National strategy for the survival of released line-caught fish: tropical reef species

I.W. Brown, W.D. Sumpton, M. McLennan, D.J. Welch, J. Kirkwood, A. Butcher, A. Mapleston[1], D. Mayer, G. Begg[1], M. Campbell, I. Halliday and W. Sawynok[2].

Queensland Department of Primary Industries and Fisheries
[1] Fish and Fisheries Research Centre, James Cook University, Townsville
[2] Australian National Sportfishing Association; Infofish Services, Rockhampton

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National strategy for the survival of released line-caught fish: tropical reef species (FRDC 2003/019)

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Enquiries should be addressed to:

Intellectual Property and Commercialisation Unit
Department of Primary Industries and Fisheries
GPO Box 46
Brisbane Qld 4001

or

copyright@dpi.qld.gov.au
Tel.: +61 7 3404 6999

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

2003/019 **National strategy for the survival of released line-caught fish: tropical reef species.**

PRINCIPAL INVESTIGATOR: Dr Ian W Brown

ADDRESS

Principal Fisheries Scientist
Department of Primary Industries and Fisheries
Southern Fisheries Centre
13 Beach Rd (P.O. Box 76)
DECEPTION BAY QUEENSLAND 4508
E-mail: ian.brown@dpi.qld.gov.au
Phone: +61 7 3817 9580
Fax: +61 7 3817 9555

1. OBJECTIVES:

a. To quantify the effects of hook type, hooking damage, barotrauma and barotrauma relief procedures on the short-term post-release survival (PRS) of key tropical and sub-tropical line-caught fish species.

b. To quantify the effects of hook type, hooking damage, barotrauma and barotrauma relief procedures on the long-term post-release survival (PRS) of key tropical and sub-tropical line-caught fish species.

c. To develop and extend 'best practice' handling procedures applicable to the recreational, commercial and charterboat sectors in Queensland, the Northern Territory and Western Australia.

d. To estimate the condition of fish caught and released in the commercial and charterboat line fisheries.

2. NON TECHNICAL SUMMARY:

OUTCOMES ACHIEVED TO DATE

1. A growing awareness among recreational and commercial line-fishers throughout Australia of the conservation benefits of carefully handling fish that are to be returned to the water. This has been achieved through the project's integral involvement in and contribution to the national 'Gently Does It' (Released Fish Survival) media campaign.

2. Increasing awareness among anglers in northern Australia of the survival advantages of treating barotrauma-affected tropical coral reef fish either by venting or using a shotline weight.

3. Provision of best-practice handling and release procedures to the tropical recreational line-fishery, highlighting the influence of various hook patterns and barotrauma-relief procedures on six key tropical reef species.

Experiments were conducted in northern, central and southern Queensland to investigate the effects of hook design and size on the incidence of hooking injury, and the effects of a number of factors, including barotrauma-treatment method, on post-release survival rates of a suite of key reef-associated demersal fish species of particular importance to Queensland's reef line fishery. The key species examined were common coral trout (*Plectropomus leopardus*), redthroat emperor (*Lethrinus miniatus*), crimson snapper (*Lutjanus erythropterus*), saddletail snapper (*Lutjanus malabaricus*), red emperor (*Lutjanus sebae*) and spangled emperor (*Lethrinus nebulosus*).

The work comprised four components –

(i) Analysis of existing datasets in terms of discarding/release rates in the commercial, recreational and charter sectors and estimation of barotrauma treatment effects;

(ii) Field trials to determine experimentally the effects of three hook patterns (J-hooks, offset circles and non-offset circles) and two sizes (small: 4/0 or 5/0, and large: 8/0) on hooking injury, location of hook lodgment and catch rate;

(iii) Field experiments using specially-developed vertical floating enclosures to test short-term (3-day) survival rates of fish treated to relieve barotrauma by venting or shotline releasing;

(iv) A community-based tag-release-recapture experiment involving recreational anglers to test the effects of barotrauma treatment and other covariates on long-term (months to years) post-release survival.

Discarding rates of some species have increased since 1997 largely as a result of increases in legislated minimum legal size limits and the introduction of maximum size limits. In December 2003 the minimum legal size (MLS) limit for red emperor was raised significantly, from 45 cm (TL) to 55 cm. Concurrent increases in MLS of bluespot coral trout, redthroat emperor and spangled emperor did not result in an observable change in discard rate. By 2005 the reported recreational discarding rates for coral trout, redthroat emperor, spangled emperor and saddletail snapper ranged between 42% and 55%, but for crimson snapper the rate was 69%, and for red emperor it was 83%. Between 1989 and 2003 some 300–620 t of coral trout and 33–95 t of redthroat emperor were discarded annually by the commercial reef line fishery on the GBR. Modelling of potential high-grading after the introduction of a (competitive) total allowable commercial catch for coral trout indicated that discarding of this species could increase to as much as 3,900 t. Spatial (but not temporal) differences in discarding rates were significant, and modelling indicated a potential for large increases in discarding rates and subsequent cryptic mortality as a result of changes in management arrangements.

The effects of hook pattern varied between species, with no consistent significant trends. Across all species only a relatively small proportion of fish (< 4%) were deep-hooked (in the throat or gut). Small hooks (5/0 circle and 4/0 J-hooks) were more likely to lodge in the lip or mouth than large hooks, although the effect was weak. Crimson snapper were significantly less prone to damage from non-offset circle hooks than either of the other patterns, but the opposite trend occurred with saddletail snapper. There was also a weak tendency for coral trout to sustain more injuries when captured on J-hooks or offset circle hooks than on non-offset circles. Hook size showed a more consistent trend, with large (8/0) circle or J-hooks being more frequently associated with injury than small hooks in all species, but this was statistically significant only in coral trout and blackblotch emperor.

Our controlled short-term (3-day) field experiments revealed that hook location was a major determinant of short-term survival in coral trout, crimson snapper and saddletail snapper. Even when the hooks were left in place according to best practice procedures, survival rates among deep-hooked fish were considerably reduced compared to those hooked in the mouth or lip. The modelled survival rates of shallow and deep-hooked fish repectively were as follows: coral trout 81 and 50%, redthroat emperor 86 and 59%, crimson snapper 96 and 35%, and saddletail snapper 73 and 38%. This represents an overall reduction across species in survival rate of around 50% as a result of deep hooking, even when the hooks were left in place. The results of our hooking damage experiment showed that the incidence of deep hooking was generally low across the species examined (< 4%), so that the predicted added mortality due to deep hooking would be in the order of 0.04 × 0.50, or 2%. However this figure probably underestimates the actual value, as not all anglers are prepared to cut their hooks off if the hooks have become lodged in the gullet or gut. It is also likely that the higher level of angling skill among researchers conducting the hooking trials accounted for a lower incidence of deep-hooking than might be expected across the general angling community.

Long term experiments using community based anglers showed that release condition was the most important factor affecting the subsequent recapture rate of all species. Initial capture depth was a significant factor for all species apart from crimson snapper and redthroat emperor with recapture rate decreasing with increasing capture depth. Three species (crimson snapper, saddletail snapper and redthroat emperor) were inferred to benefit from barotrauma treatment based on significantly higher recapture rates of treated fish. There was apparently no benefit in treating red emperor for barotrauma, a result consistent with findings of the short term experiment.

One of the best and most consistent predictors of post-release survival, evident in all experimental work and historic analyses, was the anglers' subjective assessment of the condition of the fish at release. As this assessment is only practicable after the fish has been placed back in the water, it is not particularly useful for identifying what (if any) pre-release treatment should be administered. However, if assessed using consistent criteria, release condition could be a useful index of the probability of recapture in tagging studies.

Unlike the community-based tag-release-recapture component of the project, the short-term deep enclosure experiments provided estimates of *absolute* mortality rates experienced by the various species under different handling/treatment regimes; tagging studies can (at best) only provide estimates of *relative* mortality. Even so, our short-term experiments were less than optimal for estimating post-release survival statistics, in that they were unable to incorporate the effect of predation on floating fish. It was originally anticipated that this, along with chronic effects relating to internal soft-tissue trauma, could be accounted for in the results of the tagging study. However, despite continued frequent contact and encouragement from Project staff, the community-based tagging study suffered critically from a lack of scientific rigour. This stemmed principally from participants' non-adherence to the experimental protocols. Some anglers failed to use the provided shot-release weights, and many only treated fish that they thought required treatment (i.e. were showing overt signs of barotrauma). Spatial differences in the balance between treatments and controls, and in the intensity of angling (recapture) effort, compromised the experiment to the extent that a large proportion of the data had to be excluded from the analysis to avoid an unacceptable level of bias, even after attempts by research staff to boost the numbers of appropriately-treated releases.

While the short- and long-term barotrauma relief experiments yielded variable and to some extent inconsistent results with each other and with the historical data, it was nevertheless clear that one key species (red emperor) stands out as being particularly robust in its capacity to withstand or recover from the effects of barotrauma. Red emperor had a high absolute survival rate in the short term experiments (98%) and may have a highly-developed capacity to repair perforations in the swimbladder, judging from the frequency of multiple recaptures recorded in the tagging database. The most susceptible species appears to be the saddletail snapper, which survived poorly relative to other species in the short-term experiments but responded positively to treatment, particularly venting. The closely-related crimson snapper had a much higher survival rate than saddletail snapper, but (partly for this reason) the survival of treated fish was not greatly different from that of the untreated controls. Redthroat emperor, with a 3-day survival rate of 85%, is one species that the results of the community-based long-term tagging experiment suggested would benefit more from shotline releasing than venting.

Our results suggest that red emperor caught from depths less than about 50 m should be released as soon as possible according to best-practice arrangements but without venting or shotlining. On the other hand, all other species that we tested will probably benefit from treatment prior to release, even though in most cases the magnitude of the benefit (increased survivability) may be quite small. The question of whether venting is superior to shotline-releasing or *vice versa* is problematic: our results show that except for better survival rates among vented saddletail snapper, the beneficial effects of the two treatments differ only marginally. There is little doubt that, in general, bloated fish unable to submerge effectively as a result of Stage 1 and 2 barotrauma will benefit from some sort of barotrauma amelioration on release. Our results showed that neither treatment had a significant detrimental effect on survival, and that fish which were able to submerge immediately on release into the deep enclosures suffered lower mortality rates than those that floated. There is also circumstantial evidence for very short-term delayed bloating, reinforcing the logical recommendation for minimising the time the fish is out of water, and focussing attention on some potentially adverse (but as yet unquantified) barotrauma-related effects of tag-release fishing activities on long-term post-release survival. Further work on alternative methods for overcoming positive buoyancy, such as the release capsule described briefly in the report, would be valuable, particularly if they were demonstrably safer for the average angler to use than the existing methods of venting and shotline releasing. Although not tested as part of this project, the various ‘common sense’ best-practice procedures currently being recommended to anglers should of course be reinforced. These include the use of knotless landing nets, de-hookers, leaving deeply-lodged hooks *in situ*, handling fish with a wet cloth to prevent the removal of the protective mucus layer, keeping the fish cool and covering its eyes.

1. ACKNOWLEDGEMENTS

Specific acknowledgements are included at the end of each individual chapter in this report. However we would like to thank the members of the Released Fish Survival Steering Committee for their advice and encouragement in establishing this Project. We also very gratefully acknowledge the contribution made by Dr Jill St John in communicating the results of her work in WA and exploring potentially better ways of addressing some of the experimental design issues. Many staff of the Reef Research CRC (now the Reef and Rainforest Research Centre) and the Department of Primary Industries and Fisheries assisted with the research work in one way or another, for which we are very grateful. We also acknowledge with thanks the financial contribution from the Australian Government’s Fisheries Research and Development Corporation (FRDC) which enabled this research to take place.

2. BACKGROUND

A considerable part of the tropical and sub-tropical line catch of fish is returned to the water because of minimum legal size (MLS) and bag limit regulations designed to protect pre-spawners and limit catches. It has been estimated that for many species more than half of the fish caught by recreational anglers are released (McLeay *et al*. 2002). There is growing concern about the fate of these released fish in offshore reef fisheries where barotrauma and poor handling techniques may reduce post-release survival (PRS). This has been recognised by a number of fisheries agencies throughout Australia that are seeking to conduct research to improve line caught fish PRS.

