the catch was killed (dead trips). Vessels sampled were selected from a large pool of known operations on the basis of skippers' willingness to participate and vessels' Queensland Department of Transport survey sufficient to accommodate an observer legally. Strict randomisation of vessels to sampling times or live or dead trips was impossible due to logistic constraints of normal fishing activities and the voluntary nature of the accommodation of observers by skippers.
Observers recorded the daily movements of the primary vessel throughout each trip, including the location, arrival and departure times for each anchorage. The observer spent each fishing day in one of the fishing dories or on the primary vessel (if fishing was done from the primary vessel). Data from primary vessels and dories were considered separately because of the different mobility and fishing practices relevant to each. Only dory data from observers are presented in this report. The dory to be sampled each day was chosen haphazardly without replacement until all dories were sampled once and then the process
was repeated throughout the trip. The observer remained in a dory throughout all fishing sessions (AM, PM, or All Day (AD)) during a day, recording for each hang (specific fishing location) the following details:
i) the time taken to search for the hangs;
ii) the time taken to set the anchor and position the dory for fishing;
iii) the hang location (by hand held GPS);
iv) the water depth (by depth sounder);
v) the time fishing started and ceased;
vi) the time each line was retrieved;
vii) the result of each retrieved line (whether the hook had no bait, was still baited or the line had been cut, or a fish was landed) and, if a fish was landed, its species, relative size, and fate (kept alive, killed, or released);
viii) if the catch was a coral trout, its relative size was recorded (small: $\sim 38<43 \mathrm{~cm}$, medium: $\sim 43<50 \mathrm{~cm}$, large: $>50 \mathrm{~cm}$ total length), and if it was a common coral trout ( $P$. leopardus), its colour (red, green) was also recorded ${ }^{3}$; and
ix) the time taken to reset the bait after retrieving the previous line.

On return to the primary vessel at the end of each session, the observer recorded the catch per session from each of the other dories operating from the primary vessel, and the approximate time spent fishing for that catch. The catch (number and/or weight of fish) for each dory in each session was categorised according to the main species groups used for the sale of commercial product. Comparison of catch rates per session between dories with and without observers and between days when each fisher was or was not accompanied by an observer indicated that the presence of the observer was likely to have biased the catch rates of the fisher.

## Analysis of Observer Data

Data from trips on which observers were present fell into two categories: those collected by observers in dories during sessions; and those related to other dories or the primary vessel collected only at the end of each session or day. Further, data generally related to three scales of activity; within sessions (for some observer data only); between sessions or days (all dory data and some primary vessel data); and for the trip (some primary vessel movement data).

Hang level observations (e.g., hang duration) were averaged within sessions because sequential observations of the same fisher within a session were likely to be nonindependent. Thus, the data analysed for observations on hangs were per-session means, and analogous to session level data. Accordingly, both hang level and session level variables were analysed by ANOVAs with the between dory factors Market, Season, Year (1996-97, 1997-98), and trip (nested within Market, Season \& Year), and the within dory (repeated measures) factor Session. Days within trips (which were unavoidably confounded with fishers because the observer could accompany only one fisher at a time) were the lowest units of replication in these analyses. The analytical model for these data was:

$$
\begin{aligned}
& y_{i k l m n}=\mu_{\ldots \ldots .}+\mathbf{M}_{i \ldots \ldots}+\mathbf{S}_{j \ldots \ldots}+\mathbf{Y}_{\ldots \ldots \ldots}+\mathbf{M S}_{j \ldots \ldots}+\mathbf{M Y}_{i, \ldots \ldots}+\mathbf{M S Y}_{i j \ldots \ldots}+\mathbf{t}(\mathbf{M S Y})_{j j k l . .}+\mathbf{A}_{\ldots \ldots .}+
\end{aligned}
$$

$$
\begin{align*}
& \mathbf{M S Y A}_{j k . . m .}+\mathbf{t}(\mathbf{M S Y}) \mathbf{A}_{j k k m .}+\varepsilon_{j i k l m n} \tag{1}
\end{align*}
$$

where
$y_{i j k / m n}=$ the observation (or mean) from the $n^{\text {th }}$ fisher/day in AM or PM session $m$ on trip / to supply Market $i$ in Season $j$ of Year $k$;
$\mu_{\ldots . . . . . ~}=$ population mean of possible observations; and
$\varepsilon_{i j k / m n}$ is a normally distributed error associated with observation $y_{i j k m n}$.

[^2]Variation among trips ( $\mathbf{t}(\mathbf{M S Y})$ ) provided the denominator for F-tests of the effects of Market, Season and Year and their interactions with each other. The main effect of Session and its interactions with Market, Season, and Year were tested against the trip*session interaction ( $\mathrm{t}(\mathrm{MSY}$ ) $\mathbf{A}$ ).
Session level catch data existed for all fishers on all days of each observer trip. Again because sequential observations from the same fishers throughout a trip might be expected to be non-independent, data were averaged across days for each fisher within each session and these means provided the base data for analyses. Analyses were by models analogous to those above, but with the average (over days) from each fisher, not days, being the lowest level of replication.
Movement data for the primary vessels involving within trip movements (e.g., reef to reef transit distances) were analysed by the following model, with the basic unit of replication being average movement (e.g., from reef to reef) within days.

$$
\begin{equation*}
y_{i k k n}=\mu_{\ldots \ldots . .}+\mathbf{M}_{i \ldots . \ldots}+\mathbf{S}_{j \ldots . .}+\mathbf{Y}_{\ldots . . .}+\mathbf{M S}_{i \ldots . \ldots}+\mathbf{M} \mathbf{Y}_{i . k .+}+\mathbf{M S} \mathbf{Y}_{i j k . .}+\mathbf{v}(\mathbf{M S Y})_{j k k l}+\varepsilon_{i j k n} \tag{2}
\end{equation*}
$$

where
$y_{i k / n}=$ the observation (or mean) from the $n^{\text {th }}$ day during a trip by vessel $/$ to supply
Market $i$ in Season $j$ of Year $k$;
$\mu_{\ldots . . . .}=$ population mean of possible observations; and
$\varepsilon_{i j k n}$ is a normally distributed error associated with observation $y_{i j k n}$.
The effects of Market, Season and Year were tested against the variation among vessels in the above model.
Analyses of trip level data (e.g., trip length), however, included only the factors Market, Season and Year, with trips (which were confounded with vessels) providing replication within each cell, as follows:

$$
\begin{equation*}
y_{i k l n}=\mu_{\ldots \ldots . .}+\mathbf{M}_{i . . .}+\mathbf{S}_{j . .+}+\mathbf{Y}_{\ldots . k+}+\mathbf{M S}_{i j .+}+\mathbf{M} \mathbf{Y}_{i . k .}+\mathbf{M S} \mathbf{Y}_{i j k .+}+\varepsilon_{j i k n} \tag{3}
\end{equation*}
$$

where
$y_{i j l n}=$ the observation (or mean) from the $n^{\text {th }}$ trip by to supply Market $i$ in Season $j$ of Year $k$;
$\mu_{\ldots . .}=$ population mean of possible observations; and
$\varepsilon_{i j k n}$ is a normally distributed error associated with observation $y_{j i k n}$.
All effects in this model were tested against the residual variation ( $\varepsilon$ ).
The variables analysed, their scale(s) and the models by which they were analysed are given in Table 3.

Table 3: Variables analysed to assess the effects of market intention, season and year on effort dynamics, catch rates and catch composition (Subject) on fishing trips accompanied by research observers. Scale indicates the temporal scale at which observations were made and Model indicates the analytical model (from above text) used to analyse each variable.

| Subject | Variable | Scale | Model |
| :---: | :---: | :---: | :---: |
| Effort Dynamics Primary Vessels |  |  |  |
|  | Trip length | Trip | 3 |
|  | $\mathrm{N}^{\circ}$ stops per trip | Trip | 3 |
|  | Steaming distance Reef $\rightarrow$ Reef | Day or less | 2 |
|  | Port $\rightarrow$ Reef | Trip | 3 |
|  | Reef $\rightarrow$ Port | Trip | 3 |
|  | Distance from port | Day | 2 |
|  | Steaming Time Reef $\rightarrow$ Reef | Day or less | 2 |
|  | Port $\rightarrow$ reef | Trip | 3 |
|  | Reef $\rightarrow$ Port | Trip | 3 |
|  | Time spent at each reef | Day or less | 2 |
| Dories | Search Time | Hang | 1 |
|  | Distance between Hangs | Hang | 1 |
|  | Anchor Set Time | Hang | 1 |
|  | Fishing Depth | Hang | 1 |
|  | Fishing Time | Hang | 1 |
|  | Hang Duration | Hang | 1 |
|  | $\mathrm{N}^{0}$ Hangs per session | Session | 1 |
|  | Session Duration | Session | 1 |
|  | Fishing time per session | Session | 1 |
|  | ${ }^{\circ} \mathrm{Sessions}$ per day | Day | 2 |
| CPUE | CPUE coral trout (all species) | Hang \& Session | 1 |
|  | CPUE red throat emperor | Hang \& Session |  |
|  | CPUE mixed reef species | Hang \& Session | 1 |
|  | Proportion of successful bait sets | Session | 1 |
|  | Released coral trout per unit effort | Session |  |
| Catch Composition | Proportion of coral trout in catch | Session | 1 |
|  | Proportion of under-size coral trout | Session | 1 |
|  | Proportion of small coral trout | Session | 1 |
|  | Proportion of large coral trout | Session | 1 |
|  | Proportion of 'red' P. leopardus ${ }^{4}$ | Session | 1 |

[^3]
## Voluntary Research Logbooks

Voluntary research logbooks were designed in consultation with commercial fishers to provide more detailed daily catch and effort information than routinely recorded in the QFMA compulsory logbooks, but with minimum inconvenience to vessel skippers. The data recorded in the research logbooks were geographically more specific than records in the QFMA compulsory logbooks, with catch and effort recorded by reef, rather than the 30' or 6' grids. Further, catch was recorded in voluntary logbooks by dory and session (AM/PM/AD) rather than by primary vessel and day, as is the case in the QFMA compulsory logbooks.

Data were analysed from 126 fishing trips recorded in voluntary logbooks by 17 commercial line fishing operations supplying the frozen fish market and 17 commercial line fishing operations selling their catch alive in 1997 and/or 1998.

## Analysis of Voluntary Logbook Data

The voluntary logbook data included multiple trips by each vessel within a season \& year. Although some vessels reported data from more than one season, year and market category, many did not and so we selected vessels without replacement for different seasons, years and market categories. Accordingly, analyses of primary vessel movements included the factors Market, Season and Year (1997, 1998), and vessel (nested with Market, Season and Year), with the analytical model analogous to equation (2). For within-trip variables, the additional factor trip nested within vessel also occurred, resulting in the model:

$$
\begin{align*}
& y_{i k k m n}=\mu_{\ldots \ldots . .}+\mathbf{M}_{i \ldots \ldots}+\mathbf{S}_{j \ldots \ldots}+\mathbf{Y}_{\ldots . . . .}+\mathbf{M} \mathbf{S}_{i \ldots \ldots}+\mathbf{M} \mathbf{Y}_{i . k \ldots}+\mathbf{M S Y}_{i j k . .}+\mathbf{v}(\mathbf{M S Y})_{i j k l . .}+ \\
& \mathbf{t}(\mathbf{v}(\mathbf{M S Y}))_{i j k m .}+\varepsilon_{j j k n} \tag{4}
\end{align*}
$$

where
$y_{i j k l m n}=$ the observation (or mean) from the $n^{\text {th }}$ day during trip $m$ by vessel $/$ to supply
$\quad$ Market $i$ in Season $j$ of Year $k$;
$\mu_{\ldots \ldots . . .}=$ population mean of possible observations; and
$\varepsilon_{\varepsilon_{j j k m n}}$ is a normally distributed error associated with observation $y_{i j k l m n .}$

Catch data from each dory (and fisher) reported in voluntary logbooks were averaged over days for each session within each trip, similarly to analogous data from observer trips. These means were then analysed by the following model, with trip-average data from individual dories \& fishers being the lowest level of replication.

$$
\begin{aligned}
& y_{i k k m t n}=\mu_{\ldots \ldots \ldots}+\mathbf{M}_{i \ldots \ldots}+\mathbf{S}_{j \ldots \ldots}+\mathbf{Y}_{. . k \ldots}+\mathbf{M S}_{j j \ldots . \ldots}+\mathbf{M Y}_{i . k \ldots \ldots}+\mathbf{M S Y}_{i j \ldots \ldots}+\mathbf{v}\left(\mathbf{M S Y}_{i j k l .}+\right.
\end{aligned}
$$

$$
\begin{align*}
& \mathbf{S Y} \mathbf{A}_{j \text { jk.m. }}+\mathbf{M S Y A}_{j k . m . .}+\mathbf{v}(\mathbf{M S Y}) \mathbf{A}_{j k k m .}+\mathbf{t}(\mathbf{v}(\mathbf{M S Y}))_{j k k . t}+ \\
& \mathbf{t}(\mathbf{v}(\mathbf{M S Y})) \mathbf{A}_{j k k l m t .}+\varepsilon_{j k l m p n} \tag{5}
\end{align*}
$$

where
$y_{i j k l m t n}=$ the observation (or mean) from the $n^{\text {th }}$ fisher-dory in AM or PM session $m$ on trip $t$ by vessel / to supply Market $i$ in Season $j$ of Year $k$;
$\mu_{\ldots . . . . .}=$ population mean of possible observations; and
$\varepsilon_{j j k l m n}$ is a normally distributed error associated with observation $y_{j k k m t n}$.
The variables analysed by each of these models are shown in Table 4.

Table 4: Variables analysed to assess the effects of market intention, season and year on effort dynamics catch rates and catch composition (Subject) as reflected in voluntary logbook records. Scale indicates the temporal scale at which observations were made and Model indicates the analytical model (from above text) used to analyse each variable.

| Subject | Variable |  | Scale | Model |
| :---: | :---: | :---: | :---: | :---: |
| Effort Dynamics Primary Vessels | Trip length |  |  |  |
|  |  |  | Trip | $4 *$ |
|  | $\mathrm{N}^{\circ}$ stops per trip |  | Trip | $4 *$ |
|  | Steaming distance | Reef $\rightarrow$ Reef | Day or less | 4 |
|  |  | Port $\rightarrow$ Reef | Trip | $4 *$ |
|  |  | Reef $\rightarrow$ Port | Trip | $4 *$ |
|  | Distance from port |  | Day | 4 |
|  | Steaming Time between reefs |  | Day or less | 4 |
|  | Time spent at each reef |  | Day or less | 4 |
| CPUE | CPUE coral trout (all species) CPUE red throat emperor CPUE mixed reef species |  | Session | 5 |
|  |  |  | Session | 5 |
|  |  |  | Session | 5 |
| Catch Composition | Proportion of coral trout in catch |  | Session | 5 |

* For these variables there was only a single observation per trip and so the term $\mathbf{t}(\mathbf{v}(\mathbf{M S Y}))$ was dropped from the analytical model in equation (4).


## QFMA Compulsory Logbook Data

Data reported to QFMA in compulsory commercial line fishing logbooks was provided by the QFMA. The data span the years 1988 -present, with the compulsory daily reporting scale being by $30^{\prime}$ grid reference and optional reporting at 6 ' sites within grids. A relatively high proportion (64-74\%) of fishers has reported their catch by the optional smaller scales of 6 ' site, reef, or latitude and longitude since 1992. Accordingly, we used data only from 1992 to 1997 for this work. Thus, the QFMA data provided relatively coarse spatial information but by far the most complete fleet and temporal data about the commercial reef line fishery.