The FRDC had already funded research in Western Australia (FRDC 2000/194) on the effects of catch and release on snapper (*Pagrus auratus*) and dhufish (*Glaucosoma hebraicum)*. The effects of post-capture stress levels on barramundi (*Lates calcarifer*) (FRDC Project 2002/039) were also being studied in the Northern Territory. A number of other projects had been proposed by fisheries research agencies and as a result the FRDC sought to consolidate these into a national strategic program. To achieve this a study was commissioned (FRDC 2001/101) "National Strategy for the Survival on Line-caught Fish: A Review of Research and Fishery Information” and the final report has recently been made available (McLeay *et al*. 2002). This report recommended the establishment of two technical projects, one focussing on a suite of tropical and sub-tropical species, and the other on a suite of temperate species. The tropical/sub-tropical component (this proposal) related to species that had been identified in the McLeay *et al*. Report (2002) as being potentially the most susceptible to low PRS throughout the northern Australian States. These species include coral trout (*Plectropomus spp.*), redthroat emperor (*Lethrinus miniatus*), spangled emperor (*Lethrinus nebulosus*), golden snapper (*Lutjanus johnii*), red emperor (*Lutjanus sebae*), crimson snapper (*Lutjanus erythropterus*) and saddletail snapper (*Lutjanus malabaricus*). Two other priority species (Spanish mackerel and barramundi) that were also ranked as susceptible in the report were not included in this proposal. Barramundi was currently being investigated in the NT (FRDC Project 2002/039), and Spanish mackerel (*Scomberomorus commerson*) is a fast swimming pelagic species not amenable to caged experimentation; the preferred method of research highlighted by McLeay *et al*. (2002). Further, under existing size and bag limits, undersized mackerel make up a very small proportion of the catch, and legal sized specimens are rarely released. Until the results of current research into the use of 'gene tags' are available it was considered premature to embark on an extensive tagging program on this species.

This project addresses PRS issues for key tropical and sub-tropical reef fish species and involves close collaboration between the Department of Primary Industries and Fisheries (DPI&F Queensland), the CRC for Reef Research (now the Rainforest and Reef Research Ccentre, Townsville), and the Australian National Sportfishing Association (ANSA). The project maintained links with a project currently being developed in NSW which seeks to estimate and maximise the survival of released fish from coastal temperate ecosystems, and provides information that has been fed directly into the 'National Strategy for the Survival of Released Line Caught Fish: planning, project management and communication' project (FRDC 2002/099).

The development of 'best practice' handling procedures and the extension of these to the general fishing community has the potential of greatly increasing the PRS of the many millions of tropical and subtropical fish released each year. The quantification of PRS will also increase the precision of stock assessments provided to fisheries managers and increase the level of confidence with which management decisions can be made.

3. NEED

The report 'National strategy for the survival of line-caught fish: a review of research and fishery information' (McLeay *et al*., 2002) summarises the need for this research as follows:

"The commercial and recreational line fisheries are the most highly participatory of all Australia's fisheries. They are managed by a complex array of regulations, including size and catch limits, which create a high potential for captured fish to be released. The growing interest of recreational and charter fishers in catch-and-release practices has also increased release rates of line-caught fish. The susceptibility of line-caught fish to post-release mortality (PRM) is largely unknown, and is not taken into account in most current stock assessments".

Perhaps half of the fish caught by line in Australia are released, for a variety of reasons including minimum legal sizes, bag limits, catch-release philosophy etc. However, we have little idea of how many of these die as a result of hook damage, inappropriate handling, barotrauma or capture stress, nor what effect this source of 'cryptic' mortality will have on the long-term sustainability of the various fisheries.

While there is good information on release rates in the recreational line fishing sector there is also a need to test the supposition that the commercial sector catches few undersized fish and also establish any differences between the general recreational community and the charter sector.

To more realistically appreciate the full effect of line fishing on the various species, the released catch needs to be described and quantified, and an attempt made to estimate post-release survival (PRS) rates. Alternative capture methods (hook designs) need to be tested, to determine whether a change in apparatus (via regulation or a Code of Practice) could reduce the catch of undersized fish. Pre-release handling and barotrauma relief procedures need to be evaluated to determine whether any changes may increase survival of fish returned to the water.

CHAPTER 1. EFFECT OF BAROTRAUMA-RELIEF PROCEDURES ON THE SHORT-TERM SURVIVAL OF RELEASED LINE-CAUGHT RED EMPEROR (*Lutjanus sebae*).

I. Brown, W. Sumpton, M. McLennan, M. Campbell, J. Kirkwood, A. Butcher, I. Halliday, D. Mayer, A. Mapleston, D. Welch and G. Begg.

1.1 ABSTRACT

Red emperor (*Lutjanus sebae*) are an important component of the recreational and commercial handline fishery in tropical and subtropical Queensland coastal waters. A recent increase in the minimum legal size for this species has resulted in a substantial increase in discarding rate, but in the absence of knowledge about post-release survival the conservation value of this management intervention was uncertain. This paper describes a new experimental apparatus (a floating, cylindrical soft-mesh net 15 m deep and 2 m in diameter) for estimating short-term survival of released line-caught tropical reef fish, and its initial application in estimating post-release survival of red emperor.

To evaluate the effectiveness of the new apparatus we compared the 3-day survival rate of red emperor constrained in sunken cages with that of fish released into the vertical enclosure. None of the 34 caged fish survived the experiment, while all 30 fish in the vertical enclosures survived. The high cage mortality was probably due to abrasive damage to the fish resulting from wave-induced movement of the cages, so we opted to use the vertical enclosure in subsequent experiments to test the effectiveness of two barotrauma-relief procedures (venting and shotline-releasing) on red emperor.

The extent of visible signs of barotrauma varied significantly with capture depth, but extreme signs occurred less frequently in fish from the deepest depth ranges (40-50 m) than in those from intermediate depths (10-40 m). This counter-intuitive observation may be explained by our hypothesised Stage 3 barotrauma, in which gas previously released into the body cavity as a result of swim bladder rupture is completely vented from the body through terminal rupture of part of the alimentary canal. Small fish (22-27 cm) were less susceptible to barotrauma than large fish (32-48 cm). Eighteen fish that disappeared from the enclosures were ignored in the analysis, but of the 122 remaining only two (both of which had been shotline-released) died during the experimental period. Neither venting nor shotline releasing resulted in a significant improvement in short-term survival over non-treatment. We conclude that *L. sebae* has a comparatively low susceptibility to the effects of barotrauma, and unless a long-term survival advantage can be demonstrated from other data (such as might result from rapid removal of fish from the influence of near-surface predators) there seems little to be gained from promoting the use of barotrauma-relief procedures for this species.

1.2 INTRODUCTION

The tropical coral reef handline fishery in Queensland, Australia, is one of the State's most valuable fisheries. Annual commercial catches are currently estimated at 1500 t, worth about $33 million, and the recreational catch approximately 2600 t (Department of Primary Industries and Fisheries, 2007). In addition to the tropical coral reef fishery, there is also a very important handline fishery targeting subtropical and temperate rocky reef assemblages, particularly in the southern part of the State. In recent years attention has been drawn to the fact that not all fish released from the line fishery – for reasons of minimum legal size, bag limits or angling ethos – necessarily survive. Fish may sustain injury from poor handling practices, hook damage (Muoneke and Childress 1994; Cooke and Suski 2004) or barotrauma

(Rummer and Bennett 2005) leading to a chronic reduction in physiological fitness and reproductive potential or to acute or delayed mortality.

The realisation that such cryptic mortality may be a significant contributor to actual fishing mortality has led to attempts to estimate the proportion of the catch that is released in a number of fisheries. Diary and telephone surveys of recreational anglers in Queensland (Higgs 1999, 2001) and more generally throughout Australia (Henry and Lyle, 2003) indicate that about half of the recreational catch (by number) of line-caught fish is released. With the application of increasingly stringent minimum and maximum legal sizes and bag limits as management mechanisms for maintaining effective spawning stock sizes and limiting fishing mortality, the release rate in many of these fisheries is likely to increase. For example, the change in the MLS of red emperor (*Lutjanus sebae*) in 2003 from 45 to 55 cm has almost certainly resulted in a marked increase in the discard rate of this species in both the commercial and recreational sectors. Recent boat ramp surveys in Central Queensland have revealed that 89% of the recreational catch of red emperor had been released (B. Sawynok, pers. comm.). The corresponding decrease in the retention rate is highlighted by recent marked declines in the recreational catch of *L. sebae* from 393 t in 2002 to 232 t in 2005 (Annual Status Report – Coral Reef Finfish Fishery, 2007). Even more dramatic has been the progressive decline in commercial landings of red emperor, from around 200 t in 2001–02 to 28 t in 2005–06, as reported through the State's compulsory commercial logbook program (L. Olyott, pers. comm.), although this may be partly accounted for by the introduction of a quota system.

Although the potentially adverse pressure-related effects of bringing a line-caught fish from depth to the surface has been recognised for some time (e.g. Harden-Jones 1952; Blaxter and Tytler 1978), much of the recent literature on quantifying the effects of fishing on post-release survival have focussed on the importance of hook damage (e.g. Muoneke 1992; Muoneke and Childress 1994; Malchoff 1995; Bacheler and Buckel 2004; Conron *et al*. 2004; Cooke and Suski 2004). Many studies have attempted to evaluate the survival advantage to the target species of using a specific hook pattern – particularly the circle hook (Otway and Craig 1993; Arterburn and Berry 2002; Cooke *et al*. 2003; Meka 2004; Cooke and Suski 2004; Bacheler and Buckel 2004), but also barbless hooks (Schill and Scarpella 1997; Schaeffer and Hoffman 2002), and lures (Malchoff and Heins 1997; Faragher 2004).

Species inhabiting deep water are subject to barotrauma, or pressure-related injury, when hauled to the surface (Bruesewitz *et al.* 1993). One of the clearest external signs of barotrauma is an enlargement of the body cavity due to over-inflation of the hydrostatic organ or swim bladder. This can cause the fish to become positively buoyant and experience difficulty in swimming down from the surface when released, making it vulnerable to predators. In severe cases this may extend to an everted gut, with part of the alimentary canal protruding from the mouth or gill cavity, exophthalmia (bulging eyes) or external haemorrhaging around the vent. In addition to these visible signs, a suite of external and internal symptoms which can be severe enough to cause mortality, termed catastrophic decompression syndrome (CDS), has been described by Rummer and Bennett (2005). Barotrauma was identified by McLeay *et al.* (2002) as a potentially important contributor to post-release mortality in Queensland's tropical reef fish stocks, which in the main are physoclistous (with closed swim bladders) and caught from depths at which barotrauma has been documented in similar taxa elsewhere.

This research, set up on the establishment of the National Strategy for increasing the survival of released line-caught fish (an initiative of the Fisheries Research and Development Corporation and various Australian recreational fishing bodies) aimed to evaluate two different barotrauma-relief methods. The two methods involved are (i) venting (deflating the over-expanded swim bladder by puncturing the body wall with a hollow needle), and (ii) shotline releasing (compressing the swim bladder to its original volume by forcing the fish back down to its capture depth).

Venting has been recommended for some years by the angling industry in the USA (Florida Sea Grant, 1999) and more recently Australia with the 'National Strategy for increasing the survival of released line-caught fish – *Gently Does It'* program (www.info-fish.net/releasefish). It is achieved by puncturing the swim bladder with a 1.5" 16-gauge (38.1 x 1.6 mm) monoject hypodermic needle attached to a disposable 3 ml plastic syringe with the plunger removed. The needle was inserted under a scale through the body wall in line with the top of the pectoral fin base and below the fourth dorsal spine (all experimental species had spinous first dorsal fins). Once the epidermis had been punctured the syringe was lifted to a more vertical orientation with respect to the side of the fish, and pushed through the musculature into the swim bladder. A successful procedure was indicated by the audible hiss of gas escaping through the syringe, facilitated if necessary by gentle pressure on the body wall.

Shotline releasing involves attaching the fish to a barbless hook embedded in a heavy lead weight, then lowering it to a suitable depth where it achieves neutral buoyancy and is released by jerking the line (Bartholomew and Bohnsack 2005). The shotline release rig has come to light in Australia only in the last few years with its production and sale by a few tackle manufacturers, initially in Western Australia. While it is being promoted as a possible alternative to venting, its relative effectiveness for mitigating the effects of barotrauma has received little formal attention (Bartholomew and Bohnsack 2005), although St John and Syers (2005) found it an effective way to release Westralian dhufish (*Glaucosoma hebraicum*).