## Analysis of QFMA Compulsory Logbook Data

Compulsory logbook data from L2 operations were analysed in three ways. First, vessels were selected that completed both live and dead trips in both the spawning and off-spawning season of a year. Several such operations were identified in 1994, 1995, 1996 or 1997, though there were data from too few operations for analyses of some variables in some years (particularly 1996). The vessels selected in this category were mutually exclusive among the years 1994, 1995, 1996 or 1997. Hence, these operations were compared by split-plot ANOVA with the factors Market, Season, Year and vessel nested within Year. The model for these analyses was:

$$
\begin{align*}
& y_{i k k n}=\mu_{\ldots \ldots}+\mathbf{M}_{i \ldots . .}+\mathbf{S}_{j \ldots . .}+\mathbf{Y}_{\ldots . .}+\mathbf{M S} \mathbf{S}_{i \ldots}+\mathbf{M} \mathbf{Y}_{i . k .}+\mathbf{M S} \mathbf{Y}_{i j k . .}+\mathbf{v}(\mathbf{Y})_{\ldots k l}+ \\
& \operatorname{Mv}(\mathbf{Y})_{\mathrm{i} . \mathrm{k} l}+\mathbf{S v}(\mathbf{Y})_{\mathrm{j} . \mathrm{k} l}+\mathbf{M S v}(\mathbf{Y})_{\mathrm{ijk}!}+\varepsilon_{\mathrm{j} k \mathrm{l}} \tag{6}
\end{align*}
$$

where
$y_{j k k n}=$ the observation (or mean) from the $n^{\text {th }}$ trip by vessel $/$ to supply Market $i$ in Season jof Year k;
$\mu_{\ldots \ldots}=$ population mean of possible observations; and
$\varepsilon_{i j k n}$ is a normally distributed error associate with observation $y_{i j k \mid n}$.
Where data arose from each day within a trip (e.g., distance from the nearest port), those data were averaged over days within that trip. Repeated trips by each vessel were the lowest level of replication in these analyses. Variation among vessels was the error term for the test
of year effects, whilst the effects of Market, Season and Market*Season were tested against their respective interactions with vessel variation.
The same data used for the above analyses were used also to examine the effects of effort class and their interactions with seasonal and market effects. Tests for the effects of effort class here allowed us to examine the potential for the combination of physical size and fishing power (number of lines) of operations to substantially colour the results of analyses in which vessels of different classes were pooled. Since the number of vessels in each effort class in each year were too few to include both effort class and year as factors in the one analysis, in this analysis trips were used from all the years 1994-97. Thus, the analytical model was analogous to that shown in (4) above, but with the factor Effort Class replacing Year.

Second, a set of vessels was selected that fished as dead operations for at least 2 years between 1992 and 1994 (inclusive) and then fished for at least 2 years as live operations between 1995 and 1997 (inclusive). This set of vessels was compared to a second set that had fished for 2 years in each period, but had not changed their marketing practice. Because few of these operations fished frequently in both seasons in all years, only trips from the off-spawning seasons were used in these analyses. As before, data were averaged within trips and trip means used for the analyses. These data were analysed by an MBACI analytical design (Keough \& Mapstone 1995). The analyses involved the 'between vessel' factors Fleet (Dead \& then Live or Dead only, fixed), Effort Class (as in Table 2, fixed) and vessel (nested within Fleet \& Effort Class) and the 'within vessel' factors Period (Before and After the development of the live fishery, fixed) and Year (nested within Period, fixed). The analytical model, therefore, was:

$$
\begin{align*}
& y_{j k k m n}=\mu_{\ldots \ldots . .}+\mathbf{F}_{i, \ldots . .}+\mathbf{E}_{j \ldots \ldots}+\mathbf{F E}_{j j \ldots \ldots}+\mathbf{v}(\mathbf{F E})_{j k \ldots . .}+\mathbf{P}_{\ldots \ldots . .}+\mathbf{F P}_{i, \ldots . .}+\mathbf{E P}_{. j, \ldots}+\mathbf{F E P}_{i j, 1 . .}+ \tag{7}
\end{align*}
$$

where
$y_{i k k m n}=$ the observation (or mean) from the $n^{\text {th }}$ trip by vessel $k$ from Fleet $i$ in Effort class $j$ during Year $m$ of Period $I$ (before or after the onset of live fishing);
$\mu_{\ldots . . . . .}=$ population mean of possible observations; and
$\varepsilon_{i j k l m n}$ is a normally distributed error associate with observation $y_{i j k l m n}$.
The effects of principal interest in these analyses were the interactions between Fleet and Period and Fleet, Effort Class and Period, which were where a causal link between changed market intention and the variables we measured were expected to manifest. The error variance for tests of these effects was the vessel*Period interaction mean square.
Third, operations were selected without replacement that supplied each market and fished both seasons in each of the years 1994-1997 inclusive. Trip-averaged data from each year were analysed separately by a model comprising the factors Market, Season, Effort Class and vessels nested within Market and Effort Class. The model for these analyses was:

$$
\begin{align*}
& y_{i k k n}=\mu_{\ldots \ldots .}+\mathbf{M}_{i \ldots \ldots}+\mathbf{S}_{j \ldots . .}+\mathbf{E}_{\ldots . . .}+\mathbf{M S}_{i \ldots . \ldots}+\mathbf{M E}_{i k . .}+\mathbf{M S E}_{i j k . . .}+\mathbf{v}(\mathbf{M E})_{i . k l .}+ \\
& \mathrm{Sv}(\mathbf{M E})_{\mathrm{j} \mathrm{j} l . .}+\varepsilon_{\mathrm{j} k / n} \tag{8}
\end{align*}
$$

where
$y_{i k / n}=$ the observation (or mean) from the $n^{\text {th }}$ trip by vessel / in Effort Class $k$ supplying Market $i$ in Season j;
$\mu_{\ldots} \ldots=$ population mean of possible observations; and
$\varepsilon_{j j k / n}$ is a normally distributed error associate with observation $y_{i j k n n}$.
Variance among vessels was the error term for tests of Market and Effort Class and their interaction, whilst the Season effect was tested against the Season*vessel variance.
Data from L3 operations in years when more than five such operations reported live trips were analysed only by a model analogous to equation (8) but without the factor Effort Class, all L3 operations being in Effort Class A (Table 2).

In all analyses of QFMA compulsory logbook data we were required by confidentiality provisions not to present any results that represented fewer than five operations. Variables from the QFMA compulsory logbook data analysed by each model are listed in Table 5.

Table 5: Variables analysed to assess the effects of market intention, season, year and effort class on effort dynamics, catch rates and catch composition (Subject) as reflected in QFMA compulsory logbook records. Scale indicates the temporal scale at which observations were made and Model indicates the analytical model (from above text) used to analyse each variable.

| Subject | Variable | Scale | Model |
| :---: | :---: | :---: | :---: |
| Effort Dynamics Primary Vessels |  |  |  |
|  | Trip length Steaming distance | Trip | 4, 5, 6, 7 |
|  |  |  |  |
|  | Reef $\rightarrow$ Reef | Day | 4, 5, 6, 7 |
|  | Port $\rightarrow$ Reef | Trip | 4, 5, 6, 7 |
|  | Reef $\rightarrow$ Port | Trip | 4, 5, 6, 7 |
|  | Distance from port | Day | 4, 5, 6, 7 |
| CPUE | Mean CPUE coral trout (all species) | Day | 4, 5, 6, 7 |
|  | Mean maximum CPUE coral trout | Day | 4, 5, 6, 7 |
|  | Mean CPUE mixed reef species | Day | 4, 5, 6, 7 |
|  | Mean maximum CPUE mixed reef spp | Day | 4, 5, 6, 7 |
|  | Mean CPUE pelagic species | Day | 4, 5, 6, 7 |
|  | Mean maximum CPUE pelagic spp | Day | 4, 5, 6, 7 |

## Skipper Interviews

Interviews with skippers and owners of commercial reef line fishing operations formed part of a larger project aimed at gaining a better understanding of the motivations driving the fishing behaviour of reef line fishers and the economic characteristics of their fishing operations. A draft questionnaire was developed and pilot interviews completed during 1995. The main interviews were done during 1996-1997, in a face-to-face format, with 54 commercial reef line skippers/owners. The interview contained 138 questions in seven sections: i) fishing history, ii) primary vessel and dory characteristics, iii) crew characteristics, iv) vessel movement, v) processing information, vi) views on management and research, and vii) personal background. For the purposes of consistency, interviewees were asked to respond to the questions on the operational or economic aspects of their fishing operation based on the previous 12 month period. Each interview took approximately $2-3$ hours to complete.
A subset of the data from these interviews was used in this study to examine the effect of marketing product alive on fishing behaviour, principally primary vessel movement, and the characteristics of the fishing operations. Operations were classified as either live (in this case, $>50 \%$ of annual catch marketed live), dead ( $>50 \%$ of annual catch marketed frozen) or chilled ( $>50 \%$ annual catch market chilled). Only 2 of the 54 interviewees were classified as chilled operators. The remaining 52 interviewees were evenly divided between the live and dead categories. Variables examined for primary vessel movements included: trip length (minimum, maximum and average); number of reefs fished per trip; time spent on a reef (minimum, maximum and average); and steaming time from port to reef and reef to port.
Only basic summary statistics from relevant interview data were calculated for comparison with results from other data in this report.

## Results

## Effort Responses to the Trade in Live Fish

## Responses in Effort Distribution

Live fish were first landed in 1993 from the Mackay and Swains regions (see Fig. 2 for regions), with less than 5 operations reporting fewer than 100 days when live fish comprised more than $40 \%$ of their catch of coral trout. In 1994, a total of 344 operation days were reported on which the catch comprised over $40 \%$ of live fish. These reports were from the Far Northern, Cairns and Townsville regions. The distribution of live fishing effort reported in 1995-97 is shown in Fig. 5 relative to the effort reported where catch was mostly or exclusively killed for market.
Three main points arise from the data presented in these plots. First, effort associated with substantive landings of live coral trout then increased substantially in 1995, 1996 and 1997, to 1068,2980 and 4,267 operation days respectively. These figures are likely to be indicative only of the relative growth in the trade in live fish, however, because of the absence from the QFMA logbooks before 1997 of a specific product category for live fish. It was up to the skipper to take the initiative to indicate that his catch prior to mid 1997 was to be sold alive (rather than simply as whole fish) and accordingly the absolute levels of live catch and effort would be expected to be greater those above.
Second, the reporting of live fish in 1996 and 1997 had spread substantially to the north and south from its distribution in 1995. The percentage of all live effort that was reported each year within $1.5^{\circ}$ latitude of Cairns progressively decreased from $78.8 \%$ in 1994 , to $58.1 \%$ in 1995, 45.7\% in 1996 and 42.3\% in 1997.

Third, there were considerable increases in live effort between Mackay and Cairns from 1995 to 1996, and considerable increases in total effort between Townsville and Port Douglas from 1996 to 1997, accompanied by a reduction in effort between Townsville and Mackay. Whilst much of the additional effort reported between Townsville and Cairns in 1997 was apparently supplying the dead market, the major increase in effort between Cairns and Cooktown could be attributed to operations marketing their catch alive.
The annual catch of live reef fish of different species groups reported in QFMA compulsory logbooks is given in Table 6. These figures under-estimate total landings of live fish for reasons already discussed, but the comparison of these logbook data with (unpublished) export records from the Australian Quarantine and Inspection Service indicate that the degree of under-estimation has decreased with time and was negligible in 1998-99 (M. Elmer, QFMA, pers. com.).

Table 6: Total live catches ( kg ) of different species groups reported in the QFMA compulsory logbooks between 1992 and 1997.

| Common Name | Scientific Name | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Coral Trout | Plectropomus spp \& Variola spp. | 0 | 8773 | 30,565 | 81,164 | 218,020 | 254,767 |
| Barramundi Cod | Cromileptes altivelis | 0 | 0 | 33 | 146 | 591 | 1546 |
| Other Cods | Epinephelus spp \& Cephalopholis spp | 0 | 397 | 1,226 | 758 | 2,317 | 8,888 |
| Maori Wrasse | Chelinus undulatus | 0 | 0 | 137 | 291 | 827 | 1,087 |
| Emperors \& Sweetlip | Family Lethrinidae | 0 | 0 | 0 | 1,313 | 891 | 486 |
| Others |  | 0 | 0 | 0 | 288 | 311 | 309 |



## Main Boat Effort Dynamics

We found statistically significant ( $\mathrm{p} \leq 0.1$ ) effects of Market (Live or Dead), either as main effects or in interaction with other factors (season or year) on the characteristics of movements by primary vessels from all data (observers, voluntary logbooks, and QFMA compulsory logbooks). Vessels keeping their catch alive generally made shorter fishing trips, fished closer to ports, visited fewer reefs per trip, and stayed slightly shorter times at each reef than vessels that were killing and freezing their catch. In general, the two groups of vessels steamed for similar periods and distances between reefs during their trips.

## Trip Duration

Trips to supply the live fish market were consistently shorter (by up to half) than those when catch was killed (Fig. 6; Table 7). Voluntary logbook and observer data showed that less than $7.5 \%$ of live trips were longer than 9 days, compared with $60 \%$ of dead trips that exceeded 9 days. Conversely, less than $10 \%$ of dead trips were shorter than 3 days, whilst over $22 \%$ of live trips were shorter than 3 days. It is notable that trip length also varied with the source of the data, with vessels on which observers were present apparently making longer trips on average than those that provided voluntary logbook data which, in turn, reported longer trips than were estimated from the compulsory logbook data. The pattern related to the intended market for the catch was consistent despite these differences among data sources (Table 7; Fig. 6).
Information obtained from interviews with skippers is also consistent with this pattern. Average minimum and maximum trip lengths for live trips (minimum: 4.3 days, maximum: 10.5 days) were less than half those reported for dead trips (minimum: 9.7 days, maximum: 20.7 days).

Table 7: Significant effects of Market on mean trip length from several analyses. Only the statistically significant effects of highest order involving Market effects are shown. No effects of Market on trip length were significant for L3 operations ( $\mathrm{F}<1$ in all cases).
Key to Analyses: QFMA Logs - S*Y: Operations that did both live and dead trips in each season of 1994, 1995 or 1997 analysed by year; QFMA Logs - S*EC: Operations that did both live and dead trips in each season of 1994, 1995, 1996 or 1997 analysed by Effort Class over all years; QFMA Logs - MBACI: MBACI analyses of operations that changed to live and those that didn't between 1992 and 1997; QFMA Logs - L|D (L2|L3): Comapisons of operations that did only live or only dead trips in each of the years indicated (1994-1997).

| Data | Effect | F | df | Prob |
| :---: | :---: | :---: | :---: | :---: |
| Observers | Market | 21.13 | 1,21 | <0.001 |
| Voluntary Logs | Market | 27.57 | 1,29 | <0.001 |
| QFMA Logs - $\mathrm{S}^{*}$ Y | Market | 3.70 | 1,12 | 0.078 |
| QFMA Logs - S*EC | Market*Season*Effort Class | 3.72 | 2,12 | 0.055 |
| QFMA Logs - MBACI | None |  |  |  |
| QFMA Logs - L\|D - 1994 | Market | 6.01 | 1,111 | 0.016 |
| (L2) -1995 | Market | 19.98 | 1,118 | <0.001 |
| - 1996 | Market | 12.24 | 1,120 | 0.001 |
| -1997 | Market*Season | 2.89 | 1,122 | 0.092 |
| QFMA Logs - L\|D (L3) | None |  |  |  |

There was also a notable progressive decline in the difference between the durations of live and dead trips from 1994 to 1997 (Fig. 6). Note that in 1997 although the lengths of dead trips reported in the compulsory logbooks varied with season (but those of live trips did not, Market*Season effect, Table 7), the lengths of dead trips were greater than the lengths of live trips in both seasons (Fig 7).

Figure 6: Mean length of fishing trips (days) by intended market (Live, Dead) for the catch. The left figure summarises main effects of market in data from different sources. The QFMA Logs data here were from vessels that did both live and dead trips within a year. The right figure shows the main effects of market in compulsory QFMA logbook data from all L2 operations that reported either live or dead trips throughout each year. Error bars are standard errors.



Figure 7: Mean duration of fishing trips where market effects interacted with other effects. Top: L2 vessels that reported either live or dead trips in QFMA logbooks in 1997. Bottom: Interaction between effort class, season, and market for vessels that reported both live and dead trips in each season in either 1994, 1995, 1996, or 1997. Error bars are standard errors.




When operations were selected that reported both live and dead trips in each season within either 1994, 1995, 1996 or 1997 and analysed by effort class, there was a slightly more complex relationship between intended market and the duration of fishing trips (Market*Season*Effort Class interaction, Table 7; Fig. 7). Despite this interaction, live trips tended to be slightly shorter than dead trips for most operations in most seasons, though the difference was statistically significant only for effort classes $A$ and $B$ in the off-spawning season. The notable exceptions were that smaller operations (Effort Class A, 1-2 lines per day) reported longer live trips than dead trips on average during the spawning seasons of 1994, 1995, 1996 \& 1997. Live and dead trips were more similar in length for the largest operations (Effort Class C, 5-7 lines per day) than the in the other two effort classes (Fig. 7).

## Distance from Port

QFMA compulsory logbook data indicated that operations keeping their catch alive usually travelled shorter distances to their first fishing location, fished closer to port throughout their trip, and completed their trips closer to port than did operations killing their catch (Fig. 8, Table 8). Data from voluntary logbooks showed the same pattern (Table 8). The single exception in these analyses was for L3 operations (QFMA logbooks) in 1996, where the 6 live operations fished substantially further from port on average than the $250^{+}$dead operations reporting catch in that year.

Figure 8: Mean distances from nearest port to fishing sites at the beginning of a trip (top), averaged throughout the trip (middle), and at the end of a trip (bottom). All plots represent the comparison of compulsory logbook data from all operations keeping their product alive with those killing their product in both seasons of each year. Error bars are standard errors.

L2 Endorsed Operations




L3 Endorsed Operations




Table 8: Significant main effects of Market on mean distances from the nearest port to the first fishing location, on average during trips, and to the last fishing location. Results for main effects are shown only if no higher order effects involving Market were significant. N/a indicates that higher order effects were significant (see text); none - no market effects significant.
Key to Analyses: QFMA Logs - $\mathrm{S}^{*}$ Y: Operations that did both live and dead trips in each season of 1994, 1995 or 1997 analysed by year; QFMA Logs - S*EC: Operations that did both live and dead trips in each season of 1994, 1995, 1996 or 1997 analysed by Effort Class over all years; QFMA Logs - MBACI: MBACI analyses of operations that changed to live and those that didn't between 1992 and 1997; QFMA Logs - L|D (L2)/(L3): Comapisons of operations that did only live or only dead trips in each of the years indicated (1994-1997).

| Data | First Reef | Trip Average | Last Reef |
| :---: | :---: | :---: | :---: |
| Observers | None | None | None |
| Voluntary Logs | $\mathrm{F}_{1,31}=5.89, \mathrm{p}=0.021$ | $\mathrm{F}_{1,29}=3.99, \mathrm{p}=0.055$ | $F_{1,30}=3.75, p=0.062$ |
| QFMA Logs - ${ }^{*}$ Y | $\mathrm{F}_{1,10}=4.61, \mathrm{p}=0.057$ | $\mathrm{F}_{1,12}=3.75, \mathrm{p}=0.077$ | None |
| QFMA Logs - S*EC | N/a | $\mathrm{F}_{1,12}=4.20, \mathrm{p}=0.063$ | N/a |
| QFMA Logs - MBACI | N/a | N/a | N/a |
| QFMA Logs - LID - 1994 | $\mathrm{F}_{1,108}=10.16, \mathrm{p}=0.002$ | $\mathrm{F}_{1,111}=11.24, \mathrm{p}=0.001$ | $\mathrm{F}_{1,105}=9.21, \mathrm{p}=0.003$ |
| (L2) -1995 | $\mathrm{F}_{1,115}=10.94, \mathrm{p}=0.001$ | $\mathrm{F}_{1,118}=15.91, \mathrm{p}<0.001$ | $F_{1,110}=16.39, p<0.001$ |
| - 1996 | $F_{1,117}=22.38, p<0.001$ | $\mathrm{F}_{1,120}=20.88, \mathrm{p}<0.001$ | $F_{1,119}=17.09, p<0.001$ |
| -1997 | $F_{1,120}=14.28, p<0.001$ | $\mathrm{F}_{1,122}=17.44, \mathrm{p}<0.001$ | $\mathrm{F}_{1,115}=10.51, \mathrm{p}=0.002$ |
| QFMA Logs - LID - 1995 | $\mathrm{F}_{1,77}=3.27, \mathrm{p}=0.074$ | $\mathrm{F}_{1,79}=3.33, \mathrm{p}=0.072$ | $\mathrm{F}_{1,62}=3.56, \mathrm{p}=0.064$ |
| (L3) -1996 | $F_{1,128}=13.14, p<0.001$ | $\mathrm{F}_{1,132}=9.59, \mathrm{p}=0.002$ | $\mathrm{F}_{1,105}=8.77, \mathrm{p}=0.004$ |
| -1997 | $F_{1,146}=4.06, p=0.046$ | $\mathrm{F}_{1,149}=4.37, \mathrm{p}=0.038$ | $\mathrm{F}_{1,120}=3.89, \mathrm{p}=0.051$ |

Analyses of operations that supplied both live and dead markets within the same year and season indicated that the above patterns were a result of the change in market strategy, though there were indications that the pattern was in some cases moderated by either season or the effort class of the operations. When averaged over all effort classes, initial and average distances from port were less when fishing live than dead (distance to first reef: 52.5 vs 62.2 nm ; Average distance from port: 52.6 vs 63.9 nm ), though the end points of trips did not differ significantly with intended market (Table 8). When these operations were compared according to their effort class, without respect to the year of operation, fishing throughout live trips was on average closer to port than that during dead trips ( 53.1 vs 64.4 nm , Table 8). The smallest and largest operations (Effort Classes A \& C) began fishing significantly closer to port on live trips than on trips when their catch was killed (Fig. 9b), but no such effect was apparent for the operations with 3-4 lines (Effort Class B) (Market*Effort Class interaction, $\mathrm{F}_{2,10}=4.18, \mathrm{p}=0.048$ ). Moreover, operations in all effort classes ended their live trips closer to port on average than their dead trips during the off-spawning season, but stopped fishing at approximately the same distance from port for both trip types during the spawning season (Fig. 9b, Market*Season interaction, $\mathrm{F}_{1,10}=4.17, \mathrm{p}=0.046$ ).

When operations that changed from dead to live markets over several years were compared with operations that consistently killed their catch over the same periods, similar effects of intended market on distance from port were found (Fig. 9c). Distances from port to their first fishing location were similar between the two groups prior to any change to supplying the live markets. Operations that shifted to the marketing of live product, however, started fishing closer to port after this shift. Operations that continued to supply dead markets did not change their behaviour over the same period (Fig. 9c, Market*Period interaction, $\mathrm{F}_{1,87}=8.70$, $\mathrm{p}=0.004$ ). This result was consistent across effort classes. The same pattern occurred for both average distance from port throughout trips (Market*Period interaction, $\mathrm{F}_{1,90}=10.64$, $\mathrm{p}=0.002$ ) and the average distance from port to the trip end points (Market* Period interaction, $F_{1,82}=10.37, p=0.002$ ) (Fig. R4c).

Figure 9: Mean distances from nearest port to fishing sites at the beginning of a trip, averaged throughout the trip, and at the end of a trip. Plots derived from compulsory logbook data from operations that completed both live and dead trips within years (a, b), voluntary logbook data (a) or comparison of operations that changed to the live market over several years with operations that did not (c). Error bars are standard errors.
a) L2 operations fishing live \& dead in each season of either 1994, 1995 or 1997 analysed by year (irrespective of effort class) as reported in compulsory logbooks (left) and vessels returning voluntary research logbooks (right).


b) L2 operations fishing live \& dead in each season of either 1994, 1995, 1996 or 1997 analysed by effort class (irrespective of year).


c) Comparisons of L2 operations that changed to the live market with those that did not between 1992 and 1997. All trips in the Before category were dead trips, whilst those in the After category were live trips for those operations that changed to live fishing (Dead \& Live) and dead trips for those that did not. (Dead Only)




The average distances between fishing sites and the nearest port during trips on which we had observers did not differ significantly between operations keeping their catch alive and those that were killing their catch, with considerable variation among the operations within each group. The live vessels made the initial transit from port to first reef fished significantly quicker during spawning seasons than did dead vessels in spawning seasons, however (Fig. 10, Market*Season interaction, $\mathrm{F}_{1,15}=5.84, \mathrm{p}=0.029$ ).

Figure 10: Mean transit times (hours) from home port to first fishing site by live and dead vessels on which observers were present during the Off-spawning and Spawning seasons of 1996-98. Error bars are standard errors.


The vessels on which we had observers on average travelled longer distances and greater times from port to reef in 1997-98 (109nm, 16.6hr) than in 1996-97 (68nm, 9.7hr) (Main effects of Year: Distance $-\mathrm{F}_{1,16}=8.94, \mathrm{p}=0.009$, Time $-\mathrm{F}_{1,15}=4.67, \mathrm{p}=0.047$ ). A similar pattern was apparent for return transits from reef to port (1997-98-90nm, 16.2hr; 1996-97$60 \mathrm{~nm}, 9.0 \mathrm{hr})$, though the pattern was statistically significant only for the time taken for the return journey ( $\mathrm{F}_{1,7}=6.91, \mathrm{p}=0.034$ ). Variation among years was apparent also when live and dead operations were compared in each year on the basis of compulsory logbook data, but only for the live operations and most notably for the L3 operations (Fig. 8). No significant differences between 1997 and 1998 in distances to the fishing ground were apparent in the voluntary logbook information ( $p>0.1$ for all main effects and interactions involving years).

## Movements Between Reefs

Movements between reefs during trips were not consistently related to whether the trip was for live or dead markets. On trips where observers were present, the average distances moved among reefs were similar between live and dead trips in the off-spawning season but greater for live trips than for dead trips during the spawning seasons (Fig. 11, Market*Season interaction, $\mathrm{F}_{1,22}=3.10, \mathrm{p}=0.092$ ). The pattern from voluntary logbook data was more complex (Market*Season*Year interaction, $\mathrm{F}_{1,23}=4.85, \mathrm{p}=0.038$ ). In this case, live vessels on average moved further between reefs than did dead vessels in the off-spawning season of 1997, the reverse occurred during the spawning season of the same year, and reef-reef transit distances did not differ significantly between live and dead trips in 1998 (Fig. 11).
Compulsory logbook data indicated that, overall, live L2 operations transited approximately half as far on average among fishing sites during trips as did dead operations in 1995 (3.2 vs 6.4 nm ; Market main effect, $\mathrm{F}_{1,112}=3.21, \mathrm{p}=0.076$ ), but within-trip transits were more similar and did not differ significantly in most other circumstances ( $p>0.1$ ). Vessels that did trips for both live and dead markets within the same year showed the same pattern in 1995, a similar (though not statistically significant) pattern in 1997, and the reverse in 1994 (Fig. 11, Market*Year interaction, $\mathrm{F}_{1,11}=8.32, \mathrm{p}=0.006$ ). The only other effect on reef-reef transits was from effort class of L2 operations in $1997\left(\mathrm{~F}_{1,7}=2.42, \mathrm{p}=0.093\right)$, with transits increasing with effort class ( $5.1 \mathrm{~nm}, 7.2 \mathrm{~nm}, 8.0 \mathrm{~nm}$ for $1-2$ line. $3-4$ line \& $5-7$ line operations respectively). At other times, L2 operations moved on average from 6.1 to $7.3 n m$ between locations whilst L3 operations moved on average $5.0-7.3 \mathrm{~nm}$.

Figure 11: Mean transit distances between reefs during live and dead trips, based on observer data (bottom left), voluntary logbooks (bottom right) and compulsory logbook data from L2 operations (top right). Error bars are standard errors.



Steaming times between reefs were very similar over all trips in the voluntary logbook data (1.9hr) and the observer data from three of the four seasons we covered (1.9hr). The single exception was in the spawning season of 1997, when steaming times were significantly greater on live trips than on dead trips that we observed (Fig. 12, Market*Season*Year interaction, $\mathrm{F}_{1,7}=4.47, \mathrm{p}=0.049$ ).

Figure 12: Mean steaming times (hours) between reefs during trips by live and dead vessels when observers were on board. Error bars are standard errors.


## Time spent at each Location

Live vessels tended to stay at each fishing location for less time than did dead vessels (voluntary logbooks: Live - 25.0 hr , Dead - $34.4 \mathrm{hr}, \mathrm{F}_{1,32}=5.52$, $\mathrm{p}=0.025$ ) though from observer data this difference appeared trivial in 1996-97 and substantial in 1997-98 (Fig. 13, Market*Year interaction: $\mathrm{F}_{1,21}=5.94, \mathrm{p}=0.024$ ). Despite staying less time at each reef, live vessels generally stopped at fewer reefs within a trip (voluntary logbooks: mean 6.3 reefs/trip) than did dead vessels (mean 12.7 reefs/trip) ( $F_{1,29}=18.54, p<0.001$ ), reflecting predominantly the difference in trip lengths (Fig. 6). Responses from interviews with skippers were consistent with these results. Skippers of live vessels reported visiting fewer reefs per trip and staying at each reef for slightly shorter times than did skippers of operations killing their catch (reefs fished: 14.4 vs 19.1; mean stay per reef: 1.5 d vs 1.8 d ).

Figure 13: Mean duration of stays at each fishing site (reef) during live and dead trips on which observers were present. Error bars are standard errors.


## Number of Trips

The average numbers of trips reported per season in QFMA compulsory logbooks by vessels varied with intended market of their product, but often in interaction with other factors. When the mutually exclusive sets of live and dead operations were compared in each of the years 1994-1997, significant effects of market were apparent for L2 operations in 1994, 1996 and 1997 and for L3 operations in 1997 (Fig. 14). Operations keeping their catch alive made significantly fewer trips than those killing their catch in the off-spawning seasons of 1994 (L2) and 1997 (both L2 and L3), but made either similar numbers or more trips than the dead operations in the spawning seasons of those years (Market*Season interactions: L2, 1994 $\left.F_{1,111}=6.20, p=0.014 ; L 2,1997-F_{1,122}=4.37, p=0.039 ; L 3,1997-F_{1,149}=2.74, p=0.100\right)$. Moreover, although the relative lengths of the off-spawning and spawning seasons differed considerably ( 9 vs 3 months), the numbers of live trips often did not reflect this difference. This resulted in relatively greater density of live trips during the spawning seasons than in the off-spawning seasons, especially for L2 operations in 1994 and L3 operations in 1997 (Fig. 14).

In 1996, the relative numbers of trips made by live and dead operations depended on effort class and season (Market*Effort Class*Season interaction: L2, $1996-\mathrm{F}_{2,120}=5.58$, $\mathrm{p}=0.005$ ). There was no consistent pattern in the relative numbers of trips made per season by live and dead operations across effort classes or seasons, however (Fig. 14). Live operations in Effort Class A made fewer trips than dead operations in Effort Class A during the offspawning season, but the reverse was apparent in the spawning season (Fig. 14). Live operations in Effort Class C tended to make fewer trips in both seasons than dead operations, though the difference was statistically significant only in the off-spawning season. Live operations in Effort Class B, however, made more trips than those killing their catch in the off-spawning season, but both live and dead operations made similar numbers of trips in the spawning season (Fig. 14). For most operations, considerably more trips were made in the off-spawning than in the spawning season, as would be expected from the lengths of the seasons.

Figure 14: Mean number of trips by live and dead operations reported in QFMA compulsory logbooks. Plots represent L2 operations unless otherwise indicated. Error bars are standard errors.





When the same operations were compared over several years before and after the start of the export trade in live food fish, the number of trips (in the off-spawning seasons) did not differ with the shift to keeping catch alive (Market*Period, $\mathrm{F}_{1,90}=1.75$, $\mathrm{p}=0.190$ ), but did differ with effort class (Main effect of Effort Class, $F_{2,90}=2.53, \mathrm{p}=0.085$ ). Operations with only 1-2 lines made fewer trips (mean 7.5 trips) than those with either 3-4 lines (10.2 trips) or 5-7 lines (11.2 trips). Vessels that did both live and dead trips within both seasons of 1994, 1995 or 1997 did fewer trips on average when keeping their catch alive than when killing their catch in the off-spawning seasons, but similar numbers of trips of each type in the spawning seasons (Fig. 15). This result is consistent with that for the analyses of the fleet in general in each year.