A number of studies have examined the effectiveness of venting as a barotrauma-mitigation procedure, but with inconsistent results. Swim-bladder deflation by venting was found to improve the survival rate of released black sea bass (Collins *et al.* 1999), vermilion snapper (Collins *et al.* 1999), groupers (Wilson and Burns 1996) and yellow perch (Keniry *et al.* 1996). However other studies on rockfish (Gotshall 1964), burbot (Bruesewitz *et al.* 1993), and red snapper (Render and Wilson 1994) failed to detect any significant improvement in survival as a result of venting, and Bartholomew and Bohnsack (2005) caution that more conclusive evidence is needed before venting can be advocated as a generally beneficial barotrauma treatment.

A review of the status of research and fishery information about released fish survival (McLeay *et al.* 2002) recommended the adoption of certain consistent experimental protocols for investigation of short-term survival rates in fish potentially subject to the effects of barotrauma. These reflected the techniques adopted and later published by St John and Syers (2005), which involved containing fish in small enclosed cages sunk to an appropriate depth and moored for a period of 3-4 days. A variation on this method, involving the addition of a video camera and an automatic-opening escape door to the cage has been used successfully in a study of the release behaviour of *Sebastes* species after recompression (Hannah and Matteson 2007). As a result of considerable discussion following a technical workshop at the Southern Fisheries Research Centre (September 2003), the Project team decided to pursue the concept of an open-top floating enclosure as an alternative experimental apparatus to the closed cages used previously in WA by St John and Syers (2005), and more recently in NSW by Stewart (2008).

A serious weakness of experiments using enclosed cages is that cages do not allow for untreated controls. Forcing non-vented fish to the bottom in a cage does not constitute ‘non-treatment’, but is itself a treatment, approximating the shotline release. Moreover, cage experiments are a poor simulation of reality, as they fail to reflect the sequence of events typically experienced by fish released after being caught and brought to the surface. Untreated release occurs frequently in reality, and may result in a bloated fish either recovering to the extent that it is able to swim down to equilibrium depth or being damaged or killed by predators. Cages do not allow these possibilities to be examined, even qualitatively (Pollock and Pyne 2007). Logistic considerations are also important. Ideally, once a fish is caught and vented it should be released as soon as practicable to avoid exposure to unduly long and variable surface intervals (i.e. the time between capture and release). If capture events are infrequent, it may not be possible to place more than 3 or 4 fish to a cage without seriously extending the surface interval. An experiment may therefore require the use of many small cages to be deployed simultaneously, with the need for a large amount of costly mooring equipment.

In considering issues of experimental design, logistics and reality simulation, we designed a vertical enclosure or ‘sock’ into which fish could be placed. The advantages of this system were that it should (i) provide for the inclusion of untreated controls in the experimental design (i.e. the apparatus itself did not constitute a treatment, as it did in the case of the cages), (ii) provide an environment into which fish could be released with the aid of a shotline, (iii) allow for an examination of the situation where a released fish may drift on the surface, during which time (in its natural environment) it could be at considerable risk of predatory mortality, (iv) reduce the surface interval by allowing marked fish to be released into the apparatus at any time, and (v) improve the efficiency of the experiment by enabling significantly more fish (30-40) to be held in the apparatus at any one time.

Prior testing of the vertical enclosure on the eastern side of Moreton Bay along the north-western shore of Moreton Island satisfied one of our major concerns about its deployment – i.e. whether it would hang more or less vertically in the currents expected in areas likely to be close to fishing locations. The other major unknown was whether fish caught in depths exceeding 15 m would be able to equilibrate effectively at 2.5 atmospheres (the pressure at the bottom of the sock). If they could not, then the sock in its planned configuration may not be an appropriate apparatus to use for these experiments.

Given the agreement between researchers working on post-release survival (PRS) projects under the National Strategy to adopt similar research protocols, apparatus and data reporting systems, we agreed that it would be appropriate to conduct initial trials to compare the relative effectiveness of the sock and cages as experimental apparatus. This would also provide us with information we could compare with that derived from the WA project, although the cage designs and deployment arrangements were not identical.

The National PRS Steering Committee was asked (10 Nov 2003) to comment on our intentions to adopt what we considered to be a more appropriate experimental apparatus and our proposed experiment to compare the effectiveness of the two types of gear. The Steering Committee considered our justification and provided written endorsement of our plan (16 Nov 2003), with support from the FRDC.

As part of a more extensive project supported by the Australian Government’s Fisheries Research and Development Corporation, we designed an initial experiment (Experiment A) to (i) evaluate the deployment and retrieval of the experimental apparatus under field conditions, (ii) determine whether one key tropical reef fish species could equilibrate at 2.5 atm regardless of capture depth, and (iii) compare the survival rates of fish held in cages and vertical enclosures. A follow-up experiment (Experiment B) was designed as the first application of the new vertical enclosure apparatus in testing the effectiveness of two barotrauma-relief procedures on the short-term survival of red emperor.

1.3 MATERIALS AND METHODS

1.3.1 Experimental site selection

An area north of Double Island Point (25° 55’S, 153° 11’E; Figure 1-1) was chosen as the main site of this experiment, because of its proximity to reefs supporting populations of red emperor fished regularly by a local charterboat operator prepared to collaborate with the project. The area was also reasonably protected from prevailing south-easterly winds and ocean swells. Additional data on a small number of red emperor were also collected from a site off the north-east corner of the Heron Island Reef (23° 25’S, 151° 59’E; Figure 1-1).

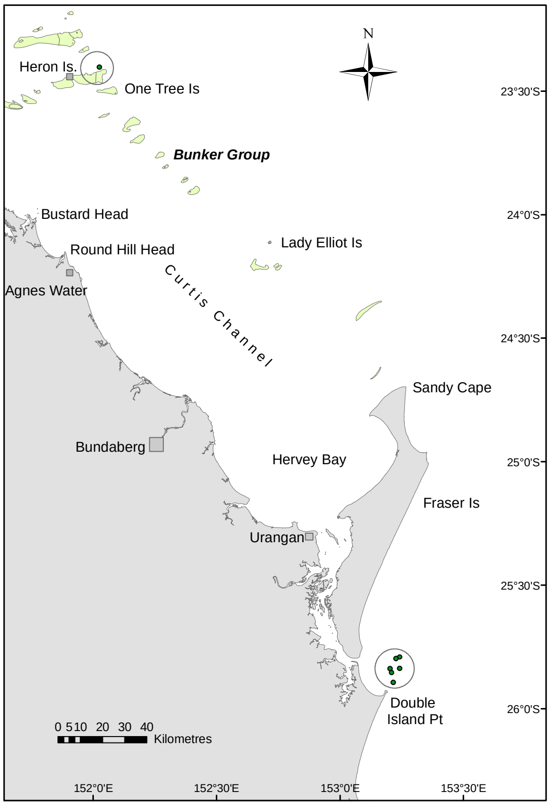

Figure 1-1. Location of experimental sites off Double Island Pt and Heron Island (circled).

1.3.2 Experimental design: small cage and large vertical enclosure comparison

The following 3-day experimental design was used to test for differential survival of fish captured from depths of 30–50 m and released either into an enclosure (control, shotlined or vented), or submerged in cages (no treatment). Each cage was to contain no more than three fish, and two cages were asigned to each of the two depths (15 and 30 m). The total number of fish (experimental units) required was therefore:

(2 cages × 2 depths × 3 fish × 1 release method × 3 day reps) + (1 enclosure × 5 fish × 3 release methods × 3 day reps) = 36 + 45 = 81 (i.e. 27 fish per day).

1.3.3 Apparatus design

Cages were similar in size to those described by St John and Syers (2005) and of comparable design to the collapsible traps used in the Queensland blue swimmer crab fishery. These consisted of two 1 m diameter metal hoops separated by four 350 mm high tubular plastic risers and covered with either 50 mm x 36 ply orange nylon mesh or 25 mm x 9 ply blue nylon mesh. Fish were placed into the cage via a drawstring-constrained opening in the upper surface. Cages were deployed in strings of four. The first cage was suspended (at 15 or 30 m depth) from a surface float which was moored by a 10 kg anchor on 60 m of rope, and trailed a dan-buoy with radar reflector, flag and night-light. The second cage, with its own surface float, was attached to the first cage's float line via a 15 m line with a heavy stainless steel clip-ring which slid down the first float line to the top of the first cage. This arrangement allowed each successive cage to be deployed and retrieved with minimal disturbance to the previous one.

Vertical enclosures comprised eight horizontal 1.9 m diameter steel hoops separated by approximately 2.5 m of 101 mm x 36 ply brown mesh, except for the top two hoops which were held 0.5 m apart by solid welded rods (Figure 1-2). Four large floats were attached to the inside of the second metal ring to give the sock positive buoyancy at the surface. The eighth (bottom) ring was approximately 15 m below the surface. A 20 m x 12 mm retrieval rope was connected to a 1.2 m 4-arm ‘spider’ chain, which was in turn attached to the seventh spacer ring 2.5 m from the bottom of the apparatus. The retrieval rope was held centrally inside the top ring by a 50 mm s/s locating ring. On retrieval by crane, the apparatus collapsed in concertina-fashion except for the bottom-most compartment holding the fish, which could then be released from the ‘cod end’ of the enclosure.

Each enclosure was held in place by two in-line anchors (16 kg and 10 kg) linked by 10 m of 8 mm chain and 60 m of anchor rope. A dan-buoy was attached directly to the retrieval rope on the second sock and floated approximately 5 m downwind of the apparatus, allowing easier release of fish into the enclosure. Net lights were attached to the upper ring of each enclosure and to the cage arrays.

Experiment A: Comparison of cages and vertical enclosures.

This experiment was conducted over the period 7-13 August 2004 at Double Island Pt (25º 50’ S; 153º10’ E). Fishing was conducted from the RV *Tom Marshall*’s tender, a second outboard-powered research vessel, and from the charterboat *Bait Runner* by charter clients. Red emperor caught during the experimental period were tagged, treated and released into either the cages or enclosures.

Data for each fish recorded at the point of capture included fisher name, time of day, species, fish fork length (FL), hook type and size, capture depth, hook penetration location (lip, mouth, throat, gut or other/foul), hook damage (mouth, gill, eye), evidence of bleeding or scale loss (nil, slight or severe), and external signs and extent of barotrauma (nil, bloating, gut extrusion and/or exophthalmia). After insertion of a uniquely-numbered HallPrint™ dart tag into the dorsal musculature, the fish was placed into a holding tub filled with clean seawater and as soon as practicable transported to the cage array or enclosures, a distance of approximately 3 km. The surface interval (time between capture and release into the experimental apparatus) was kept as brief as possible, as we recognised that this interval in our experiments was likely to far exceed that occurring in a typical recreational angling context. Fish destined for the cages were not treated, while those destined for the vertical enclosures were either left as untreated controls, vented or placed into the enclosure using a shotline release device. The two treatments and control were done in sequence to ensure an equal number of replicates for each. The condition of vented and control fish on release into the enclosure was assessed subjectively and given a score from 1 (excellent condition, with the fish swimming away and down strongly) to 5 (moribund or probably dead). It was clearly not possible to evaluate the condition of shotline-released fish in the same way.

During the experimental period the behaviour and condition of the fish in the vertical enclosures were observed by underwater video camera lowered from the surface, and periodic observations on the enclosures were also made by SCUBA-equipped divers.

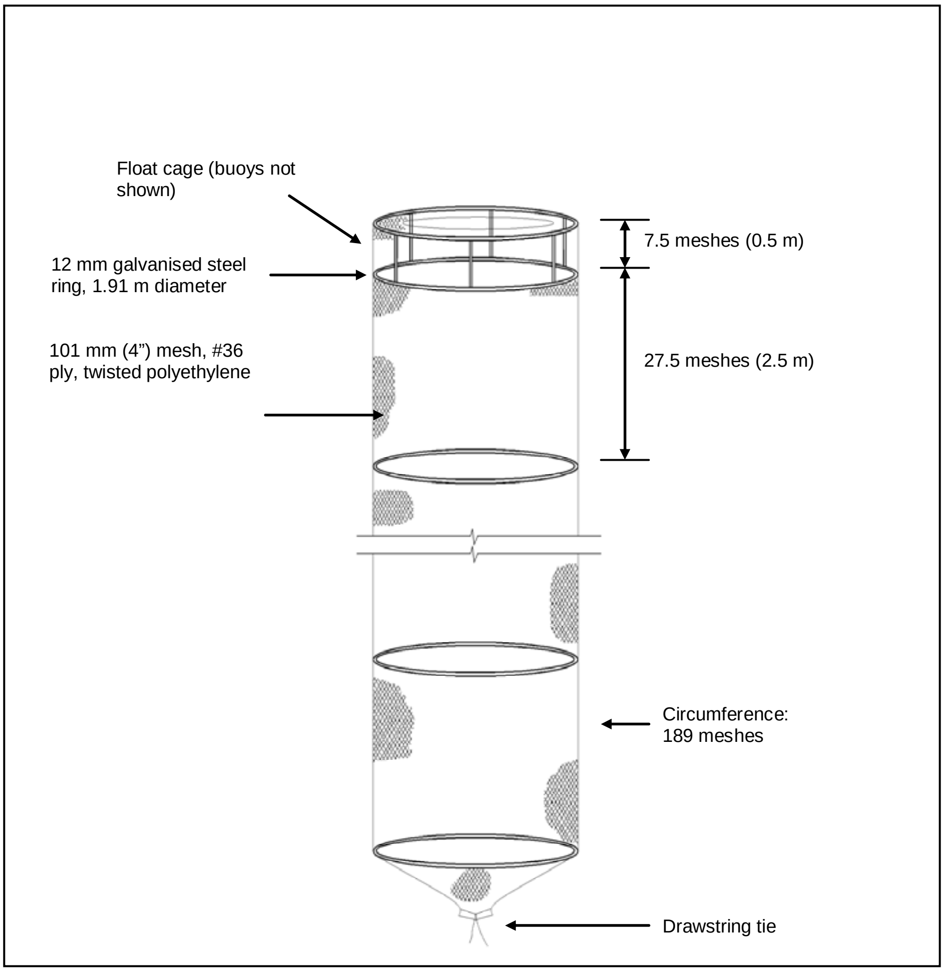

Figure 1-2. Diagrammatic representation of the vertical enclosure (not to scale). Note that the four inflatable buoys in the float-cage are not shown.

After each enclosure or line of cages had been deployed for 3 days the apparatus were retrieved (the cage lines by hand from the small vessels and the enclosures using a hydraulic crane on the RV *Tom Marshall*). On retrieval the condition of each fish was noted and recorded (together with its tag number) and the survivors were released.

Experiment B: Effect of release method on survival.

Following analysis of the data from the first experiment it was clear that vertical enclosures were superior to small cages for testing short-term survival in red emperor. Additional data were therefore obtained during two subsequent operations near Heron Island (6-9 March 2005 and 11-13 June 2005 respectively). Apart from some modifications to the ground tackle, deployment technique and safety arrangements, the same experimental protocols were followed as during the first deployment. The final experiment was again conducted at Double Island Point (26-28 July 2005).

1.3.4 Data analysis

The data from this experiment were analysed by multi-factor generalised linear models (GLMs; McCullagh and Nelder 1989) in GenStat (2007) with the binomial distribution and logit link function. Survival was the binary response variate, with block (a combination of trip and enclosure number), entry condition and treatment the predictor variates. Additional GLM analyses were used to examine the effect of capture depth and body size (FL) on the incidence of barotrauma symptoms. In three sequential analyses the binary response variates were (i) no barotrauma signs, (ii) swelling or bloating, and (iii) stomach eversion. In all cases the models tested the effects of three depth ranges (shallow: 8-13 m; moderate: 32-45 m; and deep: 46-49 m) as categorical variates and fork length (mm) as a continuous variate.

1.4 RESULTS

1.4.1 Experiment A: Comparison of cages and vertical enclosures.

Deployment of apparatus

Deployment and retrieval of the vertical enclosures revealed some minor operational problems, including less than optimal night-time visibility. The new compact cylindrical radar reflectors were not particularly effective, so they were replaced by the traditional diamond-shaped aluminium reflectors. The night lights were too low, being only marginally above the top of the float frame. While it was possible to slide the camera down the central lifting line to observe the fish inside, there was a significant risk of its snagging on the mesh or spider in strong currents.

Problems were encountered in lifting the enclosure from the bottom, as fish became entrapped in folds of collapsing mesh between adjacent support rings, and were difficult to remove without cutting the mesh. We recommended modifications to the lifting system to prevent the bottom section of the enclosure from collapsing when being retrieved, and to avoid the need for divers to assist in the retrieval process. The mooring system required the use of a dory to disconnect the anchor line from the enclosure prior to retrieval by the RV *Tom Marshall*'s hydraulic crane. We also concluded that a less complicated mooring arrangement, which did not require the use of the dory, would be an advantage.

Cages were time-consuming to set up and deploy. With two or three ropes and a buoy attached to each cage, there was a high probability of fouling or snagging ropes. In a small vessel in poor sea conditions this is an undesirable work situation. Floating the cages from a surface buoy exacerbates cage-surge effects because of the influence of ocean swells. An alternative option – anchoring each (buoyant) cage individually – was considered. However, the need to compare survival of fish in cages at both 15 and 30 m depths would require that each cage be not only anchored to the sea floor, but also buoyed at the surface in case of gear loss. This would require another three anchors and associated attachment ropes for each line of cages, and given the likelihood of gear tangling, such an experimental procedure would only be feasible in very sheltered waters at an unacceptably large distance from the point of fish capture.

As a result of these operational difficulties and shortcomings during the first experiment, certain changes were made to the enclosure mooring and rigging system to streamline the deployment and retrieval process.

Experimental apparatus comparison

a) Depth equilibration of red emperor

Twelve red emperor between 22.5 and 43.0 cm FL, caught in depths ranging from 42.5 to 48.5 m, were released into the two socks without any barotrauma-relief treatment. These fish all swam down into the vertical enclosure as soon as they were released, and none was observed floating on or near the surface. Observations by divers and with an underwater video camera lowered into the enclosure on three occasions over the next three days revealed that the fish were swimming in the area about 1 m above the bottom-most ring, apparently with no adverse equilibration effects. Some of the fish had a slightly ‘head-up’ orientation, but appeared unstressed, frequently approaching the camera and divers in an inquisitive manner. Likewise, all treated fish survived the 3-day holding period in the enclosure (Table 1-1).

b) Difference in survival of red emperor between cages and enclosures

The results of this aspect of the experiment were quite clear, and statistically significant ($\chi^2_{(1\ \mathrm{d.f.})} = 64.0$; $P < 0.001$). None of the 34 red emperor contained within the experimental cages survived the 3-day period, regardless of the depth of capture or the depth at which the cages were suspended (Table 1-1). In contrast, all 35 fish released into the vertical enclosures were alive and in excellent condition when they were retrieved at the end of the experiment, although some were reported to have sustained some slight damage (split fin rays) to the caudal fin. When released following retrieval of the enclosures after the 3-day experimental period, the fish swam away and downwards from the release point. It is interesting to note that the only fish needing to be vented after being brought to the surface in the sock was one that had already been vented as a treatment on initial capture.

Table 1-1. Summary of survival results from the enclosure and cage comparison.

Apparatus	Treatment	No. fish	Survived	% mortality
Cage line 1 (30 m)	nil	8	0	100
Cage line 2 (15 m)	nil	8	0	100
Cage line 3 (15/30 m)	nil	8	0	100
Cage line 4 (15/30 m)	nil	10	0	100
Cage Totals	nil	34	0	100
Enclosure	control	12	12	0
	vented	11	11	0
	shotlined	12	12	0

1.4.2 Experiment B: Effect of release method on survival.

Comparison of barotrauma-relief release methods

The success of the vertical enclosure compared to the suspended cages from Experiment A provided justification for adopting the former apparatus in the barotrauma-relief method comparisons undertaken in Experiment B.

Over the period of the four field trials at Double Island Point and Heron Island, 142 red emperor were captured, tagged, treated according to the experimental protocols, and introduced into one of three identical vertical enclosures. Approximately equal numbers of fish were vented, shotline released and used as untreated controls (n = 46, 48 and 48, respectively; Table 1-2). Note that the data from the 2004 trials (Table 1-1) were also used in the analysis of Experiment B.

During Trip 4 (Heron Island) two red emperor, as well as several individuals of other species being tested at the same time, disappeared from the enclosure (Table 1-2). Strong currents were experienced, causing the enclosures to lie over in the water. The angle at which they were hanging allowed the lip of the top opening to dip below water level, providing an opportunity for fish to escape. In addition, on retrieval some small holes were seen near the bottom of the enclosure, probably as a result of a shark attacking a dead fish lying against the mesh. As neither of the two missing red emperor had exhibited signs of barotrauma, hooking injury or bleeding on capture, we suspect that they probably escaped from the top of the enclosure.

Table 1-2. Summary of the numbers and fate of fish used in the experimental enclosures during the four field operations

Treatment	Count	Trip Number				Total
		2	4	5	6	
Control	N	12	2	1	33	48
	Survived	12	1	1	27	41
	Died	0	0	0	0	0
	Missing	0	1	0	6	7
Vented	N	11	1	0	34	46
	Survived	11	1	0	30	42
	Died	0	0	0	0	0
	Missing	0	0	0	4	4
Shotline released	N	12	2	0	34	48
	Survived	12	1	0	26	39
	Died	0	0	0	2	2
	Missing	0	1	0	6	7
Total	N	35	5	1	101	142
	Survived	35	3	1	83	122
	Died	0	0	0	2	2
	Missing	0	2	0	16	18

Sixteen fish also disappeared from one of the enclosures during Trip 6 (Double Island Point; Table 1-2). When the enclosure was lifted there were signs of considerable damage to the net and metal framework. The cause of this damage is not known, but is thought to have resulted from contact with a passing vessel during the night. From the tag numbers of the fish remaining in the enclosure it was possible to identify which individuals had escaped and to which treatments they had been subjected. Six control and six shotline-released fish were among the escapees, as were four vented fish. The difference between these numbers was not significant, so it appears unlikely that the treatment was associated with the fact that they escaped. These fish were excluded from further analyses of survival rates.

Two fish in separate enclosures died, with the result that the overall survival rate of red emperor in this experiment was 98.4%. The two fish were approximately the same size (32 and 30.5 cm FL), and had been caught by different anglers in depths close to either end of the range of reported capture depths (32 and 49 m). Because there were only two deaths, there is little ‘signal’ in the data. The initial GLM showed that neither the enclosure-site combination (block) nor the method of barotrauma relief had a significant effect on short-term survival rate, with probability levels of 0.85 and 0.10 respectively (Table 1-3).

A second GLM examined the effect of entry condition on survival, a subjective classification of the overall condition of the fish on release into the experimental enclosures. Condition was scored on a scale from 1 (excellent) to 5 (moribund or dead), and for the purposes of this analysis was deemed to represent the combined effects on the animal's behaviour of all injury and stress potentially resulting from capture, handling, tagging and surface interval. As block was the less influential factor in the initial analysis, this was dropped to allow the effects of entry condition and treatment to be tested simultaneously.

As in the first analysis, neither factor was significant at the 95% level of probability (Table 1-4). The modeled adjusted mean survival rates for vented and control fish were the same at ~100%, and were slightly less for shotline-released fish at 95%.

Table 1-3. Analysis of deviance table from 2-factor GLM showing the significance of the main effects Treatment and Block on survival.

Source	d.f.	Deviance	Mean Deviance	Deviance Ratio	Approx. P (Chi sq)
Block	7	3.3262	0.4752	0.48	0.853
Treatment	2	4.6192	2.3096	2.31	0.099
Residual	114	12.5307	0.1099		
Total	123	20.4761	0.1665		

Table 1-4. Analysis of accumulated deviance table from GLM showing the significance of the main effects Treatment and Entry Condition on survival rate.

Source	d.f.	Deviance	Mean Deviance	Deviance Ratio	Approx. P (Chi sq)
Treatment	2	1.6208	0.8014	0.81	0.445
Entry condition	2	4.5959	2.2980	2.30	0.100
Residual	119	14.2593	0.1198		
Total	123	20.4761	0.1665		

Effect of capture depth and body size on barotrauma

The 112 red emperor for which both capture depth and barotrauma symptom data were available were taken from depths ranging from 8 to 49 m (mean: 43.3 ± 8.2 s.d). Those caught at Heron Island were from depths shallower than 15 m, while those at Double Island Point were from depths greater than 25 m. To investigate whether the various observed barotrauma symptoms were a function of capture depth or body size, data were analysed by successive GLMs, with each barotrauma category (none, swollen body, and everted gut) a binary response in turn. No red emperor in this study showed signs of exophthalmia. There was a slight but statistically significant inverse relationship between fish size and capture depth (r: -0.288; $P < 0.001$).