Figure 15: Mean number of trips by L2 operations that reported both live and dead trips in each season in either 1994, 1995 or 1997 in compulsory logbooks Error bars are standard errors.


Responses from interviews with skippers indicated that operations marketing live fish on average made more than twice the number of trips per year ( 24.1 trips/yr) than operations marketing their product frozen (mean 10.4 trips/year).

## Days Off Between Trips

The number of days between trips did not generally vary significantly with the intended market of the catch from the following trip. The single exception occurred for those L2 operations with 5-7 dories (Effort Clas C) that did both live and dead trips within the same seasons, in which case periods in port before dead trips during the off-spawning season were about twice those before live trips in the same season (Fig. 16) (Market*Effort Class*Season interaction, $\mathrm{F}_{2,12}=3.30, \mathrm{p}=0.072$ ). More generally, L 2 operations averaged between 18 and 30 days off between trips, although these estimates were characterised by high variances because many operations apparently fished only intermittently.

Figure 16: Mean number of days in port between trips. Data are from L2 operations that reported both live and dead trips in each season in either 1994, 1995 or 1997 in QFMA compulsory logbooks. Error bars are standard errors.



## Dory Effort Dynamics

The dynamics of fishing from dories within each day also were affected by the state in which the catch was kept, though few of these effects were consistent over seasons, sessions or years.

## Session Duration

The duration of sessions (time spent away from the primary boat continuously) varied slightly between live and dead fishing and over years for live fishing. Live sessions were slightly shorter on average than dead sessions in 1996-97, but increased in length in 1997-98 to the point where they were of slightly longer duration than dead sessions (Fig. 17) (Market*Year interaction: Observers - $\mathrm{F}_{1,22}=4.01, \mathrm{p}=0.06$ ). In both cases, however, the effects were minor $(\sim 7 \%)$, with the overall average session duration being 3.8 hours. Session duration was slightly greater in the mornings (4.3hr) than in the afternoons (3.3hr) and this effect was consistent for all fishers (Main effect of Session: Observers - $\mathrm{F}_{1,24}=29.73, \mathrm{p}<0.001$ ). Both of these patterns were accentuated slightly when only the time spent fishing per session was considered, suggesting that live fishers spent slightly more time 'searching' for their fishing sites in 1996-97, and all fishers spent less time actually fishing (as opposed to searching) in the afternoons than in the mornings.

Figure 17: Mean duration of fishing sessions (hours) by dory fishers keeping their catch alive and killing their catch in each of two years. Data were from research observers accompanying the dory fishers. Error bars are standard errors.


## Hang Numbers and Duration

Live fishers consistently fished at approximately $30 \%$ more sites (hangs) within each session than did dead fishers ( 6.9 vs $5.3 ; \mathrm{F}_{1,22}=4.78 \mathrm{p}=0.04$ ). As might be expected from this behaviour, both the average duration of hangs and the average fishing time per hang were significantly shorter for fishers keeping their catch alive than for those killing their catch (Fig. 18 , Hang duration $-F_{1,23}=3.75, p=0.07$, Fishing time $-F_{1,24}=4.47, p=0.05$ ).

Figure 18: Mean hang duration (left) and fishing time per hang (right) for fishers keeping their catch alive or killing their catch. Data were from research observers accompanying the dory fishers. Error bars are standard errors.



## Searching Times

Average times spent searching for each hang location also varied with the intended market of the catch and with season (Market*Season interaction: $F_{1,23}=3.60, p=0.07$ ). Fishers retaining catch alive spent longer searching for hangs than did fishers supplying dead fish in the spawning season, but the reverse was true in the off-spawning season (Fig. 19). Further, all fishers on average spent slightly less time searching for hangs during AM sessions than in PM sessions in 1996-97, but equal times searching in both sessions in 1997-98 (Fig. 19) (Session*Year interaction: $\mathrm{F}_{1,23}=3.22, \mathrm{p}=0.08$ ).

Figure 19: Mean time spent searching for a new hang by dory fishers who kept their catch alive and those who killed their catch during the spawning and off-spawning seasons (left) and between AM and PM session in two years (right). Data from research observers accompanying dory fishers. Error bars are standard errors.



## Set Times

The times taken to 'set' each hang, being the period from deciding where to fish and actually beginning fishing, tended to be similar for live fishers and dead fishers, although this pattern was complicated by interaction with the effects of year, season and session (Market*Season*Session*Year interaction: $\mathrm{F}_{1,21}=5.01, \mathrm{p}=0.04$ ). Set times were less when fish were to be kept alive than when they were to be killed during AM sessions in the offspawning season of 1996-97 and both seasons of 1997-98 and during PM session in the offspawning seasons of both years (Fig. 20). Such apparent differences were statistically significant, however, only during both sessions in the off-spawning seasons of 1997-98. Set times were significantly greater for live than for dead fishers in both AM and PM sessions of the spawning season in 1996-97 (Fig. 20).

Figure 20: Mean time spent setting the anchor and dory prior to fishing at each hang by dory fishers who kept their catch alive and those who killed their catch during AM (left) and PM (right) sessions of spawning and off-spawning seasons over two years. Data were from research observers accompanying the dory fishers. Error bars are standard errors.



## Movement Between Hangs

Patterns in movements between hangs were also complex. Whilst mean distances moved by live fishers tended to be greater than those moved by dead fishers during the spawning seasons of both years (Fig. 21), neither effect was statistically significant. Conversely, live fishers tended to move shorter distances than dead fishers in the off-spawning seasons, with the effect being statistically significant in 1997-98 (Fig. 21) (Market*Season*Year interaction: $\mathrm{F}_{1,21}=3.32, \mathrm{p}=0.08$ ). Overall, the average distance moved between hangs was approximately $0.45 \mathrm{~nm}(\sim 900 \mathrm{~m})$.

Figure 21: Mean distances moved between hangs by fishers who kept their catch alive and those who killed their catch during the spawning and offspawning seasons of 1996-97 and 1997-98. Data were from research observers accompanying the dory fisheries. Error bars are
 standard errors

## Fishing Depths

Finally, the depths at which dory fishers fished varied with the intended market for their catch, though again in interaction with session, year and season ( $\mathrm{F}_{1,20}=3.12, \mathrm{p}=0.09$ ). Fishers keeping their catches alive fished in significantly shallower water in both AM and PM session during the off-spawning seasons of both 1996-97 and 1997-98 (Fig. 22). In the spawning season of 1996-97, however, live fishers fished in deeper water on average than did dead fishers, irrespective of session, whilst in the spawning season of 1997-98 fishing depth did not differ significantly with the intended market for the catch (Fig. 22).

Figure 22: Mean fishing depths for fishers who kept their catch alive and those who killed their catch during the spawning and off-spawning seasons of 1996-97 and 199798. Results are presented separately for AM sessions (left) and PM sessions (right). Data were from research observers accompanying the dory fishers. Error bars are standard errors.


## Effects on Catch Rates

## Catch Rate Estimates from On-board Observers

Catch per unit effort (CPUE) calculated from observer recorded data in dories varied significantly with the intended market of the catch for catches of coral trout and demersal byproduct species. Effects of market were generally dependent on other factors, however, including session, year and season.

## Hang Level CPUE

When only fishing times per hang were used for calculations, catch rates of coral trout being kept alive were either similar to or greater than those when fish were being killed, dependent on session and year (Market*Session*Year interaction: $\mathrm{F}_{1,21}=4.82, \mathrm{p}=0.04$ ). Live CPUE was significantly greater than dead CPUE in AM sessions during 1997-98, but did not differ significantly from dead CPUE at any other times (Fig. 23). CPUE of coral trout also varied with session for both live and dead trips, but the patterns in variation also varied with year (Fig. 23).

Hang level catch rates of mixed reef species also were significantly greater (by ~ 200\%) on live trips than on dead trips in PM sessions in 1996-97, but not at other times (Fig. 23) (Market*Session*Year interaction: $\mathrm{F}_{1,21}=4.72, \mathrm{p}=0.04$ ). Hang level catch rates of red throat emperor (Lethrinus miniatus), however, were significantly greater over all on dead trips (2.1 fish/line-hour) than on live trips ( 0.9 fish/line-hour) $\left(F_{1,21}=9.79, p=0.005\right)$.

Figure 23: Hang level CPUE from observations by research observers in fishing dories. Effort was the time spent actually fishing at each hang, excluding the times spent searching for and setting up the hang. Average CPUE is shown for coral trout (left) and mixed demersal reef species (right) in AM and PM sessions in 1996-97 and 1997-98 on trips when catch was killed or kept alive. Error bars are standard errors.



## Session Level CPUE

When CPUE was calculated from the accumulated catch per session from dories in which observers were present and indexed by the accumulated actual fishing time in a session, CPUE of coral trout was greater on live than on dead trips in both sessions and both years, despite different relationships among sessions for different product types (Fig. 24; Market*Session*Year interaction: $\mathrm{F}_{1,21}=5.86, \mathrm{p}=0.025$ ). The pattern changed little when catch was indexed against the total duration of each session (rather than only the time spent actually fishing), except that live CPUE fell below those from dead operations in AM sessions in 1996-97 (Fig. 24; Market*Session*Year interaction: $F_{1,21}=8.74, p=0.008$ ).
When catches from all dories on the observer trips (including those on each day that did not have observers on board) were considered, the result changed. In this case, there were no statistically significant effects of market on catch rates of coral trout ( $p>0.1$ for all effects), although the average CPUE on dead trips appeared greater than that on live trips (2.6 vs 1.9 fish/line-hour, $\mathrm{p}=0.184$ ). The difference between these and previous results is likely to be attributable to the difference between analysing all catch (including releases) from observer data but only harvested catch when all dories were considered since release rates were greater on live trips than on dead trips (see below).

Figure 24: Session level CPUE of coral trout by market category, year and session from observations by research observers in fishing dories. Effort was the time spent actually fishing during each session (left) or the total time spent away from the primary vessel (right). Error bars are standard errors.



Catch rates of red throat emperor based on actual fishing times at session level were greater for dead trips than for live trips in both AM \& PM sessions (Fig. 25), despite a Market*Session interaction ( $\mathrm{F}_{1,21}=3.09, \mathrm{p}=0.093$ ). The interaction arose because catch rates were lower in PM than in AM sessions on dead trips, but did not vary with session on live trips (Fig. 25). When total catch was indexed to total session time (as it would be for estimates of CPUE from voluntary logbooks), only the main effect of market was significant, with an average of 1.8 L . miniatus being landed per line-hour on dead trips and 0.7 fish per line-hour landed on live trips ( $\mathrm{F}_{1,21}=15.07, \mathrm{p}=001$.
As with hang level data, catch rates of mixed fish in dories where observers were present showed greater catch rates on live trips than on dead trips ( 5.1 fish/line-hour vs 3.4 fish/linehour, $\mathrm{F}_{1,21}=4.43, \mathrm{p}=0.048$ ). When catches from all dories (including those without observes present and comprised of only the fish that were retained) were considered, however, the pattern was reversed (Dead=4.3 fish/line-hour, live $=1.5$ fish/line-hour, $\mathrm{F}_{1,24}=16.46, \mathrm{p}<0.001$ ).

Figure 25: Session level CPUE of red throat emperor from observations by research observers in fishing dories. Effort was the time spent actually fishing during each session. Error bars are standard errors.


## Released Coral Trout

The rate of release of coral trout (releases per unit of effort) followed a very similar pattern to the catch rates of coral trout (Market*Session*Year interaction: Fishing time - $\mathrm{F}_{1,21}=4.47$, $\mathrm{p}=0.05$; Session time - $\mathrm{F}_{1,21}=7.08, \mathrm{p}=0.01$ ), though the differences between live and dead trips were slightly more exaggerated for released fish than for overall catch rates (Fig. 26).

Figure 26: Session level rates of releases of coral trout per unit effort (RPUE) from observations by research observers in fishing dories. Effort was the time spent actually fishing during each session (left) or the total session time (right). Average RPUE in AM and PM sessions in 1996-97 and 1997-98 on trips when catch was killed or kept alive are shown. Error bars are standard errors.



## Success Rates of Line Sets

Finally, the proportion of baits set that resulted in catch varied significantly but by small amounts depending on the intended market of catch, session, year and season (Market*Session*Year interaction - $\mathrm{F}_{1,21}=5.26, \mathrm{p}=0.03$; Market*Session*Season interaction $\left.F_{1,21}=3.34, p=0.08\right)$. In most cases, the success rate of sets on live trips were either similar to or slightly lower than on dead trips (Fig. 27).

Figure 27: Proportion of lines set that resulted in catch (= were successful) per session by fishers observed by observers during live and dead trips in 1996-97 and 1997-98 (right) and in spawning and off-spawning seasons (right). Error bars are standard errors.



## Catch Rate Estimates from Voluntary Logbooks

Data from voluntary logbooks indicated that catch rates (kg/dory/session) of coral trout did not differ significantly with the intended market of the catch, but did differ with session ( $\mathrm{AM}=9.7, \mathrm{PM}=6.1, \mathrm{AD}=8.9 \mathrm{~kg} /$ dory $/$ session; $\mathrm{F}_{2,55}=6.77, \mathrm{p}=0.002$ ). Catch rates of mixed reef species (including red throat emperor), however, on average were $60 \%$ greater on dead trips than on live trips (14.6 vs 9.1 fish/dory/session, Market main effect $-F_{1,34}=4.85, p=0.034$ ).

## Catch Rate Estimates from QFMA Compulsory Logbooks

Catch rates (kg fish/line/day) from QFMA compulsory logbooks also showed significant variation with the intended market of the catch, though often in interaction with other effects. In general, the compulsory logbook data indicated that mean and maximum catch rates of coral trout and mixed reef species were lower on live trips than on dead trips.

When those boats that supplied both live and dead markets in each season of 1994, 1995 1997 were considered, mean and maximum catch rates of coral trout varied with Market and Year (Mean CPUE - $\mathrm{F}_{2,12}=3.43, \mathrm{p}=0.066$; Mean Maximum CPUE - $\mathrm{F}_{2,12}=6.20, \mathrm{p}=0.014$ ). In 1994 and 1995 reported catch rates of coral trout on dead trips were greater than on live trips, with the difference in average catch rate diminishing from $45 \%$ to $25 \%$. In 1997, catch rates on live trips appeared greater than on dead trips (Fig. 28), but the differences were not statistically significant for either the mean of the average maximum CPUE.

Figure 28: Average (left) and mean maximum (right) CPUE of coral trout derived from QFMA compulsory logbook data for L2 operations that supplied both live and dead markets in both spawning and off-spawning seasons in 1994, 1995 or 1997. Error bars are standard errors.



When these same operations were analysed by Effort Class (across years), average maximum catch rates of coral trout varied with Market and Effort Class (Market*Effort Class interaction $-\mathrm{F}_{2,12}=4.865, \mathrm{p}=0.029$ ). Catch rates were significantly greater on live trips than on dead trips by operations using only 1-2 lines per day (Effort Class A), did not differ significantly with intended market on operations using 3-4 lines per day (Effort Class B), and were significantly greater on dead trips than on live trips on operations using 5-7 lines per day (Effort Class C) (Fig. 29).

Figure 29: Average maximum catch rates of coral trout derived from QFMA compulsory logbook data for L2 operations that supplied both live and dead markets in both spawning and off-spawning seasons in either 1994, 1995 or 1997 and analysed by effort class. Error bars are standard errors.