Body size (fork length) influenced the susceptibility of red emperor to barotrauma, as indicated by the primary signs described above; for bloating $P = 0.006$ and for gut eversion $P = 0.042$ (Table 1-5). In the shallowest depth class (mean depth: 9.7 ± 0.8 m) none of the fish exhibited any external signs of barotrauma, regardless of their size (Figure 1-3a). However in intermediate depths (mean: 43.3 ± 0.3 m) large fish were more likely to be bloated than small individuals (Figure 1-3b), and in the deepest depth range (mean = 47.3 ± 0.19 m) gut eversion was more prevalent among small than large fish (Figure 1-3c).

Table 1-5. Accumulated deviance table from three GLM analyses of the effects of capture depth and body size on the susceptibility of red emperor to barotrauma.

Response variate	Source	d.f.	Deviance	Mean deviance	Deviance ratio	Approx. P (Chi sq.)
No b/t sign	Capture depth	2	3.269	1.634	1.63	0.195
	Length	1	1.922	1.922	1.92	0.166
	Length.Capture depth	2	3.975	1.988	1.99	0.137
	Residual	106	112.209	1.059		
	Total	111	121.375	1.093		
Swollen	Capture depth	2	2.789	1.394	1.39	0.248
	Length	1	7.586	7.586	7.59	0.006
	Length.Capture depth	2	1.860	0.930	0.93	0.395
	Residual	106	83.143	0.784		
	Total	111	95.378	0.859		
Gut everted	Capture depth	2	2.179	1.089	1.09	0.336
	Length	1	4.152	4.152	4.15	0.042
	Length.Capture depth	2	0.009	0.004	0.00	0.996
	Residual	106	56.300	0.531		
	Total	111	62.640	0.564		

Incidental observations on dissected red emperors have revealed that swim-bladder rupture is common. Of the five red emperor sampled from the research catch at Double Island Point on 28/4/06, four showed evidence of swim bladder rupture, with one or more perforations apparent in the ventral surface. All five fish had been captured at the same depth (56 m), and they ranged in size from 27 to 44 cm FL. The individual whose swim bladder was intact was the second smallest of the sample (33 cm). Another sample of several fish species was taken from deeper water (72 m) SE of Double Island Pt on 12/12/06. The one red emperor in this sample was a small fish (26.5 cm FL) whose swim-bladder had a 15 mm perforation in its ventral surface (Figure 1-4).

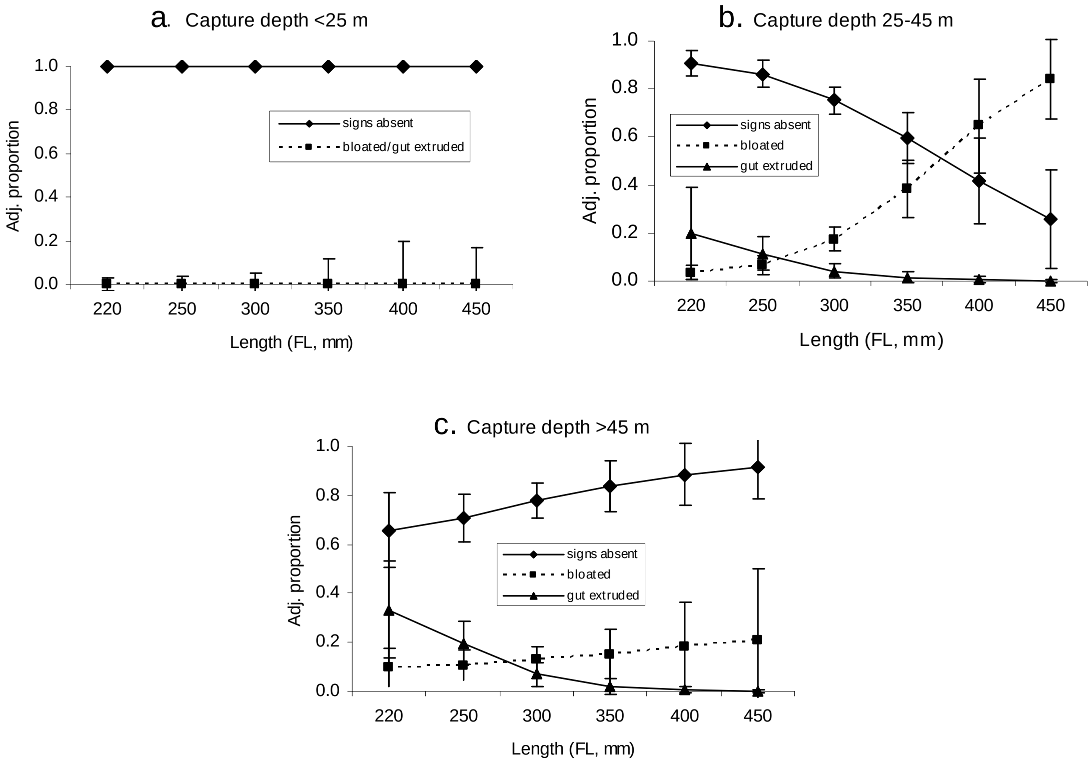

Figure 1-3. Effect of body size on the presence and severity of barotrauma symptoms in red emperor caught from shallow water (a), intermediate depths (b), and deep water (c). Values are GLM adjusted mean proportions estimated from separate models, so may not necessarily sum to unity at a particular fork length value.

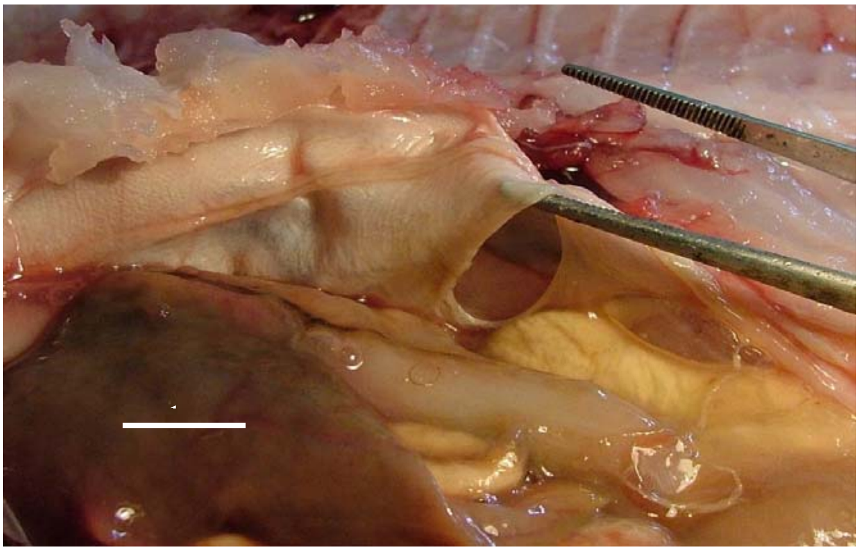

Figure 1-4. Perforation in the swim bladder of a 26.5 cm red emperor.

Multiple recaptures of tagged red emperor

Additional insights into the post-release survival of red emperor in the longer term are beginning to emerge from Queensland's State-wide recreational anglers' tag-recapture (SunTag) database, administered by Infofish Services Inc. Many anglers in Queensland specialise in tag-release activities and contribute comprehensive information to this database.

Since 2003 some 4740 red emperor have been tagged and released, and of these 514 (10.8%) have been recaptured on at least one occasion. Eighty-one fish have been recaptured twice, 25 three times, 7 four times, 4 five times, and 4 on more than five occasions. Two individuals have been recaptured on eight separate occasions over a 24 month period, and many of the recaptures occurred within days or even hours of release. Although the mean depth of capture was around 40 m, very few of these tagged and released fish had received any pre-release barotrauma treatment, suggesting that this species exhibits a relatively high degree of resilience to the effects of barotrauma.

1.5 DISCUSSION

Certain minor issues arose with respect to the deployment and retrieval of the vertical enclosures or socks. These included visibility at night, type and position of radar reflectors, the need for a simpler mooring system, and a better arrangement for lifting the sock to prevent bunching of the net between spacer rings. Real-time observation of fish in the sock was possible, but a better system for lowering and raising the camera needed to be developed to prevent snagging. These were not critical issues, but all were addressed later in the project to streamline the field operation.

The results of the initial survival comparison were unequivocal. All fish in the cages had died after three days, while all of the fish in the vertical enclosures appeared quite healthy after the same period. This indicates that at least one key coral reef species is capable of equilibrating at 15 m depth, even when caught from depths close to 50 m and released without venting or the aid of a shotline.

The unexpectedly high mortality of fish in the enclosed cages is attributed to vertical movement of the cages as a result of swell and sea conditions. On retrieval, all caged fish were in a relatively advanced state of decomposition and showed signs of significant scale loss, probably as a result of abrasion against the mesh wall of the cage. Similar, although less serious, problems of midwater cage movement and 'sand-blasting' of fish in bottom-set cages were experienced during experiments on survival of snapper and dhufish in Western Australia (J. St John, pers. comm.). On the other hand high survival was observed among cage-held tautog in Chesapeake Bay despite rough sea conditions (Lucy and Arendt 2002). The difference in survival rate of red emperor between vertical enclosures and cages strongly indicates that, at least in the sea conditions experienced in our study area, the former is far the more suitable for this type of experiment.

Our experiments show red emperor to be a relatively robust species and not especially susceptible to the short-term effects of barotrauma. This contrasts significantly with the situation in the congeneric red snapper (*L. campechanus*) in the Gulf of Mexico described by Rummer and Bennett (2005). These authors found over 80% of red snapper taken from depths of 30-60 m showed external signs of barotrauma. Moreover, nearly a quarter of the vented fish died within an hour of the venting procedure, and another 10% died during transport or within 12 hr of return to the laboratory.

While we found a clear depth-related difference in the frequency of red emperor exhibiting external signs of barotrauma, it was not a consistent trend. Other studies suggest considerable variability between species in the relationship between barotrauma signs and depth of capture. Progressive increases in the incidence of swim-bladder over-inflation, stomach eversion and exophthalmia with increasing capture depth have been reported in West Australian dhufish (St John and Syers 2005), tautog (Lucy and Arendt 2002) and black rockfish, blue rockfish and yelloweye rockfish, but not canary rockfish (Hannah and

Matteson 2007). In laboratory decompression trials simulating a range of equivalent capture depths, Rummer and Bennett (2005) found no depth-related differences in external barotrauma signs in red snapper, despite considerable evidence of soft-tissue damage and high short-term mortality.

If the severity of barotrauma is a function of depth, the occurrence of signs such as bloating and gut extrusion would be expected to continue to increase as capture depth increases. Conversely, the occurrence of fish with no observable signs of barotrauma would be expected to be greatest in fish from the shallowest depths and least in fish from deeper water. The explanation for external barotrauma signs being less frequent than expected in red emperor when caught from deep water may have to do with circumstances surrounding and following swim bladder rupture. Swim bladder rupture occurs in red grouper (*Epinephelus morio*) at capture depth exceeding 20 m (Burns and Restrepo 2002), and in red snapper at 30 m (Rummer and Bennett 2005). We suggest that there are three distinct stages of barotrauma with respect to visible symptoms:

Stage 1: Initial inflation of the swim bladder in response to reducing ambient pressure. This leads to the swelling of the body as the available space within the body cavity is occupied by the expanding hydrostatic organ, as a result of which the fish becomes increasingly buoyant.

Stage 2: Over-inflation and rupture of the swim bladder. The perforated bladder collapses, releasing gas directly into the body cavity. If the swim bladder is strong and relatively inelastic, the increase in gas volume might be quite sudden and potentially traumatic to the fish. At this point the gas surrounds the visceral organs, taking up available space within the confines of the partly distensible body wall. Pressure exerted on the alimentary tract may result in intussusceptions, prolapses and evagination of parts of the gut through the mouth, gill chamber or anal area.