Mean CPUE and mean maximum CPUE of mixed reef fish from these operations also varied with the intended market of the catch, in each case without interaction with other factors.
(Market main effects: Mean CPUE - $\mathrm{F}_{1,11}=12.70, \mathrm{p}=0.004$; Mean maximum CPUE -
$\mathrm{F}_{1,11}=21.25, \mathrm{p}=0.001$ ). Mean and average maximum CPUE of mixed fish on dead trips (14.6
\& $24.6 \mathrm{~kg} / \mathrm{line} /$ day respectively) were consistently greater than on live trips ( 7.9 \& 11.9 $\mathrm{kg} / \mathrm{line} /$ day respectively).
Effects of changed market destinations also affected catch rates of coral trout and mixed reef fish on those operations that were tracked from before to after their switch to live fishing when compared to operations that did not change markets over the same periods
(Market*Period interactions: Coral trout, mean CPUE - $\mathrm{F}_{1,85}=3.60, \mathrm{p}=0.061$; Coral trout,
maximum CPUE - $\mathrm{F}_{1,84}=6.29$, $\mathrm{p}=0.014$; Mixed reef fish, mean CPUE $-\mathrm{F}_{1,78}=3.72, \mathrm{p}=0.057$; Mixed reef fish, maximum CPUE - $\mathrm{F}_{1,75=8.74, \mathrm{p}=0.004 \text { ). Prior to the switch to live fishing, }}$ operations that subsequently switched had higher mean and maximum catch rates of coral trout than those operations that subsequently continued to kill their catch (Fig. 30). After changing to the live market, however, both mean and maximum catch rates of coral trout dropped by about 50\%, whilst those on the 'dead only' operations changed little (Fig. 30). Mean and maximum catch rates of mixed reef species showed an even larger reduction with the switch to marketing most of the catch (of coral trout) alive that was not matched by changes on operations that continued traditional marketing strategies (Fig. 30).

Figure 30: Average (left) and mean maximum (right) catch rates of coral trout (top) and mixed reef fish (bottom) derived from QFMA compulsory logbook data for L2 operations that switched from killing their catch to keeping their catch alive and those that continued to kill their catch over the same period. 'Before' refers to the two years between 1992 and 1994, before operations switched to keeping their fish alive, whilst 'After' refers to two years between 1995 and 1997. Error bars are standard errors.


When the mutually exclusive groups of L2 operations that supplied live and dead markets were compared in each year, catch rates of coral trout on dead trips were again found to be greater than those on live trips in all years. The magnitude of difference between overall mean and mean maximum CPUE on live and dead trips decreased progressively from 1994 to 1997 (Fig. 31), with differences being statistically significant in 1995 (Mean $-F_{1,111}=5.44$, $\mathrm{p}=0.022$; Maximum $-\mathrm{F}_{1,110}=7.11, \mathrm{p}=0.009$ ) and 1996 (Mean $-\mathrm{F}_{1,119}=4.17, \mathrm{p}=0.043$; Maximum $-\mathrm{F}_{1,118}=4.44, \mathrm{p}=0.037$ ). In 1997, the difference in average maximum CPUE was significant only during the off-spawning season (Fig. 31; Market*Season interaction, $F_{1,117}=4.95$, $\mathrm{p}=0.028$ ).

Figure 31: Average (left) and mean maximum (right) CPUE of coral trout from L2 operations that kept their catch alive and those that killed their catch in 1994-97 (top) and in the spawning and off-spawning seasons of 1997 (bottom). Error bars are standard errors.




By contrast, catch rates of coral trout were significantly greater on live trips than on dead trips by L3 operations in 1996 and 1997, the only years in which there were more than 5 operations reporting substantial amounts of live product ${ }^{5}$ (Fig. 32; Main effects of Market, Mean CPUE: $1996-\mathrm{F}_{1,110}=11.48, \mathrm{p}=0.001$; $1997-\mathrm{F}_{1,126}=11.17, \mathrm{p}=0.001$; Mean maximum CPUE: $\left.1996-F_{1,110}=26.57, p<0.001 ; 1997-F_{1,126}=9.11, p=0.003\right)$.

Figure 32: Average (left) and mean maximum (right) CPUE of coral trout from L3 operations that kept their catch alive and those that killed their catch in 1996 and 1997. Error bars are standard errors.



Mean and maximum CPUE of mixed reef fish on dead trips by L2 operations were generally more than twice those on live trips in most years (Fig. 33, Main effects of Market, Mean CPUE: $1994-\mathrm{F}_{1,101}=2.62, \mathrm{p}=0.109$; $1995-\mathrm{F}_{1,105}=5.10, \mathrm{p}=0.026$; $1996-\mathrm{F}_{1,109}=15.05$, $\mathrm{p}<0.001$; $1997-\mathrm{F}_{1,112}=19.21, \mathrm{p}<0.001$; Mean maximum CPUE: 1994- $\mathrm{F}_{1,99}=4.66, \mathrm{p}=0.033$; $1995-F_{1,102}=10.11, \mathrm{p}=0.002 ; 1996-\mathrm{F}_{1,108}=20.09, \mathrm{p}<0.001$; 1997- $\mathrm{F}_{1,109}=23.12, \mathrm{p}<0.001$ ).
A similar pattern in catch rates of mixed reef species was evident on L3 operations in 1997 (Mean CPUE, Live=9.76, Dead=36.32, $\mathrm{F}_{1,131}=3.58, \mathrm{p}<0.061$ ), though not in earlier years.

[^4]Figure 33: Average (left) and mean maximum (right) CPUE of mixed reef fish from all operations that kept their catch alive and those that killed their catch in each of four years. Error bars are standard errors.



## Effects on Catch Composition

## Proportion of Coral Trout in Catch

When catches from all dories on observer trips were considered, the proportion of total catch for which coral trout accounted was consistently related to the intended market, being 50$100 \%$ greater on live trips than on dead trips despite a significant Market*Year*Session interaction (Fig. 34, $\mathrm{F}_{1,19}=5.34, \mathrm{p}=0.032$ ). The proportion of the catch from observed dories for which coral trout accounted varied with intended market, season, session and year ( $\mathrm{F}_{1,21}=3.24, \mathrm{p}<0.087$ ). In all instances but one (PM sessions in the spawning season of 1996-97), however, coral trout comprised a significantly greater proportion of catch when fish were being kept alive than when the catch was being killed (Fig. 34). The difference in proportion was greatest in the spawning season of 1997-98, when coral trout comprised over $50 \%$ of the catch on live trips but less than $25 \%$ of the catches on dead trips (Fig. 34).

Figure 34: Average proportions of catches per session comprised of coral trout. The figures below are based on observer records from dories in which they were present, whilst the figure to the right represents data from all dories from trips accompanied by a research observer. Error bars are standard errors.




The proportion of coral trout in the catch reported in voluntary logbooks also varied with intended market, season, year and session ( $F_{2,50}=5.05, \mathrm{p}=0.010$ ). Despite this apparent complexity, for AM, PM and All Day (AD) sessions in the off-spawning seasons of 1997 and 1998 and the spawning season of 1997 coral trout comprised significantly more of the catch on live trips than on dead trips (Fig. 35). In the spawning season of 1997, coral trout comprised over twice the proportion of catch on live trips as that on dead trips (Fig. 35).

Figure 35: Proportions of coral trout in catches reported in voluntary logbooks plotted by session (AM, PM \& AD - All Day), year and season. Error bars are standard errors.



## Colour of Coral Trout

The composition of coral trout catches also varied with their intended market, again usually in interaction with other factors. The proportion of the $P$. leopardus catch that was red in colour was generally about $1.5-2$ times greater on dead trips than on live trips, though the effect varied with the other factors we considered (Fig. 36; Market*Year*Session interaction, $\mathrm{F}_{1,19}=5.41, \mathrm{p}=0.032$; Market*Season*Session interaction, $\mathrm{F}_{1,19}=4.59, \mathrm{p}=0.045$ ).

Figure 36: Proportions of red coral trout in catches observed by researchers during live and dead trips. Mean proportions are shown for AM and PM sessions in the spawning and off-spawning seasons over 2 years (left) and averaged over both seasons in each year (right). Error bars are standard errors.



## Size of Coral Trout

The relative sizes of coral trout also varied with the intended market, with the average proportion of under-sized (and released) coral trout being significantly greater overall on live trips ( 0.36 ) than on dead trips ( 0.29 ) ( $\mathrm{F}_{1,27}=2.93, \mathrm{p}=0.100$ ).
Significant differences between live and dead trips also occurred for the proportion of small and large legal sized coral trout in the catch, though these effects varied with year (Market*Year interaction: Small $-\mathrm{F}_{1,26}=5.33, \mathrm{p}=0.03$ : $\mathrm{F}_{1,25}=5.93, \mathrm{p}=0.02$ ). Small coral trout comprised relatively less of the catch on live trips than on dead trips in 1996-97 but the reverse was the case in 1997-98 (Fig. 37). In each case, the proportions differed by approximately $10 \%$. These patterns were reversed for large coral trout, but the magnitudes of the effect of intended market were far greater for large coral trout than for small coral trout, especially in 1997-98 (Fig. 37).

When estimated for catches from all dories, the proportions of small coral trout also varied with trip type, but in interaction with season ( $\mathrm{F}_{1,6}=4.83, \mathrm{p}=0.07$ ) and session ( $\mathrm{F}_{1,8}=3.49$, $\mathrm{p}=0.10$ ). Mean proportions of small coral trout in catches did not differ significantly between
live and dead trips in the off-spawning season or during AM sessions, but were greater for dead than for live trips during the spawning seasons and PM sessions (Fig. 37).

Figure 37: Relative size composition of catches of coral trout (all species) from dories on which observers were present (top) and all dories (bottom) during live and dead trips in 1996-97 and 1997-98. Mean proportions of the catch that were small ( $\sim 38<43 \mathrm{~cm} \mathrm{TL}$ ) are shown on the top left and both bottom figures and proportions that were large ( $>50 \mathrm{~cm} \mathrm{TL}$ )are shown on the top right. Error bars are standard errors.





## Discussion

The results of analyses of data from all sources showed significant and often considerable consequences of a change in marketing strategy on the dynamics of effort in the GBR commercial reef line fishery. When keeping catch alive, commercial fishing operations tended to make shorter trips, remained closer to ports during those trips, and spent shorter periods at fishing sites than they or their counterparts did when killing their catch. There also tended to be fewer live trips than dead trips per operation at certain times of year. In other respects, such as periods in port between trips and distances travelled between fishing locations, fishing dynamics generally were not affected by the change in handling and market strategy. Changes in fishing dynamics were apparent also at the level of individual fishers, with those targeting fish for live markets tending to fish for shorter periods per hang and session, make more returns to their primary vessels (meaning more fishing sessions per day), move more often, and spend more time searching for fishing sites than fishers killing their catch.
Many of these results were qualitatively consistent across all the sources of data we analysed. It is noteworthy, however, that the trips on which we had observers were of substantially longer duration in general than those reported from both the voluntary and compulsory logbooks. We cannot unequivocally distinguish whether this represented mainly bias in the trips on which we had observers or biases in the reporting of trips in logbooks. The consistency in results across the large number of operations that kept voluntary and QFMA compulsory logbooks suggests that the bias was likely to have been in the trips on which we had observers, assuming that there was no wholesale, uniform bias in the reporting by the entire fleet. The trips on which we placed observers were almost all on vessels that were large by fleet standards, in the largest effort class, made regular trips, and among the most experienced operations in the fleet. This bias arose because most of the smaller operations did not have a berth for an observer and it proved difficult to arrange trips with intermittent operators (most of whom also operated small vessels). It seems likely, therefore, that the results from observer trips were quantitatively representative only of the most active, and perhaps larger, operations in the fleet. Anecdotal evidence from the fleet and personal observations indicate that the operations of dories from primary vessels during trips are relatively uniform across all classes of vessel in the reef line fishery. We suggest, therefore, that observer observations on dories were more likely to be typical of the fleet than were observations of primary vessel operations (especially with respect to trip lengths).

The changes in primary vessel operations we did identify were probably driven by a combination of logistic and market considerations. Keeping fish alive requires that large amounts of water be carried on vessels, with the result that holding capacity of vessels for live product is considerably less than if the product is frozen. The greater cargo (water + fish) may decrease the efficiency of steaming long distances during live trips, especially since the amount of product that can be accumulated before having to return to port may be substantially less than for dead trips. Further, especially in the earlier years of the change to supplying the live markets, considerable anecdotal evidence suggests that there were sharply increased risks of disease and death of live fish after 5-6 days on vessels. These factors would have highlighted two important financial risks for the live operations in the face of very unpredictable beach prices that would not have existed for the dead operations. Firstly, if husbandry problems began to occur during a trip it would be important to get the fish to buyers as quickly as possible to minimise the risk of having to kill the catch and suffer the lower beach prices for frozen product. Being closer to port could make substantial difference to the costs of such losses of live fish. Second, in the face of dropping beach price, the costs of operation during a trip would be critical to the potential for profit. Hence, making trips of shorter distance, and thus being closer to port, may represent a strategy to maximise the opportunity to return to port quickly before prices drop further and thus minimise the impact on profits of the operating costs of steaming. This might be especially
important for smaller operations that have more limited holding capacity and slower steaming speeds.
The relatively fewer live trips made during non-spawning seasons, or conversely the relatively greater density of trips in the spawning season, might also be related to logistic and market considerations rather than to spawning of the main target species, $P$. leopardus. For example, some fishers allege that ripe fish are prone to spawn on board and that the presence of spawn in the tanks rapidly depletes available oxygen in the tanks, reputedly resulting in mass mortality of the fish ${ }^{6}$. The spawning season occurs, however, in the austral spring-early summer and coincides with both the calmest weather and the period leading up to Christmas, Julian New Year, and the Chinese New Year. These are times of high demand and high market prices for live reef fish in the main Asian markets, and correspondingly high beach prices in Australia. The expectation of higher prices is likely to mean that fishers are more likely to take the added risks associated with selling their product live than at other times of the year, when there is far smaller difference between beach prices for live and dead product. The coincidence of higher prices with calmer weather also means that the risk of stress to fish arising from steaming in rough seas and consequent losses of fish might be less than at other times of the year, further motivating fishers to make live rather than dead trips.
The differences in behaviours within trips by both the primary boats and the dory fishers are likely to be related to the selectivity of the buyers of live fish and the attitudes of skippers and crew. The market for live fish from Australia is highly selective for serranids, especially P. leopardus and Cromileptis altivelis, and some wrasses, especially Chelinis undulatus (Lau and Parry-Jones 1999). Consequently, many of the lutjanids, lethrinids and other taxa routinely sold as fillet are not currently saleable alive in Australia. If such fish are caught by dory fishers, they attract substantially lower pay per piece and require processing at the end of each day, prior to being packed and frozen. These features provide incentives for fishers to minimise the catch of such species and actively seek species that will be sold alive. Accordingly, the higher searching times, shorter fishing times, and more frequent movements among hangs by dory fishers on live trips perhaps reflects more targeted searching for high value species. The higher proportion of coral trout in catches and the substantially lower CPUE of by-product species on live trips than on dead trips is also suggestive of more targeted fishing by fishers keeping their catch alive.
Dory fishers often use 'view buckets' to look underwater and locate sites where they expect to catch coral trout with minimum catches of other species, and to minimise the time spent at sites where there is a greater abundance of less desirable species. Fishers fishing for live product also tended to fish over a shallower depth range than those killing their catch. This is likely to reflect primarily a desire to minimize barotrauma, and associated stress and risk of death of fish. It may also be the result of the ability of fishers to more effectively locate and target areas or habitat types associated with higher abundance of higher value target species in the shallow depths and avoid spending time catching less desirable species. In contrast, dory fishers fishing on dead boats may continue to fish at a hang if the catch rate of other species, particularly Lethrinus miniatus, remains high, as the price differential between these species and $P$. leopardus is substantially less than when coral trout are being sold alive.
The differences in effort characteristics related to the intended market for the fish we have documented are likely to be under-estimates of the real effects, at least where those estimates are derived from compulsory logbooks. The trade in live fish arose relatively quickly on the GBR and formal acknowledgment of live fish as a product category did not appear in the structure of QFMA compulsory logbooks until the second half of 1997. Thus, it was at fishers' discretion as to how they recorded their live fish in their logbooks. Clearly,

[^5]many fishers indicated that their catch was live, but we know of others who entered their live catch under the nearest appropriate category indicated in the logbooks (usually 'whole', meaning dead, whole fish). Further, since most of the fish marketed alive is exported, fishery independent estimates of the live fish catch are available from the Australian Quarantine Inspection Service (AQIS). These figures indicated that the catch of live fish reported in the QFMA compulsory logbooks was only about $65 \%$ of what AQIS records showed had been exported in 1997 (M. Elmer, pers. com), and had been less in previous years. This misreporting would have resulted in some operations that were in fact supplying the live market being classified as 'dead' in our analyses, precipitating greater similarity between the two categories than would have been expected had all operations been correctly classified.
Operations that kept their catches alive also exhibited reductions in catch rates of both coral trout and by-product species compared to their catch rates and those of their peers when killing their catch. Further, the shift to live markets apparently resulted in more targeted harvest of selected species (see above). Whilst these features of live fishing should generally be advantageous to the resource under prudent management, the relatively higher rates of capture and release of under-size fish on live trips may be cause for some concern in post release mortality is significant. This potential impact might be offset, however, by the tendency for fishers supplying the live market to fish in shallower water than those killing their catch. Barotrauma is potentially a major cause of post-release mortality and fish released after capture from shallower water are likely to be less affected by barotrauma than those released after capture from deeper water.
The growth of the trade in live fish in the face of the reduced CPUE also indicates that the commercial fishery can tolerate considerably reduced catch rates given appropriate market conditions, even when those markets are extremely labile. This phenomenon should be considered carefully in future evaluations of the fishery. Continued harvest at increased levels of effort in the reef line fishery that remains economically sustainable when catch rates are significantly reduced has the potential to result in considerable growth overfishing of the (size regulated) stocks.
It is noteworthy that the differences in catch rates between live and dead trips reported in the QFMA compulsory logbooks diminished with time. On inspections, this diminution was attributable to declining catch rates on dead trips compared with relatively stable CPUE on live trips. The stable CPUE for live operations may reflect limitations of handling times for the fish and may be unlikely to rise above those levels reported here. In the face of stable CPUE for live trips, there are at least two potential explanations for the progressive convergence of catch rates between live and dead trips. First, the declining CPUE in on dead trips might indeed reflect declining stocks of some species. Second, and equally plausible, however, the decline might reflect the growth in the trade in live fish by those operators that failed to indicate in their logs that their catch was being sold alive. This mis-reporting would tend to reduce overall catch rates in the 'dead' trips and the degree of reduction would increase with increases in trade in (incorrectly reported) live fish. Either scenario signals the need for improved reporting of live fish in the compulsory logbooks and for explicit consideration of the intended market for catch when analysing logbook data. The latter scenario should be corrected by the issuing of logbooks by QFMA in mid 1997 that explicitly catered for the reporting of live fish.
The changes in fishing practices we describe have the potential to impact on the performance of management of the fishery. Reductions in trip lengths and actual fishing time combined with little change in the periods in port between trips might be expected to result in a net reduction in fishing effort. The tendency to fish in shallower water when keeping catch alive is likely to mean that a proportion of the stock (in deeper water) is less exploited than by traditional practice. The higher beach prices for live fish, however, are likely to provide considerable incentives for the activation of latent effort in the fishery from previously incidental or inactive operations. Considerable increases in reported effort in the commercial reef line fishery between 1995 and 1998 suggest that the latter substantially outweighed the
former, although it is difficult to verify the degree to which these increases in effort were primarily the result of the live fish trade or other forces. Concurrent other events that might have stimulated real or reported increases in effort included restrictions on other fisheries in the GBR region and the instigation of a review of management strategies for the line fishery.
The tendency for live fishing effort to be focused on areas nearer international airports, at least initially, and the tendency of operations fishing live to remain closer to ports may result in localised increases in fishing mortality, and possibly localised over-exploitation. Had there been no net increase in fishing effort, such concentrations of live fishing effort would be expected to alleviate fishing pressure elsewhere and thus might not represent serious threats to the stock in its entirety, despite possible localised issues. Combined with the observed increases in effort overall, however, any localised concentration of effort is cause for concern. This risk may be alleviated as improved husbandry and technology (e.g., closed circulation holding systems) allow higher stocking densities and reduce the risks of holding fish on board for longer periods, allowing longer trips to more remote locations by the larger vessels. The spread of live fishing effort further away from Cairns in 1996 and 1997 suggest that this might now be happening.
Local concentrations of commercial effort and increased frequency of returns to port (because of shorter trips) also is likely to increase contact between recreational fishers, charter operators, the local community and the commercial fleet. Combined with regular sightings of operators off-loading live reef fish, rather than cardboard cartons of frozen fish, this is likely to exacerbate speculation that the growth in the live fish trade is resulting in localised stock depletions, irrespective of whether any depletion actually occurs. The considerable controversy over the growth of the live fishery in Queensland has tended to be greatest in the regions where live fishing effort has been most concentrated, which also happens to be where levels of recreational reef fishing are greatest (around Cairns). It is likely that some of this controversy was based on the increased visibility of the commercial fishery because of the changed practices associated with the supply of the live fish market, although real increases in commercial fishing effort were reported between Townsville and Cooktown in 1996 and 1997. It must be noted, however, that there are insufficient data to verify whether any localised depletions coincided with the growth in sales of live fish, or whether such (alleged) localised depletions pre-dated the development of the live fish market. For example, Goeden (1982) noted that population densities of coral trout increased with increasing distance from population centres, possibly indicating localised impacts of fishing 10 years prior to sales of live coral trout from Australia.

Our investigation of the effects of the development of the market for live reef fish on the commercial line fishing fleet has demonstrated significant changes in fishing practices, effort distribution and CPUE associated with the shift to marketing live product. Such effects mean that it will be important in future analyses of commercial catch and effort data, especially CPUE, to account for whether product is being landed alive or dead. Failing to factor the intended market into analyses is likely to result in misleading indicators about the performance of the fishery and/or the status of the resource on which it depends.
We also suggest, but are not able to verify in the scope of this study, that recent increases in the total level of effort and capital investment in the commercial sector of the fishery is substantially a result of the shift to marketing live reef fish. If this is correct, then there exists a risk of over-capitalisation of the fishery, possibly resulting in financial hardship for some operators. Current management strategies targeted at the entire fishery are unlikely to be responsive to issues such as those discussed above. Improved understanding of changes in effort dynamics and market strategies, however, may provide early warning of the need to be focused on particular areas or aspects of the stock in revising those strategies.

## Evidence of targeting spawning aggregations by the Queensland commercial reef line fishery

## Introduction

Targeting of spawning aggregations of fish has been a major component of many historical and modern fisheries throughout the world (Hilborn \& Walters 1992, Hutchings 1996, Rowling 1996, Ross \& Smith 1997). Increases in fishing technology, and efficiency in finding and harvesting fish when aggregated to spawn, has contributed to the substantial decline and collapse of many stocks (Colin et al. 1987, Shapiro et al. 1993, Sadovy 1994, Sadovy et al. 1994, Colin 1996, Domeier \& Colin 1997). These, and perhaps most, fisheries involving harvest of spawning aggregations, however, are trawl or purse seine fisheries and clearly stand to gain dramatically from aggregation of target species. The potential advantages to be gained by fishing spawning aggregations by line fishing are less clear than is the case for trawl fisheries.

While many of the more infamous and spectacular fisheries collapses have been large, temperate fisheries, the same principles might apply to smaller scale commercial and subsistence fisheries. In tropical coral reef subsistence fisheries, the spawning behaviour of many species of coral reef fish have been well known to indigenous peoples and they have harvested these local populations in a sustainable manner for substantial periods (Johannes 1981). Advances in fishing technology, increases in human population sizes and development of market economies in tropical regions has seen exploitation of tropical reef fish stocks in general, and impacts on spawning aggregations of some species in particular, increase (Russ 1991, Munro 1996, Sadovy 1994, 1999).
The impact of harvest on spawning aggregations has been best documented for several species of Caribbean and Atlantic serranid (Colin et al. 1987, Colin 1992, 1996). While the aggregating behaviour of coral reef fish and the increase in level of exploitation is not limited to the Caribbean, well documented cases of cause and effect from other regions are scarce and of relatively limited time series (Johannes \& Squire 1995, Johannes et al. 1999). Two conditions have to apply before targeting spawning aggregations by line fishing will result in substantial improvements in catch or have increased effects on stocks. Firstly, the fishing fleet must be able to locate spawning aggregations reliably and/or the fish must be more vulnerable to capture (e.g., because of movements to spawning sites, Fulton et al. 1999) during spawning. Secondly, catchability of fish must be at least as great when fish are spawning as when they are not. In the case of line fisheries, this means that fish must be at least as willing to take baits when spawning as when not spawning. Neither condition has been demonstrated for the GBR line fishery.
It is now clear, however, that the primary target species of the fishery, the common coral trout $P$. leopardus, does aggregate to spawn, usually on new moons between September and November in the central region of the GBR (Samoilys \& Squire 1994, Samoilys 1997). Observations of spawning by $P$. leopardus indicate, however, that the aggregations they form are small relative to many species, comprising only ~10-75 individuals (Samoilys 1997) and often fewer (Zeller 1998). Moreover, P. leopardus tend to form several spawning aggregations within each coral reef, rather than single large aggregations representing fish from a whole reef or several neighbouring reefs (Zeller 1998). The extent to which similar aggregating behaviour occurs in other regions of the GBR is not yet established. There is no evidence form previous analyses of commercial catch and effort data for the GBR line fishery that catch rates of coral trout increase during the expected spawning periods (Mapstone et al. 1996, Turnbull \& Samoilys 1997)
Fishers in the reef line fishery use particular features such as currents, water depth, bottom topography, presence of schooling bait fish, etc., to search for likely profitable fishing locations. Fishing in this way it is not uncommon for an individual dory to fish 10-15 locations
(hangs) during a session. Consequently, even if catchability does not increase when fish are aggregated to spawn, provided that it does not decrease, catch rates can increase by fishers either targeting spawning aggregations or encountering such aggregations incidentally (Fulton et al. 1999).
Anecdotal evidence from the fleet indicates that catches are greater when spawning aggregations are encountered, but the same anecdotal evidences suggests that encounter rates are relatively low, at least for some species, and in general are serendipitous rather than deliberate. A combination of low encounter rates and either static or increased catchability may result in relatively little increase in total harvest of the target stocks, despite the reported increases in catch when aggregations are encountered. Indeed, if catches are low from non-aggregation hangs at times when fish are spawning (because fish have moved off to the spawning site), net catches of coral trout may be highly susceptible to the rate of encounter of spawning aggregations (Fulton et al. 1999).
The reported benefit gained from finding spawning aggregations also varies with the target species and region. For example, there are several accounts of very large catches of the blue spot coral trout (Plectropomus laevis) arising from harvesting spawning aggregations in the northern GBR, but catches of the common coral trout (P. leopardus) from spawning aggregations are reported to be much smaller. Reports from fishers on the southern GBR, suggest that large aggregations of $P$. laevis have been encountered but the fish have not taken baits at all, whilst there are few reports of targeting spawning aggregations of $P$. leopardus in the southern GBR and no documented observations.

Despite the uncertainty of the information about the capacity of the reef line fishery to effectively target spawning aggregations of coral trout, there is considerable public, industry, and management concern about the potential effects of targeting spawning aggregations.
Seasonal spawning closures of the reef line fishery have been discussed in the public forum for some time, and are one option being considered by the Reef Line Management Advisory Committee (ReefMAC) (QFMA 1996, 1999). The effectiveness of spawning season closures as a strategy to reduce fishing mortality (at a time when targets are most susceptible to capture) depends on the validity of the above assumptions about the efficiency of the fleet in targeting aggregations and about the catchability of fish when aggregating to spawn.
In this section we examine the evidence for and against the targeting of spawning aggregations of demersal coral reef fish in the reef line fishery. We examine catch and effort dynamics of the commercial line fishery for evidence of targeting of spawning aggregations by evaluating historical logbook data and collecting additional information on the extent to which the commercial fishery was active in the targeting of spawning aggregations.

## Methods

The field and data gathering methods by which we examined the putative targeting of spawning aggregations are the same as those described in section 1. The analytical methods described in section 1 also encompassed tests for the effects of spawning season on a range of variables. In addition, we did the following analyses of QFMA compulsory logbook data.

The timing of spawning of $P$. leopardus in the central GBR has been fairly well established, being concentrated around the new moon phase in late spring to early summer (Brown et al. 1994, Samoilys 1997). Accordingly, we subsetted the daily catch and effort data according to three stages in the lunar cycle (new moon, half moon, full moon) and tested for differences in catch rates among these phases. The moon phases were represented by data from 5-6 days centred on each phase, with the half moon phase being represented by 3 days centred on the date of the first quarter and 3 days centred on the date of the third quarter. We compared the moon phases between two months preceding the earliest expected months of spawning for common coral trout and the 2 months in which spawning was most likely. This allowed us to differentiate between moon phase related patterns in catch rates that were correlated with spawning and any moon phase related patterns that existed independently of spawning activity (e.g., due to tidal flow). Mean and maximium catch rate data (kg/line/day) for coral trout and mixed reef species were calculated across operations within each effort class for each day. These data were then averaged over months within each season in each year for each moon phase and the resulting mean and mean maximum catch rates analysed. The analytical model for these tests was:

$$
\begin{align*}
& +\mathbf{M S Y}_{i j k .+} \mathbf{E Y}_{. . k l+}+\mathbf{M E Y}_{i . k l+} \mathbf{S E Y}_{j j l \mid}+\mathbf{M S E Y}_{i j k l}+\varepsilon_{j j k n} \tag{8}
\end{align*}
$$

where
$y_{i k l n}=$ the mean for operations in Effort Class $k$ during the $i^{\text {th }}$ Moon phase in the $n^{\text {th }}$ month of Season jin Year l;
$\mu_{\ldots . . . . . ~}=$ population mean of possible observations; and
$\varepsilon_{i j k n}$ is a normally distributed error associated with observation $y_{i j k n}$.
The above model applied only to L2 endorsed operations, where multiple effort classes exist. Catch rates from L3 operations (all Effort Class A) were analysed in a similar fashion, but without the effects involving Effort Class in the analytical model. Thus, for L3 operations, the analytical model was a factorial model involving Moon Phase, Season and Year.

## Results

## Seasonal distribution of Effort and Catch

Effort and catch in the reef line fishery is not distributed uniformly throughout the year (Mapstone et al. 1996). Traditionally, effort and catch were at their lowest in late DecemberMarch, increasing through autumn and winter to maxima between August and December (see Fig. 3).
The total catch of coral trout species reported in the QFMA compulsory logbooks during the spawning and non-spawning seasons each year, the effort for that catch, and the average CPUE are given in Fig 38. Between $27.5 \%$ and $31.8 \%$ of the total annual catches were taken during three months of the spawning season of common coral trout. Effort during the spawning periods comprised from $30.6 \%$ to $33.7 \%$ of the annual totals. Had catch and effort been relatively uniformly distributed with respect to spawning and off-spawning seasons, these figures would have been close to $25 \%$. Despite inter-annual variation in catch and effort, average CPUE in the spawning season was consistently close to that in the offspawning season (Fig. 38). Almost identical patterns were found for mixed reef fish (Fig. 39).

Figure 38: Total catch of coral trout (right), effort for that catch (bottom right) and CPUE ( $\pm$ SE, bottom left) taken by the GBR line fishery in the spawning and off-spawning seasons of each year between 1992 and 1997.




Figure 39: Total catch of mixed reef fish (left) and CPUE ( $\pm$ SE, right) taken by the GBR line fishery in the spawning and off-spawning seasons of each year between 1992 and 1997. Effort was almost identical to that in Fig. 38.



## Effort Responses to Spawning Season

## Main Boat Effort Dynamics

We found significant effects of season (Spawning, Off-spawning), either as main effects or in interaction with other factors (market or year), on the characteristics of movements by primary vessels from all data (on board observers, voluntary logbooks, and QFMA compulsory logbooks).

## Trip Duration

Trip lengths were shorter in the spawning season (9.9 days) than the off-spawning season ( 13.8 days) on those trips where we had observers present ( $\mathrm{F}_{1,21}=5.02, \mathrm{p}=0.036$ ). From analyses of QFMA compulsory logbook data, dead trips were considerably shorter in the spawning season than the off-spawning season for L2 operations using 1-2 lines (Effort Class A) that reported both live and dead trips during both seasons of 1994, 1995 or 1997, but at other times and for the other effort classes there was no significant effect of season on trip length (Fig. 40; Season*Market*Effort Class interaction $-\mathrm{F}_{2,12}=3.72, \mathrm{p}=0.055$ ). When fleet-wide data were analysed, trips were slightly longer in the spawning than non-spawning season for dead trips by L2 operations in 1997 (Fig. 40, Season*Market interaction, $F_{1,122}=2.89, p=0.092$ ) but no other seasonal effects on trip length were apparent ( $p>0.1$ ).