Stage 3: Terminal rupture. When the body tissues can no longer constrain the increasing volume of gas, it then escapes to the exterior through rupturing of a distended part of the alimentary canal, most likely in the region between the pharynx and oesophagus (R. Chong, Veterinary Pathologist, DPI&F, pers. comm.). In some instances fish with sharp dentition may puncture a ballooning evagination of the gut if it extends out of the buccal cavity. The everted gut may then retract back into the body cavity, creating the outward impression of an absence of barotrauma effects, and the fish again becomes neutrally buoyant.

The last of these stages is not well documented, but evidence suggests that it does occur. The observed reduction in visible signs of barotrauma in red emperor caught from the deepest depth-ranges is difficult to explain without invoking a catastrophic loss of hydrostatic gas from the body. A number of physoclistous fish species have been observed to release gas bubbles during the course of being hauled to the surface (Pearcy 1992; Nichol and Chilton 2006; W.S. pers. obs.), suggestive of terminal rupture and release of swim bladder gas to the exterior. We have not as yet conducted sufficiently detailed necropsies to identify the particular tissue in which this occurs in red emperor.

Some species have the capacity to repair damaged swim bladders remarkably quickly. For example red grouper and red snapper are known to be able to seal large perforations in the swim bladder in four days or less (Burns and Restrepo 2002), and Pacific cod within a period of 2-4 days (Nichol and Chilton 2006). We suggest that red emperor may also have the ability to heal damage to the swim bladder rapidly, although further investigation, perhaps using techniques similar to those described by Nichol and Chilton (2006), is needed to provide verification.

The evidence from our enclosure experiments and observations on the relationship between capture depth and barotrauma points to red emperor as being resilient to the effects of capture, swim bladder inflation, and handling (including tagging), at least in the short term. This is in contrast to the congeneric red snapper as described by Rummer and Bennett (2005), and highlights the large differences in susceptibility to catch-and-release injury that may exist between even closely related species (Jarvis and Lowe 2008). Whether this short-term resilience translates into long-term post-release survival depends on a number of other factors not addressed in this particular study, and is addressed in greater detail in Chapter 4. However the high incidence of multiple recaptures reported by recreational anglers suggests that red emperor are well equipped to compensate for and recover from the effects of barotrauma. As mortality rates among the untreated controls were so low, our experiments did not provide compelling evidence for using either venting or shotline release to improve the short-term survival of red emperor.

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CHAPTER 2. DOES BAROTRAUMA-RELIEF REDUCE SHORT TERM POST-RELEASE MORTALITY OF LINE-CAUGHT REEF FISH?

I. Brown, W. Sumpton, M. McLennan, M. Campbell, J. Kirkwood, A. Butcher, I. Halliday, D. Mayer, A. Mapleston, D. Welch, and G Begg.

2.1 ABSTRACT

The effects of two release treatments currently being promoted within the recreational fishing industry as a means of mitigating the adverse effects of barotrauma were tested in a series of short-term experiments off the Queensland coast. The two release methods were venting and shotline release, and the species of interest (coral trout *Plectropomus leopardus,* redthroat emperor *Lethrinus miniatus*, spangled emperor *Lethrinus nebulosus*, crimson snapper *Lutjanus erythropterus*, and saddletail snapper *Lutjanus malabaricus*) included the most important demersal reef-related species in Queensland's commercial and recreational Coral Reef Finfish Fisheries. A detailed report on red emperor (*Lutjanus sebae*), the remaining member of the suite of species examined in this project, is presented in Chapter 1. Survival rates over a three-day experimental period were estimated by placing treated and tagged fish in a floating trawl-mesh covered vertical enclosure 1.9 m in diameter and 15 m deep. In all species the subjective assessment of the fish's condition (release condition) on introduction into the experimental enclosures was a highly significant predictor of survival. Only in saddletail snapper did treatment have a significant effect on survival. When release condition was replaced by potentially contributing factors and covariates (e.g. hooking location, capture depth, surface interval, barotrauma symptoms, body size, and injury [bleeding]), treatment failed to show any significance in any species, including saddletail snapper. Hook location was a significant determinant of survival in three species – coral trout (a serranid) and the two snappers (lutjanids). In all cases survival rates among deep-hooked fish (i.e. those hooked in the throat, gullet or gut) were much lower than those among shallow-hooked fish (i.e. those where the hook lodged in the lip or mouth). Capture depth contributed significantly to survival only in coral trout, although this species and redthroat emperor were the only two for which a sufficient range of capture depths was available for analysis.

Barotrauma symptoms had a significant effect on survival in redthroat emperor, after adjusting for treatment. Individuals of this species exhibiting the classic visible sign of barotrauma (bloated body) survived better than those with more severe signs (gut extrusion and exophthalmia), but curiously there was no statistical difference in survival rate between fish with no barotrauma signs and those with severe signs. We postulate that this may be due to a proportion of the apparently unaffected fish having ruptured their swimbladders, perhaps with serious internal consequences but without externally visible physical evidence (see also Chapter 1). There was a weak barotrauma effect in crimson snapper, where the trend was in the expected direction: highest survival amongst unaffected fish and least among severely-affected fish. Body size (fork length) was influential to survival only in common coral trout, where survival among large fish was significantly higher than among small fish. In terms of short-term survival, the data *per se* do not provide any justification for recommending either venting or shotline release as a means of ameliorating the effects of barotrauma, except perhaps for saddletail snapper. However the beneficial effect of both venting and shotline releasing on reducing the probability that a fish will float (as a result of bloating) after release, and the finding that survival rates amongst floaters were generally lower than among 'submergers' leads us to conclude that anglers would be advised to administer some form of barotrauma relief on release of the fish. Although the differences were small and statistically non-significant, vented saddletail snapper showed higher survival rates than shotline-released fish, which in turn survived better than the untreated controls. We caution that a number of studies have shown that the physical effects of barotrauma may not translate into mortality for a matter of weeks or months after

capture, so the results of these short-term experiments need to be considered alongside those of the long-term tag release-recapture experiments reported in Chapter 4 of this Report.

2.2 INTRODUCTION

Reef line fisheries in Queensland are an extremely important component of the State's fishing industry. The fishery occurs in both tropical coral reef and subtropical rocky reef habitats, and includes significant commercial, recreational and charterboat components. Commercial operations in the tropical parts of the fishery (defined in terms of the State's management arrangements as the Coral Reef Finfish Fishery [CRFF]) occur predominantly within the Great Barrier Reef Marine Park (GBRMP), with operators generally using a fleet of small outboard-powered dories or tender vessels working independently from the mother vessel. Management arrangements for the CRFF include output controls (limited entry and total allowable commercial catches (TACs)) and input controls (minimum and maximum legal size limits, spawning closures, bag limits etc.). The State's legislation is contained within the Fisheries (Coral Reef Fin Fish) Management Plan 2003. Changes to the zoning of the GBRMP in 2004 as a result of the Representative Areas Programme has increased the area now classed as 'no-take' for line fishers from ~5% to ~30% of the marine park.

Annual allocated commercial TACs currently applying to the primary target species common coral trout (*Plectropomus leopardus*), redthroat emperor (*Lethrinus miniatus*), and to 'other coral reef finfish species' are 1,409.811 t, 689.673 t and 1,058.273 t respectively. TACs are shared among 412 reef-quota fishing endorsements throughout the commercial fishery by way of individual transferable quotas (ITQs). Commercial catches in 2005-06, derived from mandatory daily catch reports, amounted to 1,540 t, with an approximate gross value of production (GVP) of AU$33 million (DPI&F 2007). A large part of this catch is attributable to a live-fish export fishery for coral trout, the market for which has increased in importance over the past decade. A charterboat industry, comprising some 376 licensed operators, exists primarily within the GBR Marine Park (GBRMP), with an estimated catch in 2005 of 27 t (DPI&F 2005). The recreational sector is estimated to have taken about 2,600 t of reef species in 2005, which is more than the total catch of all other sectors combined.

In recent years more stringent minimum legal size and bag limits have been applied to a wide range of reef line species in the Queensland CRFF, largely the result of attempts to ensure the protection of an adequate spawning population and reduce any perceived risk of recruitment overfishing. Such changes are clearly designed to reduce fishing mortality, and involve the return of an increasing number of fish to the water after capture. However the effects of these regulatory changes have not been evaluated, largely because of the paucity of available information on the numbers of line-caught fish that survive after being released. Obviously, for minimum (and maximum) legal size and bag limits to be effective in terms of sustainability there must be a reasonable expectation that a significant proportion of fish that are subject to the stresses of capture, hook damage, barotrauma and on-board handling will survive for a sufficient length of time after release to contribute to the next generation of recruits.

This chapter reports on a series of experiments designed to estimate the short-term survival rates of the following five principal reef-line target species, and the benefits associated with two barotrauma-relief treatments. The species were common coral trout (*Plectropomus leopardus*), redthroat emperor (*Lethrinus miniatus*), saddletail snapper (*Lutjanus malabaricus*), crimson snapper (*Lutjanus erythropterus*) and spangled emperor (*Lethrinus nebulosus*). The barotrauma-relief methods were venting and shotline release. Venting involves piercing the side of the fish with a hollow needle in such a way as to allow the gas in the expanded swim-bladder to be released, and has been promoted widely in the U.S. (Florida Sea Grant 1999) and through a number of recreational fishing associations in Australia (e.g. the *Gently Does It* programme). Shotline release involves attaching the fish to a weighted barbless hook and lowering it to a depth at which the gas in the expanded swim-bladder is re-compressed, allowing the fish to regain buoyancy equilibrium in the water (Bartholomew and Bohnsack 2005).

2.3 MATERIALS AND METHODS

2.3.1 Site selection

The requirements for selection of study sites were that they needed to be close to a location where there was a high probability of catching an adequate number of fish of the target species, and also close to a reasonably sheltered stretch of water with a depth > 15 m where the experimental enclosures could be moored safely. As with red emperor (see Chapter 1), these requirements meant that for some species the depth range from which fish were taken was too restricted to test hypotheses relating to the effect of depth on barotrauma.

Four locations were chosen after extensive consultation with experienced recreational and commercial line-fishers. These were Heron Island Reef for coral trout and redthroat emperor (23º 25.7’S, 152º 00.1’E), Davies Reef for coral trout (18º 49.6’S, 147º 38.0’E), Cordelia Barge wreck for crimson sea-perch and saddle-tailed snapper (18º 59.1’S, 146º 43.7’E), and Gould Reef for spangled emperor (19º 30.9’S, 148º 46.8’E) (Figure 2-1).

2.3.2 Experimental design

The experiment was set up to test the relative effectiveness of two barotrauma-relief releasing methods on the short-term survival of five key tropical coral reef fish species. The two release treatments (shotline release and venting) were administered to captured fish in sequence, together with a third ‘no treatment’ control. The experiment called for a minimum sample size of 45 individuals per species and 5 per treatment (including controls), in each of the three vertical enclosures at each experimental site on one or more occasions. Individual fish were regarded as the experimental unit, with a binary response (either alive or dead) as the trial outcome. Where possible, however, as many fish as could be conveniently captured and treated (given time and budgetary constraints as well as fish availablity and catchability) were used in the experiment to achieve the maximum level of statistical power.

2.3.3 Apparatus design

A detailed description of the experimental apparatus may be found in Chapter 1 (Section 1.3.3).

2.3.4 Operational details

The experiments forming the basis of this work were conducted over the period March 2005 –June 2006, and involved nine separate field operations **(**Table 2-1). Fishing was conducted from the *Tom Marshall*’s tender and a second outboard-powered research vessel either from James Cook University (Townsville) or the Southern Fisheries Centre (Deception Bay), which had been transported by road to an appropriate launching-point.

Data collected during the experiment were as follows: date and time of capture, capture depth (m), fork length (mm), hook location (lip, mouth, throat, gut, or foul/other), barotrauma signs (nil, swollen, gut protruding, eyes bulging [exophthalmia]), bleeding (nil, light or heavy), injury (nil, jaw, eye, gills, scale loss), treatment (shotline release, vented or control), time of release into the enclosure, release condition (a subjective classification of the status of the fish on release into the enclosure following treatment, ranging from 1 = excellent condition to 5 = moribund). An additional observation was made on the released fish depending on whether they experienced difficulty on submerging presumably as a result of barotrauma effects. Fish which could not immediately swim down from the surface were termed ‘floaters’, and were most often (but not always) associated with the nil-treatment or control fish. Sometimes however a shotline released fish would become unhooked from the shot weight before it submerged below the surface, and occasionally a vented fish would float, presumably as a result of insufficient release of swim-bladder gas. Additional data in the form of comments were taken in situations where the apparatus had sustained damage (e.g. from shark bites) or had possibly not functioned as well as it should (e.g. when tilted over by strong current activity or when the lip of the opening was partly submerged due to excessive wave action). The derived variate ‘surface interval’ was calculated as the time-difference between initial capture and release into the enclosure. The mean surface interval was 45.7 ± 1.06 min, but varied from as little as ~0 min (where fish were captured and treated in the immediate vicinity of the enclosures) to over three hours (when the capture site was distant from the enclosures).

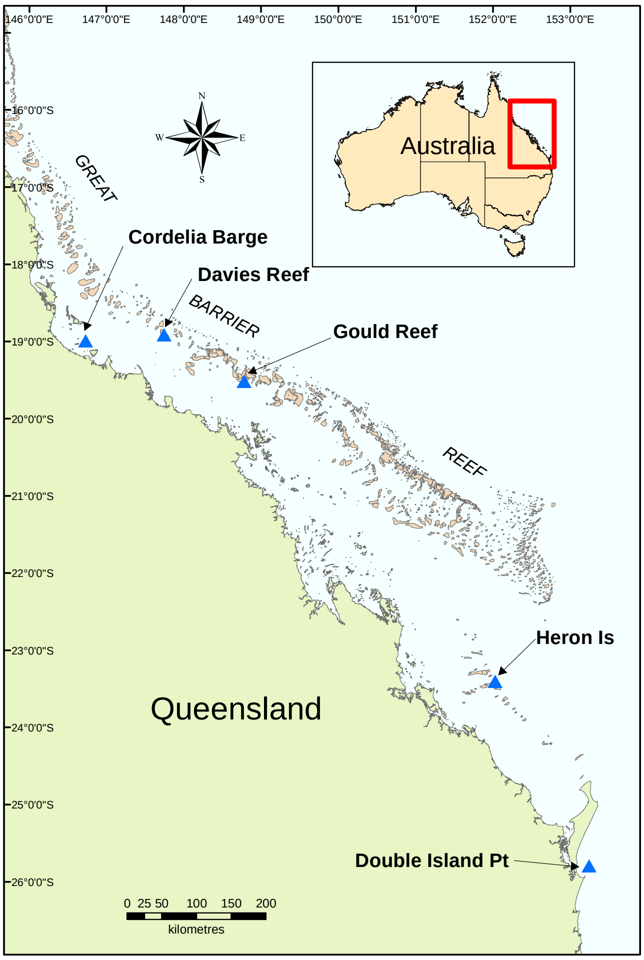

Figure 2-1. Location of the five sampling sites (blue symbols) used in the short-term survival experiments.

After the application of a uniquely-numbered HallPrint™ dart tag into the dorsal musculature the fish was placed into a holding tank filled with clean seawater on board or into a 1m diameter keeper net beside the dory. Fish were transported as soon as practicable to the cage array or enclosures. The surface interval in our experiments would exceed that normally occurring in the recreational line fishery because of the need to relocate the fish to the experimental apparatus, so we endeavoured to keep this interval as brief as possible. Prior to their introduction into the vertical enclosures, the fish were either left untreated (as controls), vented, or placed into the enclosure using a shotline-release device. The two treatments and control were done in sequence to ensure as far as possible that there would be an equal number of replicates for each.

During the experiment, periodic observations on the behaviour and condition of the captive fish were made by divers and with an underwater video camera lowered from the surface. Over the final three days of the experimental period (after each enclosure had been deployed for 3 days) the enclosures were retrieved by crane. By loosening the drawstring at the base of the enclosure, the fish were released into the deck tank. The condition of each fish was noted and recorded (together with its tag number) and surviving fish were released, in the expectation that they would contribute to the sample of treated and tagged fish released in the wild as the basis of the long-term survival experiment.

2.3.5 Data analysis

The data from this experiment were analysed by multi-factor generalised linear regression models (GLMs) in GenStat v. 9.2 (GenStat, 2007) with binomial distribution and logit link function. Data for each of the five species were analysed separately, and in all primary analyses survival was the response variate. Where there was insufficient contrast in the range of the variate (e.g. in the case of crimson and saddletail snapper that were all caught at one depth at the one site), this variate was excluded from the analysis. In cases where the numbers of observations in a significant covariate class was less than 5 (e.g. release condition 5 [moribund]) some data pooling with adjacent classes was necessary.

Initial GLMs were conducted to determine the extent to which release condition was a good predictor of the ultimate fate of the fish, taking into account the ‘environmental’ factors mentioned above – i.e. whether the apparatus had been affected by shark attack or current/wave action. It was considered that ‘release condition’ was heavily confounded with many of the other factors under consideration, and in fact would represent the combined effects of barotrauma, injury, surface interval, and other effects of capture and handling. A second level of GLM analysis was then performed to investigate the individual effects of these factors, excluding ‘release condition’. The suite of variates used in these analyses varied between species, depending on the circumstances of their capture and the amount of contrast in the individual data sub-sets.

2.3.6 Release capsule – preliminary trials

Towards the end of the Project we were approached by a fishing gear manufacturer based at Yeppoon (central Queensland) who had designed a device claimed to be a better alternative to venting and weighted release (shotlining) for overcoming positive buoyancy in fish suffering from barotrauma, and was interested in having the Project team conduct an evaluation of the device for promotional purposes. However we were unable to accommodate it in the short-term experiments (which by that time were all but complete) and FRDC was unwilling to provide additional resources to finance a related mini-project. The device was a bell-shaped capsule made from soft nylon trawl-mesh, formed around an upper and a lower steel hoop about 40 cm in diameter. The device is placed over a floating fish then lowered to an appropriate depth with an attached line, whereupon the fish - with its swim bladder re-compressed – is able to swim free.

This sort of device is not unknown in the literature (e.g. see Bruesewitz *et al.* 1993), but there is little evidence of its having been used directly for barotrauma relief rather than as a control against which the effectiveness of other methods such as venting could be assessed. Although we were unable to conduct any comparative trials with the release capsule, we examined its effectiveness qualitatively in a series of releases at Heron Island at the end of the Project, and obtained images of the capsule being lowered and releasing the fish.

2.4 RESULTS

2.4.1 General overview of sample characteristics

During the seven field operations, 1046 individuals of the five target species were captured, tagged, and released into the enclosures either (i) having been vented, (ii) with the shotline apparatus, or (iii) as controls, with no treatment (Table 2-1).

The majority of the coral trout were obtained from Heron Island Reef and Davies Reef, redthroat emperor from Heron Island Reef, and crimson snapper and saddle-tailed snapper from the Cordelia Barge wreck. Spangled emperor were sourced mostly from Gould Reef.

2.4.2 Sample sizes and losses

On a number of occasions fish were lost from the vertical enclosures. This occurred as a result of damage to the mesh walls of the enclosure by sharks, to ‘washing out’ when particularly strong currents or rough seas caused the lip of the opening to dip below water level, and once when the cod-end tie was not properly secured. On several occasions smaller coral trout were seen forcing their way through the mesh of the enclosure. Supporting evidence of the size effect is provided by the fact that the mean fork length of coral trout that disappeared (37.3 cm) was significantly less than that of trout that were retained (42.6 cm) ($t = 5.23$; $P < 0.001$ with 256 d.f.). Because of the coral trout’s fusiform body shape (in contrast to the high-bodied lethrinids and lutjanids) this species was probably the only one where active escapement through the mesh of the experimental enclosures contributed significantly to sample loss.

Table 2-1. Field operation details, showing the numbers of each species caught and used experimentally.

Operation No.	Date	Location	Coral trout	Saddletail snapper	Redthroat emperor	Crimson snapper	Spangled emperor	Total
4	6-9/03/2005	Heron Is Reef	28		139		5	172
5	11-13/06/2005	Heron Is Reef	20		108			128
6*	26-28/07/2005	Double Island Pt		1				1
7	9-10/09/2005	Cordelia Barge		103		92		195
8	16-18/09/2005	Davies Reef	89					89
9	23-25/09/2005	Davies Reef	68					68
10	7-9/10/2005	Cordelia Barge		67		191		258
11	15-17/10/2005	Davies Reef	59		9			68
12	2-5/06/06	Gould Reef					67	67
	Grand Total		264	171	256	283	72	1046

* The target species in Operation 6 was red emperor, reported in Chapter 1.

The total number of each species treated and introduced into the experimental enclosures, together with the number that disappeared either actively through escapement or passively as a result of washing out, are shown in Table 2-2.

Table 2-2. Sample sizes and numbers of fish lost, by species.

Species	Caught	Lost
Coral trout	262	57
Redthroat emperor	256	80
Saddletail snapper	171	33
Crimson snapper	283	15
Spangled emperor	72	48

As it was not possible to determine the condition of these fish at the time of their disappearance, the data could not be used in the survival analyses. Therefore we decided (on statistical advice) to exclude these records completely from the data sets used in the GLM analyses. The data were, however, used in subsidiary summaries to indicate whether the treatments administered and/or the fishes' condition on release into the enclosures were in any way linked to their disappearance.

2.4.3 Size-structure of experimental samples

Almost all the saddletail and crimson snapper caught and used in the experiment were below their present minimum legal size (40 cm), while the size ranges of coral trout, redthroat emperor and spangled emperor were more evenly spread between undersized and legal sized individuals (Figure 2-2). In analyses of the effect of size on survival rate, the latter three species were divided into two categories (small and large) on the basis of the MLS, while saddletail and crimson snapper were divided at their respective median length values.

As regulated minimum legal sizes are expressed in terms of total length, fork lengths were estimated using regression parameters either calculated from the project data when both FL and TL were recorded, or from published information on samples from the same general area (Table 2-3). The median length values for crimson and saddletail snapper were 30 and 31 cm respectively.

Table 2-3. Linear regression parameters used to convert minimum legal sizes from TL to equivalent FL.

Species	a	b	R^2	Equiv. MLS (FL, cm)
Common coral trout	-1.663	1.0404	0.996	37
Redthroat emperor	17.196	1.0095	0.984	36
Spangled emperor	-2.4021	1.1062	0.992	41

2.4.4 Capture depth of samples

To enable an analysis of the effect of capture depth on barotrauma symptoms and subsequent survival it is necessary to have some contrast in the data. Most of the coral trout were caught in depths ranging from 10 to 30 m, and some in 50 m, while most of the redthroat emperor were taken from quite shallow water (<15 m) (Figure 2-3). The median capture depths of these two species were 15 and 10 m respectively. As crimson and saddletail snapper were caught at a particular wreck site, and spangled emperor from a single coral reef lagoon, there was no measurable variability in capture depth for any of these three species (Figure 2-3). This means that it is not possible to use depth as a predictive factor when analysing post-release survival rates in any species other than coral trout and redthroat emperor.

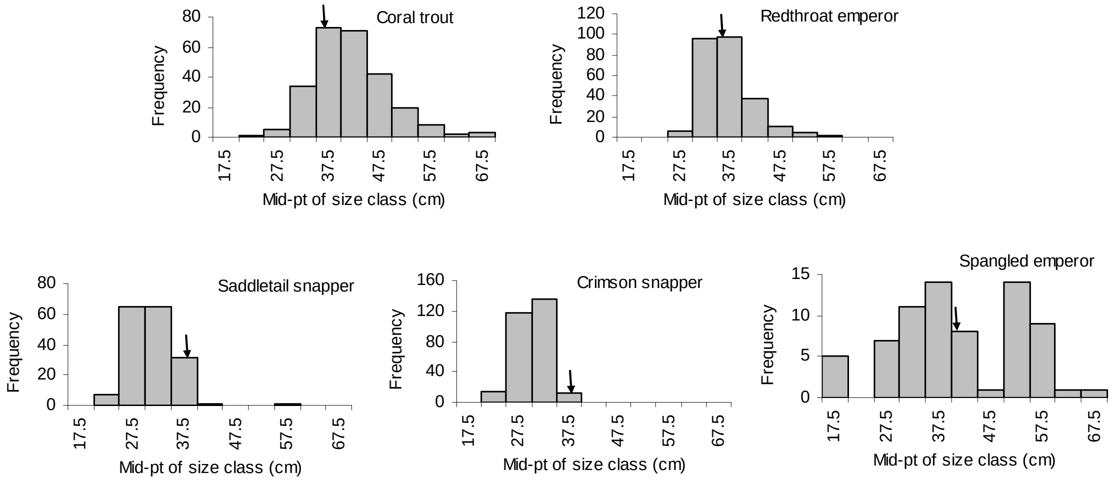

Figure 2-2. Size distribution (FL, cm) of the catch of each of the target species, pooled over location and time, showing approximate current minimum legal sizes (as FL; arrows).