Figure 40: Mean duration of fishing trips during the Off-spawning and Spawning seasons when averaged across all live or dead L2 operation in 1997 (left) and for those operations in each Effort Class (A, B, C) that did both dead and live trips in both season of 1994, 1995 or 1997(right). Error bars are Standard Errors.



## Distance from Port

Although mean distances from port to the first fishing site and from the last fishing site to port were in most cases smaller during the spawning than the non-spawning seasons, such apparent effects generally were not statistically significant ( $p>0.1$ ). In the single case where there was a significant relationship between season and distance from port (L2 operations that fished both live \& dead in both seasons), the end points of trips tended to be farther from port during the off-spawning than the spawning season ( 79.0 vs 57.7 nm ) when operations were killing their catch, but not when catch was being kept alive (Season*Market interaction, $\mathrm{F}_{1,10}=4.17, \mathrm{p}=0.069$ ).

Steaming times for transits from port to the first fishing site or from the last fishing site to port did vary with season for those trips on which we had observers. Operations embarking on dead trips tended to take longer to reach their fishing grounds during the spawning than nonspawning seasons, whereas season did not affect transit times for live operations (Fig. 41; Season*Market interaction, $\mathrm{F}_{1,15}=5.84, \mathrm{p}=0.029$ ). All operations tended to make faster transits from the last fishing site back to port during the off-spawning than in the spawning seasons (9.2 vs 13.4 hr ).

Figure 41: Mean transit times (hours) from port to reef during spawning and off-spawning seasons on trips when observers were present. Error bars are Standard Errors.


## Movements Between Reefs

Distances traversed between reefs or fishing sites were generally not strongly related to the season in which fishing occurred. There was no evidence of seasonal changes in movements during trips in the QFMA compulsory logbook data, and only occasional effects in the observer and voluntary logbook data. Vessels on which we had observers took longer to steam between reefs when on live trips during the spawning season of 1997-98 than in the off-spawning season of the same year (Fig. 42), but at all other times steaming times were very similar among trips (Fig. 42) (Season*Market*Year interaction, $\mathrm{F}_{1,18}=4.47, \mathrm{p}=0.049$ ).
Voluntary logbook data indicated that operations killing their product in 1997 moved greater distances among reefs during the spawning than in the off-spawning season (Season*Market*Year interaction, $\mathrm{F}_{1,23}=4.85, \mathrm{p}=0.038$ ), but reef-to-reef steaming properties were similar across seasons under all other circumstances (Fig. 42).

Figure 42: Reef-to-reef transit distances (from voluntary logbook data, left) and times (from observer data, right) during spawning and off-spawning seasons over 2 years. Error bars are Standard Errors.



## Time Spent at each Location

There were no significant effects of season on the periods for which operations stayed at reefs during trips. Despite this, operations on which we had observers tended to fish fewer locations during in the spawning season than in the off-spawning season (mean 6.4 vs 11.7 reefs per trip, $\mathrm{F}_{1,12}=3.47, \mathrm{p}=0.087$ ) consistent with the shorter trips they made in the spawning season (Fig. 40).

## Days off Between Trips

There were significant differences in the time spent in port between trips during the spawning and non-spawning seasons in 1996 ( $\mathrm{F}_{1,120}=4.01, \mathrm{p}=0.047$ ) and 1997 ( $\mathrm{F}_{1,122=5.18, \mathrm{p}=0.025 \text { ), }}$ and for the subset of operations doing both live and dead trips in each season in 1994, 1995 or $1997\left(\mathrm{~F}_{1,12}=5.04, \mathrm{p}=0.044\right)$ (Fig. 43). In the latter case, however, the effect was driven mainly by the L2 operations with 5-7 lines (Effort Class C) when making dead trips, with no significant differences between seasons in the numbers of days off for other effort classes (Fig. 43; Season*Market*Effort Class interaction, $\mathrm{F}_{2,12}=3.30, \mathrm{p}=0.072$ ). In all other analyses, periods in port were not significantly different between seasons, with the data being highly variable among operations.

Figure 43: Mean numbers of days in port preceding trips in spawning and off-spawning seasons, based on QFMA compulsory logbook data. Main effects shown in the left plot are from those selected operations reporting both live and dead trips in both seasons of either 1994, 1995 or 1997 ('94-97') or from comparison of the mutually exclusive sets of live or dead operations across the entire fleet in 1996 and 1997. On the right is shown the results of analyses of operations reporting both live and dead trips in 1994, 1995, 1996 or 1997 when analysed by effort class ( $A=1-2$ lines, $\mathrm{B}=3-4$ lines, $\mathrm{C}=5-7$ lines). Error bars are Standard Errors.



## Dory Effort Dynamics

## Number of Sessions and Session Duration

Dory fishers tended to return to their primary vessel more often (meaning more sessions per day) during the spawning season than in the off-spawning season of 1996-97, but the effect was absent in 1997-98 (Fig. 44; Season*Year interaction, $\mathrm{F}_{1,21}=3.61$, $\mathrm{p}=0.07$ ). The mean duration of sessions (time spent away from the primary vessel continuously) was greater in the spawning season than in the off-spawning season for the vessels on which we had observers, though only by about $8 \%$ ( 4.0 vs $3.7 \mathrm{hr}, \mathrm{F}_{1,22}=3.34, \mathrm{p}=0.08$ ).

Figure 44: Mean number of sessions per day by dory fishers during the spawning and off-spawning seasons based on observer data. Error bars are standard errors.


## Number of Hangs per Session

The number of hangs per session varied with season, but the effect depended on the year and session (AM, PM) from which data arose (Fig. 45, $\mathrm{F}_{1,22=4.72, ~}^{\mathrm{p}=0.04 \text { ). Significantly }}$ more hangs were fished during the spawning than in the off-spawning season in both AM and PM sessions in 1996-97. In 1997-98, however, fewer hangs were fished during AM session in the spawning season than in the off-spawning season, whilst similar numbers of hangs were fished per PM session in both seasons (Fig. 45).

Figure 45: Mean number of hangs per session by fishers during the spawning and off-spawning seasons in each of two years. Data were from research observers in dories. Error bars are standard errors.


## Hang Duration and Hang Dynamics

The duration of hangs varied between spawning and off-spawning seasons but this effect of season varied with year (Season*Year interaction, $\mathrm{F}_{1,23}=3.45, \mathrm{p}=0.08$ ). In 1996-97, both total hang duration and fishing time per hang were shorter during the spawning than the offspawning season, but in 1997-98 the reverse was the case (Fig. 46).
Average times spent searching for each hang also varied with the season, though this pattern depended upon the intended market of the catch (Season*Market interaction, $\mathrm{F}_{1,23}=3.60, \mathrm{p}=0.07$ ). Fishers retaining catch alive spent longer searching for hangs during the spawning season than in the off-spawning season, whereas fishers supplying dead fish spent longer searching for hangs during the off-spawning seasons of 1996-98 (Fig. 47).

Figure 46: Mean hang duration (left) and actual fishing time per hang (right) during the spawning and off-spawning seasons in each of two years. Data were from research observers accompanying the dory fishers. Error bars are standard errors.



Figure 47: Mean time spent searching for a new hang by fishers who kept their catch alive and those who killed their catch during the spawning and off-spawning seasons. Data were from research observers accompanying the dory fishers. Error bars are standard errors.



## Set Times

The times taken to set the anchor and dory at each hang tended to be similar across seasons, although there were a few significant differences that depended on whether the catch was to be kept alive or killed, the session being considered, or the year (4-way interaction, $\mathrm{F}_{1,21}=5.01, \mathrm{p}=0.04$ ). Set times were significantly less during both $A M$ and $P M$ sessions in the spawning season than in the off-spawning season of 1996-97 when fishers were killing their catch, but not significantly different when fishers were keeping their catch alive (Fig. 48). In 1997-98, live fishers (only) took longer to set-up PM hangs in the spawning than in the off-spawning season, but no effect was evident during the AM hangs (Fig. 48).

Figure 48: Mean set time at each hang by dory fishers who kept their catch alive and those who killed their catch during AM (left) and PM (right) sessions of spawning and offspawning seasons over two years. Data were from research observers accompanying the dory fishers. Error bars are standard errors.


## Movement Between Hangs

Fishers tended to travel shorter distances between hangs during the spawning seasons than off-spawning seasons when killing their catch and further between hangs in the spawning seasons when keeping their catches alive (Fig. 49). However, the suggested effects were statistically significant only for live fishers in 1997-98 (Season*Market*Year interaction, $\left.F_{1,21}=3.32, p=0.08\right)$.

Figure 49: Mean distances moved between hangs by fishers during the spawning and offspawning seasons of 1996-97 and 1997-98, classified by the intended market (live or dead) for their catch. Data were from research observers accompanying the dory fishers. Error bars are standard errors.


## Fishing Depths

In some instances fishers fished at different depths with changing season. Fishers keeping their catches alive fished in significantly shallower water during the off-spawning season than in the spawning season (in both 1996-97 and 1997-98, irrespective of session) (Fig. 50). Fishers killing their catch, however, fished in water of similar depth in both seasons (AM \& PM, 1997-98) or in deeper water in the off-spawning season (AM \& PM, 1996-97) (Fig. 50) (Season*Market*Year*Session interaction, $\mathrm{F}_{1,20}=3.12, \mathrm{p}=0.09$ ).

Figure 50: Mean fishing depths for fishers fishing during the spawning and off-spawning seasons in each of two years where catch was kept alive or killed. Results are presented separately for AM sessions (left) and PM sessions (right). Data were from research observers accompanying the dory fishers. Error bars are standard errors.


## Effects on Catch Rates

## Observer Trips

Catch per unit of effort at hang level in dories observed by researchers did not vary significantly with season for an species group ( $p>0.1$ in all cases). When data were summed to session level, however, several patterns related to season became apparent, though most varied with year or session.
Catch rates of coral trout calculated on the basis of actual fishing times varied with season, year and session ( $\mathrm{F}_{1,21}=5.83, \mathrm{p}=0.02$ ). In 1996-97, mean catch rates during the spawning season were over twice those in the off-spawning season, but in 1997-98 this pattern was reversed (Fig. 51).

Figure 51: Mean CPUE for coral trout during AM and PM sessions of the spawning and off-spawning seasons of 1996-97 and 199798, calculated at session level from dories in which observers were present. Error bars are standard errors.


The numbers of released coral trout per unit of effort (RPUE) also varied with season in interaction with other factors. RPUE during AM sessions did not differ with season but in PM sessions RPUE was less during the spawning season than in the non-spawning seasons (Fig. 52, Season*Session interaction, $\mathrm{F}_{1,20}=3.39, \mathrm{p}=0.08$ ). Further, releases per unit effort were greater during the spawning season than in the off-spawning season of 1996-97, but about half those in the off-spawning season of 1997-98 (Fig. 52, Season*Year interaction, $\mathrm{F}_{1,22}=4.06, \mathrm{p}=0.06$ ).

Figure 52: Mean numbers of coral trout released per unit of fishing effort for coral trout during spawning and off-spawning seasons in AM and PM sessions (left) and each year (right). Error bars are standard errors.



## Voluntary Logbooks

Catch rates of coral trout reported in voluntary logbooks did not vary significantly with season. Catch rates of mixed reef species and red throat emperor, however, did vary with season, though in the case of $L$. miniatus the effect varied with session and year ( $\mathrm{F} 2,53=5.19$, $\mathrm{p}=0.01$ ). Average catch rates of $L$. miniatus were significantly greater during the spawning than the off-spawning season in both AM and PM sessions during both 1997 and 1998, and were similar across seasons only for all day fishing sessions in 1997 (Fig. 53). Overall mean catch rate of mixed reef species was more than $50 \%$ greater in the spawning season than that during the off-spawning season (16.4 vs $10.4 \mathrm{~kg} /$ dory/session, $\mathrm{F}_{1,34}=4.79, \mathrm{p}=0.04$ ).

Figure 53: Mean CPUE for red throat emperor during AD, AM and PM sessions of the spawning and offspawning seasons of 1997 and 1998, calculated from voluntary logbook data. Error bars are standard errors.


## Compulsory Logbooks

Statistically significant seasonal variation in catch rates of coral trout were infrequent in the compulsory logbook data and there were no significant effects of season evident on catch rates of other demersal reef species ( $p>0.1$ in all cases). When all L2 operations were analysed independently in each year, average maximum CPUE of coral trout varied with season in interaction with Market in 1997 ( $\mathrm{F}_{1,117}=4.95, \mathrm{p}=0.028$ ) and Effort Class in 1995 ( $F_{2,110}=2.78, p=0.066$ ) (Fig. 54). In both cases, however, effects of season were slight or nonexistent, and were statistically significant only for operations using 1-2 lines per day (Effort Class A) in 1995 and for vessel selling their catch alive in 1997 (Fig. 54). L3 operations showed significant seasonal variation in mean CPUE of coral trout in 1994 only (Spawning - $16.1 \mathrm{~kg} / \mathrm{line} /$ day, Off-spawning - $15.0 \mathrm{~kg} / \mathrm{line} /$ day, $\mathrm{F}_{1,60}=3.22, \mathrm{p}=0.078$ ).

Figure 54: Mean maximum CPUE of coral trout during spawning and off-spawning seasons for L2 operations of different effort classes (left, 1995) and selling their catch to different markets (right, 1997). Error bars are standard errors.



## Patterns in Catch Rate related to Moon Phase

There were no statistically significant effects of moon phase, either alone or in interaction with other factors, on either mean or mean maximum catch rates of coral trout or mixed demersal reef fish ( $\mathrm{P}>0.1$ in all cases).
Though differences among years and effort classes were frequently significant in these analyses, they generally were not related to either spawning season or moon phase, and will not be presented here. The only seasonal effects of significance were interactions between season and effort class (L2 operations, averaged over years) for mean catch rates of coral trout ( $F_{2,293}=3.079, \mathrm{p}=0.048$ ) and main effects of season for mean maximum catch rates of coral trout for both L2 and L3 operations ( $\mathrm{L} 2-\mathrm{F}_{1,298}=8.386, \mathrm{p}=0.004$; L3 - $\mathrm{F}_{1,93}=3.857$, $\mathrm{p}=0.052$ ). In the first case (Season*Effort Class interaction), catch rates by operations in Effort Class A were approximately $25-30 \%$ greater during the spawning seasons than in the off-spawning seasons, but catch rates by operations in Effort Classes B and C did not differ with season (Fig. 55). For both main effects of season, maximum catch rates were greater in
the spawning season than the off-spawning season (L2: 54.0 vs $46.1 \mathrm{~kg} / \mathrm{line} / \mathrm{day}$; L3: 42.0 vs 34.5 kg/line/day)

Figure 55: Mean CPUE for coral trout landed during spawning and off-spawning seasons by L2 operations of different effort classes (A: 1.2 line, B: 3-4 lines, \& C: 5-7 lines per day). Error bars are standard errors.


## Effects on Catch Composition

There were significant effects of season on the compositions and sizes of coral trout caught but these effects also varied with other factors. In 1996-97, catches on observer trips in the off-spawning season were comprised of more than twice the proportion of red coral trout and significantly lower proportions of under-sized and small coral trout than catches in the spawning seasons (Fig. 56). In each case, however, the complete reverse was true in 199798 (Fig. 56) (Season*Year interactions: Red coral trout $-\mathrm{F}_{1,21}=13.18, \mathrm{p}=0.002$; Under-sized coral trout - $\mathrm{F}_{1,27}=3.91, \mathrm{p}=0.058$; Small legal sized coral trout $-\mathrm{F}_{1,26}=5.52, \mathrm{p}=0.027$ ). Proportions of small coral trout in the catch also varied with season dependent on the intended market for the fish ( $\mathrm{F}_{1,26}=5.33, \mathrm{p}=0.029$ ), with proportions substantially greater in the off-spawn than the spawning season on live trips, but the reverse on dead trips (Fig. 56). Proportions of red P. leopardus also varied with season, market and session ( $F_{1,21}=4060$, $\mathrm{p}=0.04$ ), but the only significant seasonal effect was for dead trips in the morning sessions, when proportions of red $P$. leopardus were significantly greater during off-spawning than spawning seasons.

Figure 56: Composition of catches of coral trout during spawning and off-spawning seasons of 1996-97 and 1997-98. Proportions of red coral trout in the catch (right), proportions of under-sized (\& released) coral trout (below left), and proportion of small (but legal size: $\sim 38<43 \mathrm{~cm} \mathrm{TL}$ ) coral trout (below right). Error bars are standard errors.




The proportion of catch reported in voluntary logbooks for which coral trout accounted also varied with season, in interaction with year, session and the intended market of the catch
( $F_{2,50}=5.05, p=0.01$ ). In all but one case (AM sessions on live trips in 1997), the mean proportion of coral trout in the catch was either greater during the off-spawning season than in the spawning season or did not differ significantly between seasons (Fig. 57). The relationship was not consistent over years for any session, however, and was consistent over sessions only for dead trips in 1997 and live trips in 1998 (Fig. 57).

Figure 57: Proportion of coral trout in the catches reported in voluntary logbooks for AD, AM and PM sessions of spawning and off-spawning seasons of 1997 and 1998. Error bars are standard errors.



## Discussion

We found little evidence in this study of the consistent targeting of spawning aggregations of demersal reef fish by commercial reef line fishers. Indeed, one of the difficulties we encountered during the observer program was being able to timetable trips with fishers to coincide with new moons, when common coral trout were expected to be aggregating to spawn. The problem arose because the fishers we contacted were not structuring their trips around lunar phase. This suggests either that they were unaware of the timing of spawning by coral trout or that they were not seeking to target spawning fish. Although there were occasional significant effects of season on a variety of variables, including trip length, searching \& fishing patterns by dory fishers, and the size and colour composition of catches, these were rarely consistent across years and also varied with the intended market of the catch and the class of vessel. Such infrequency and inconsistency in seasonal effects is not consistent with an hypothesis of fishers actively and successfully targeting spawning aggregations. The two most consistent effects of season were on the period spent in port between trips and the catch rates of red throat emperor (L. miniatus) and mixed reef species.

The seasonal difference in time spent in port most likely reflected the different effects of prevailing weather between the spawning and off-spawning seasons. The potential that skippers were prompted to return to the fishing grounds more quickly by the prospect of elevated catch rates in the spawning season cannot be categorically ruled out, but our data on catch rates indicated that this potential was not realised, at least for coral trout. Similar results have been reported previously by Mapstone et al. (1996) and Turnbull \& Samoilys (1997). In both these earlier studies, the significant increase in effort and catch during spring-summer that characterise the commercial reef line fishery were highlighted, but in neither was a corresponding increase in catch rate found.

The variations in catch rates of coral trout or catch composition provided only occasional evidence of elevated catchability or deliberate targeting of aggregations during the spawning seasons. Though catch rates were indeed greater in the spawning seasons of some years, the reversal of such an effect in other years indicates that the source of such elevated catch rates were not consistent. This result, together with the variable effort dynamics at the level of dories, indicates that either deliberate targeting of spawning aggregations of coral trout is a relatively minor factor in the success of fishers, and subject to the influence of other factors, or that spawning aggregations cannot be found consistently. For example, the result that fishers fished at more hangs and for shorter periods in the spawning season than the offspawning season, especially in PM sessions, is inconsistent with the targeting of spawning aggregations. If aggregations were being targeted successfully, we would have expected fewer, longer hangs in the spawning season than in the off-spawning season. Even if the slightly greater searching time for some fishers in the spawning season was interpreted as active searching for aggregations, the results for CPUE would indicate that their searching was generally unsuccessful. This suggestion is consistent with anecdotal commentary from fishers and with our observations of dory fishers, who generally did not deliberately seek 'spawning sites' but rather targeted sites where there was conspicuous evidence of baitfish or where coral trout were expected to be feeding.
Perhaps the most interesting and consistent pattern in our analyses of catch rates of coral trout was the interactions between seasonal effects and intended market of the catch (see also page 46). In general, though not without exceptions, fishers keeping their catches alive tended to search longer for hangs, took longer to anchor, and fished in deeper water in the spawning seasons than in the off-spawning seasons, whereas the reverse was generally true for fishers killing their catch. One possible reason for this difference is that (anecdotally) skippers supplying the live market dislike having 'ripe' fish in their holding tanks, either in dories or on the primary vessel (see page 46). If this is the case, then live fishers might be actively trying to avoid spawning fish during the spawning season, resulting in the above
patterns in dory-level effort dynamics. They continue to supply the live market, however, because of the elevated market demand and, therefore, higher and more stable beach prices for live fish during late spring and summer leading up to the Julian and Chinese New Year. Alternatively, it may simply that fishers using 'view buckets', as many live fishers do, are prepared to travel further with the ballast of water they have to carry with live fish and explore more areas in the calmer weather in spring-summer than they would in poorer winter weather.
The most compelling evidence for enhanced catch rates during the (coral trout) spawning season was the consistent increase in catch rates of other demersal reef fish reported in the voluntary logbooks. Although no aggregations of any species were observed by our observers in this study, there exist anecdotal reports of large aggregations of some other serranids being fished by some fishers during late spring - early summer. Although knowledge of these aggregations seems to be restricted to relatively few fishers, it is possible that the data reported in the voluntary logbooks reflects encounters with such aggregations by some operations in recent years (1997-98). Increased catch rates of $L$. miniatus during the same periods might be related to spawning by that species, which spawns between August and November (Brown et al., 1994, A. Williams unpub. data).
The relative shortage and inconsistency of evidence in our results for the active or incidental targeting of spawning aggregations of common coral trout suggests that the public issue may be more one of speculation than experience. Fulton et al. (1999) showed that even if aggregations of coral trout were not actively and successfully targeted by fishers, catch rates might be expected to increase as a result of increased availability of fish to fishers as the fish moved to spawning sites, provided that catchability did not decline during such movements. The absence of consistently increased catch rates during this study suggests either that the results of Fulton et al.'s (1999) model were liberal, that catchability of common coral trout is diminished during spawning, or that effects predicted by Fulton et al. (1999) were not consistent among fishers. We cannot discard the possibility of diminished catchability during spawning, though the abundance of 'ripe' fish in commercial catches during spawning seasons (pers. obs.) suggests any diminution is slight. Further, experience of other fisheries suggests that catchability might actually increase during spawning of reef species (Johannes \& Squire 1995).
The results we have seen, however, are consistent with those predicted by Fulton et al. (1999) if the benefits of fishing during spawning, whether derived incidentally or by targeting aggregations, are highly inconsistent among fishers. The net result would be insufficient to significantly increase average catch rates over those experienced at other times of the year, as we have recorded.
Our results for coral trout might reflect also relatively low susceptibility of $P$. leopardus to targeted harvesting during spawning. Samoilys \& Squire (1994), Samoilys (1997) \& Zellar(1998) have shown that $P$. leopardus form several relatively small spawning aggregations in shallow water, and there exist no reports of very large aggregations similar to those reported for other Plectropomus spp. (Johannes \& Squire 1995, Squire pers. Com.). Further, Fulton et al. (1999) noted that the combination of current information about the population densities of common coral trout and the size and frequency of (observed) spawning aggregations suggested that only about $6-10 \%$ of $P$. leopardus attended shallow water spawning sites at any one time. These studies may mean that many common coral trout do not aggregate to spawn or aggregate at sites hitherto undiscovered, possibly in deep water off their 'home' reefs. Under these circumstances, there would be considerable uncertainty about the location of spawning sites and the expected benefits from encountering them, and diminished incentives for searching for them. Further, if one or more spawning sites were encountered on a reef, the impact on the population of $P$. leopardus on that reef would be expected to be relatively slight, compared with that which would be expected for other species that form single very large aggregations for spawning.

In conclusion, therefore, it seems unlikely that the common coral trout, $P$. leopardus, is at great risk from the targeted harvesting of spawning aggregations. Accordingly, it seems that the periodic public controversy about the targeting of spawning aggregations is misplaced, at least with respect to common coral trout. Further, the proposed implementation of seasonal closures to coincide with the most likely times of spawning of $P$. leopardus would seem to be of marginal benefit for that species over closures at other times, at least in so far as they were intended to protect fish while spawning. The primary benefit to common coral trout from any closure of the reef line fishery during spring-early summer is likely to derive from the fact that that is the period of peak effort in the fishery.

## Benefits

Management of the reef line fishery will benefit through insights for improved analyses of commercial logbook data, the provision of direct evidence of the meaning of changes in logbook catch records and direct assessment of the relevance of spawning season closures to the reef line fishery. This information will benefit both the Queensland Fisheries Management Authority (in managing the fishery) and the Great Barrier Reef Marine Park Authority (in managing the Great Barrier Reef Marine Park, where most of the reef line fishing occurs).
Commercial fishing will benefit directly because of i) better interpretation (by management and researchers) of the data they provide about their fishing activities, ii) the provision of detailed information about the effects of live fishing on their catch rates, which will allow explicit evaluation of the cost-benefit trade-offs between alternative marketing strategies under varying product prices; and iii) direct comparison of the perceived and actual costbenefits of targeting spawning aggregations when fishing for coral trout. Indirect benefit to commercial fishing will arise from clarification of the real features of live fishing and targeting spawning aggregations in the public arena, which will attenuate much of the speculation about these activities that underlies the controversy surrounding them.
Recreational and non-fishing community benefit will accrue from the provision of accurate information about commercial fishing practices.

## Further Development

We have alluded to the correlation between increases in active effort in the commercial line fishery and the growth of the trade in live food fish. Circumstantial evidence suggests that the increase in effort may be driven in part by the higher beach prices for live fish and speculative investment. Further research on the direct impacts of the live fish trade on the total effort would be of benefit to the fishery and its management.
Much of the controversy about the trade in live reef fish relates to perceptions of local depletions of reef fish stocks as a (putative) result of the concentration nearer ports of effort by commercial operations landing their catch alive. Further research targeted specifically at the catch and effort characteristics of the commercial line fishery in such areas (e.g., between Lucinda and Cooktown) would clarify the extent to which such concerns were well founded or simply the result of increased exposure of the coastal communities to commercial fishing operations.
Whilst there exists anecdotal evidence that several species of demersal reef fish on the GBR form large aggregations to spawn and may be at greater risk than common coral trout from targeted exploitation at particular times, we found little direct evidence of this in the data we analysed. This is an area worthy of further research, as is further exploration of regional variations in the spawning behaviour of the main harvested species.

## Conclusion

The emergence of the export trade in live food fish from the Great Barrier Reef represents considerable value adding to an existing commercial line fishing industry. Accordingly, the live fish trade has considerable potential benefit to the commercial fishers and supporting local communities. This study indicates that the changes in fishing practices, especially in respect of lowered catch rates and reduced harvest of by-product species, represents significant potential benefit to target stocks and non-target species. The trade in live fish has not resulted in increased per-capita catch rates or fishing practices that are intrinsically worse than those which have characterised the traditional reef line fishery for decades.
The changed marketing strategies were found to have several significant effects on the operational characteristics and catch rates of the commercial fleet. These effects mean that it will be important in future analyses of commercial catch and effort data, especially analyses of CPUE, to account for whether product is being landed alive or dead. Failing to factor the intended market into analyses is likely to result in misleading indicators about the performance of the fishery and/or the status of the resource on which it depends.

There exists a significant risk that the potential benefits of the live fish trade may be off-set by increased total effort in the commercial fishery and / or increased competition between recreational and commercial fishers in some areas. The increased beach prices for live product is likely to have provided at least part of the incentive for considerable increases in investment and total commercial effort in the reef line fishery since 1994. Further, the concentration of effort from live operations nearer to ports and nearer to areas of high population has probably been the genesis of some of the controversy about the live fish trade because of the increased 'visibility' of commercial fishers to recreational fishers and shorthaul charter operations. The development of infrastructure to support export of live fish in major population centres also will have made the trade in live fish relatively more conspicuous than the conventional trade in frozen product.

Prudent management action is required to control effort and avoid real or perceived stock depletions in areas closer to key ports and population centres. Without such management, the value-added benefits of the export trade in live reef food fish may be overwhelmed by overdevelopment of the commercial fishery and/or opposition from other sectors of the reef line fishery.

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## Abbreviations \& Glossary

## Abbreviations

| Abbreviation | Meaning |
| :--- | :--- |
| AQIS | Australian Quarantine Inspection Service |
| CPUE | Catch Per Unit of Effort |
| ELF Project | Effects of Line Fishing Project |
| GBR | Great Barrier Reef |
| GBRMPA | Great Barrier Reef Marine Park Authority |
| GBRPM | Great Barrier Reef Marine Park |
| GPS | Global Positioning System |
| nm | Nautical Miles |
| QFMA | Queensland Fisheries Management Authority |
| ReefMAC | Reef Line Fishery Management Advisory Committee |

Glossary

| Term | Meaning |
| :--- | :--- |
| Beach Price | Price paid for fish or fish product to fishers by fish processors <br> or buyers. |
| Dead Fish | Fish intended to be sold as frozen or chilled fillet or whole fish <br> Commercial fishing operation targeting fish intended to be sold |
| Dead Fishing | as frozen or chilled product |
| Dead Product | Chilled or frozen fish product, usually fillet, whole or gutted. <br> Commercial fishing trip when most of the catch was killed for |
| Dead Trip | supply to the frozen or chilled fish markets |
| Small fishing tenders operating from a primary vessel |  |
| Endorsement | Fishing licence issue by QFMA to commercial fishing <br> operations restricting the gear used (size, number or type) |
|  | and/or the area of operation. |
| A specific fishing location where the anchor is set and fishing |  |
| is done |  |

## Appendix 1: Intellectual Property

No patentable or marketable products or processes have arisen from this research. All results will be published in scientific and non-technical literature. The raw data from compulsory fishing logbooks remains the intellectual property of the Queensland Fisheries Management Authority. Raw catch data provided by individual fishers to project staff remains the intellectual property of the fishers. Intellectual property accruing from the analysis and interpretation of raw data vests jointly with the Fisheries Research and Development Corporation, James Cook University, and the Principle Investigator.

## Appendix 2: Staff

| Principle Investigator: | Bruce Mapstone |
| :---: | :---: |
| Co-Investigators: | Campbell Davies, John McKinlay, Glen De'Ath |
| Senior Project Officer: | Stephanie Slade |
| Liaison Officer: | Annabel Jones |
| Project Staff: | Ashley Williams Kevin Kane |
| Casual Observers: | Nokome Bently <br> Michael Zaletel <br> Campbell Sullivan <br> Cameron Murchie <br> Declan O'Toole <br> Paul Costello <br> Ian Roderick <br> James Aumend <br> Mike Emslie <br> Tom Hatley <br> Daryl Airlie <br> Steve Purcell <br> Dave Hocking <br> Bob Stevens |


[^0]:    ${ }^{1}$ Commercial fishers in Queensland typically hold endorsements for multiple fisheries, allowing them to move at will and without notice among those fisheries.

[^1]:    ${ }^{2}$ Unless otherwise qualified (e.g., by reference to particular species), the term coral trout is used throughout this report to refer to all Plectropomus spp.

[^2]:    ${ }^{3}$ Fishers consistently report that common coral trout taken from deeper water (>~25m) are bright red in colour, whereas those taken from shallower water tend to be green-grey in colour.

[^3]:    ${ }^{4}$ Anecdotal evidence suggests that $P$. leopardus taken from deeper water are typically bright red in colour (with blue spots), whereas individuals taken from shallower water are typically grey-green in colour. Whilst no specific depth range for the change in colour is documented, the proportion of 'red' P. leopardus is generally considered in the fleet as an indication of the relative depth from which fish were taken. We analyse this variable here as an indicator of average depth of harvest for the live or frozen markets.

[^4]:    ${ }^{5}$ Confidentiality requirements of our use of QFMA logbook data dictate that we cannot present results from groups of less than 5 operations.

[^5]:    ${ }^{6}$ We have no direct evidence that spawning in tanks does cause mortality of fish and it is feasible that the mortalities are caused by other factors such as increased fouling of water and increased metabolic rates of fish during warmer periods correlated with spawning.