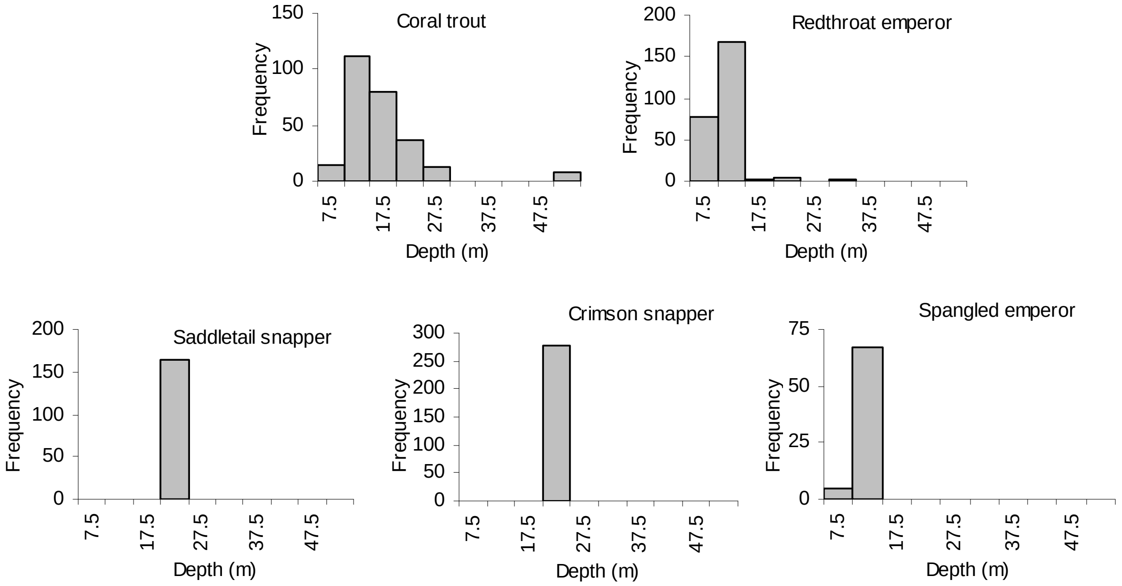

Figure 2-3. Capture depths of the five target species used in the short-term survival experiments. X-axis labels represent the mid-points of the 5 m depth-class intervals.

2.4.5 Comparison of barotrauma-relief release methods

Common coral trout

The raw experimental results, after appropriate pooling of cells with insufficient observations for effective analysis show that the overall (observed) short-term survival rate for coral trout was about 79%, but that survival varied considerably as a result of certain factors or covariates (Table 2-4). However, because of the inherently high variability in the data, initial GLM results (Table 2-5) revealed that release condition was the only factor of significance to the short-term survival of coral trout. Neither the 'environmental' differences associated with enclosure damage or distortion, observed barotrauma symptoms nor treatment appeared at all influential. In other words, once the effect of release condition had been removed by the GLM, none of the remaining model terms was significant. This provides statistical confirmation of the observed similarity between the raw mean survival rates of the two treatments and control shown in Table 2-4.

Table 2-4. Raw data results showing numbers of common coral trout in each class that survived, died, or disappeared (missing), as well as the total and proportion that survived (% surv). Note that the proportion of survivors was calculated on the basis of totals excluding those that escaped or were washed out of the experimental enclosures. Asterisks denote the result of pooling adjacent classes with inadequate numbers of observations.

Variate	Class	Survived	Died	Missing	Total	% surv
RelCondition	1	65	6	16	87	91.55
	2	70	8	23	101	89.74
	3	25	3	11	39	89.29
	4	3	25	7	35	10.71
Depth	Deep	63	33	18	114	65.63
	Shallow	100	8	39	147	92.59
Surface Int	1	59	15	19	93	79.73
	2	89	26	28	143	77.39
	3	12	1	4	17	92.31
	4*	2	0	5	7	100.00
Length	Large	133	24	22	179	84.71
	Small	27	18	34	79	60.00
Hook Locn	Shallow*	113	26	38	177	81.29
	Deep*	8	5	1	14	61.54
	Foul	4	1	1	6	80.00
Barotrauma	Nil	19	2	15	36	90.48
	Swollen	136	37	40	213	78.61
	Extreme*	6	3	1	10	66.67
Treatment	Nil	52	14	20	86	78.79
	Shotline	54	15	17	86	78.26
	Vented	57	13	20	90	81.43
Floater	0	128	28	38	194	82.05
	1	6	14	5	25	30.00
Environment	Normal	93	28	28	149	76.86
	Shark	62	14	29	105	81.58
	Washout	8	0	0	8	100.00

The adjusted survival rates for release condition 1-3 were all around 90% and were not significantly different from each other. However the adjusted mean rate for fish reported as having a release condition of 4 was significantly lower, at 10% (Figure 2-4).

A suite of variates considered potential contributors to release condition was then selected for further analysis. These were capture depth and body size (as a 2-level categorical variates), hook lodgment location, barotrauma symptoms and treatment (all 3-level categoricals), and surface interval (a continuous covariate), and the barotrauma category x treatment interaction. After the non-significant interaction term (P = 0.10) was dropped, the final GLM analysis revealed three significant terms – capture depth, body size (FL), and hook location (Table 2-6).

Table 2-5. Effects of release condition, environment, barotrauma signs and treatment on the short-term survival of common coral trout.

Source	d.f.	Deviance	Mean Deviance	Deviance Ratio	Approx Chi prob.
RelCondition	3	76.5429	25.5143	25.51	<.001
Environ	2	3.0935	1.5467	1.55	0.213
BtCat	2	0.5619	0.281	0.28	0.755
Treatment	2	3.6784	1.8392	1.84	0.159
Residual	193	123.1085	0.6379		
Total	202	206.9852	1.0247		

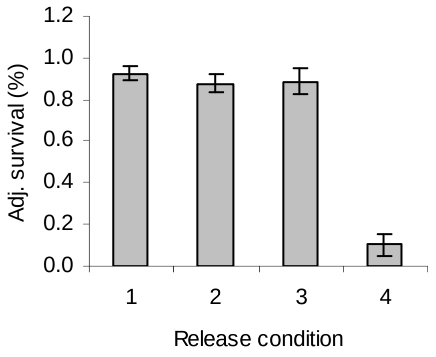

Figure 2-4. Adjusted mean survival rates for coral trout recorded with different release condition categories.

The adjusted means for each component or class of all variates tested (including those that were not significant) are shown in Table 2-7. In the case of coral trout the three depth categories used were shallow (<15 m), intermediate (15-19) and deep (>19 m). These class intervals were chosen to ensure sufficient observations for analysis. The adjusted means indicate that there was no difference in survival rate between fish caught in shallow or intermediate (moderate) depths (at about 90%), but at deeper capture depths survival was less than half of this (41%) (Figure 2-5a).

Body size was influential in determining survival, with a significantly higher proportion of large coral trout (>37 cm FL) surviving than smaller fish (83% vs. 66%; Figure 2-5b). Hook location was the third significant determinant of coral trout survival. Fish hooked in the lip or mouth (‘shallow hooked’) showed considerably higher survival rates (81%), than those hooked in the throat or gut (‘deep hooked’; 47%). The survival of foul-hooked trout (at 71%) was slightly lower than shallow-hooked individuals (Figure 2-5c), but the difference was not statistically significant (Table 2-7).

After adjusting for all the potentially influential factors, barotrauma treatment did not significantly affect coral trout survival (P = 0.74; Table 2-6). The adjusted means indicated that venting appeared most effective, followed by 'no treatment' (controls) and finally shotline release, but the differences were marginal and non-significant.

Table 2-6. Analysis of deviance table showing the effects of a suite of factors on short-term survival of coral trout.

Source	d.f.	Deviance	Mean Deviance	Deviance Ratio	Approx Chi prob.
Depth	2	40.6408	20.3204	20.32	<.001
Length	1	9.5508	9.5508	9.55	0.002
Hook Location	2	10.5560	5.2780	5.28	0.005
Barotrauma	2	2.2091	1.1045	1.10	0.331
Surface Interval	1	0.0106	0.0106	0.01	0.918
Treatment	2	0.5935	0.2967	0.30	0.743
Residual	187	138.4189	0.7402		
Total	197	201.9797	1.0253		

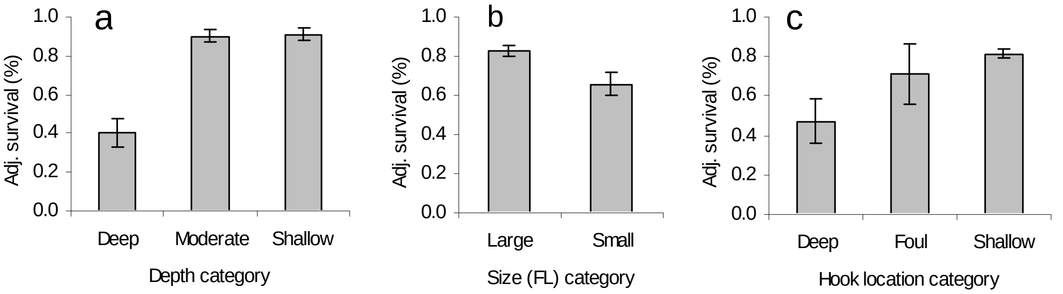

Figure 2-5. Effect of capture depth (a), body size (b) and hook location (c) on the short-term survival rate of common coral trout adjusted for all other terms in the model.

The observed data (Table 2-4) showed that most (82%) of the coral trout that were successfully released into the enclosures after treatment survived to the conclusion of the experiment. However of the fish recorded as 'floaters' (i.e. those that failed to either submerge successfully of their own accord, or remain submerged if shotline-released) only 30% survived. To investigate whether this disparity was related to their condition on capture (i.e. the observed barotrauma symptoms) or to the administered treatment or an interaction between the two, we ran another set of generalised linear models, but with 'floating' as the (binomial) response variate instead of 'survived'.

In the initial analysis capture depth and treatment were significant at the 5% level (P = 0.003 and 0.029 respectively), but the barotrauma-treatment interaction was not (P = 0.77). After removing the interaction term and re-ordering the main effect terms the model was re-run prior to estimation of the adjusted means; with only minor variations the two main effects retained their statistical significance. As determinants of whether or not a coral trout would be likely to float after capture and release, capture depth had the clearest influence (Figure 2-6). Fish caught in deep water (>20 m) were three times more likely to float – regardless of treatment – than those caught in shallower depths. Untreated fish were almost four times as likely to float as those that were released by shotline. There was no significant difference in floating rate between untreated control fish and those that were vented prior to release (Figure 2-6), although the data suggest that venting may provide a minor advantage.

Table 2-7. Mean survival estimates and associate approximate standard errors for coral trout adjusted for a range of variates. Those with superscripts beside the adjusted means were significant at the 95% level; superscripts with different alphabetic characters denote significant pairwise differences.

Variate	Class	Adj mean	s.e.
Depth	Deep	0.4061^{a}	0.072
	Moderate	0.9016^{b}	0.032
	Shallow	0.9118^{b}	0.030
Length	Large	$0{\cdot}8268^{a}$	0.026
	Small	0.6586^{b}	0.058
Hook location	Deep	0.4698^{a}	0.111
	Foul	0.7116^{b}	0.155
	Shallow	0.8137^{b}	0.024
Barotrauma	Nil	0.8552	0.026
	Bloat	0.7761	0.070
	Serious	0.8666	0.059
Treatment	Nil	0.7838	0.042
	Shotline	0.7692	0.044
	Vented	0.8117	0.035
Surface Interval	0.1	0.7846	0.043
	0.5	0.7877	0.024
	1.0	0.7916	0.038
	1.5	0.7954	0.069
	2.0	0.7991	0.103

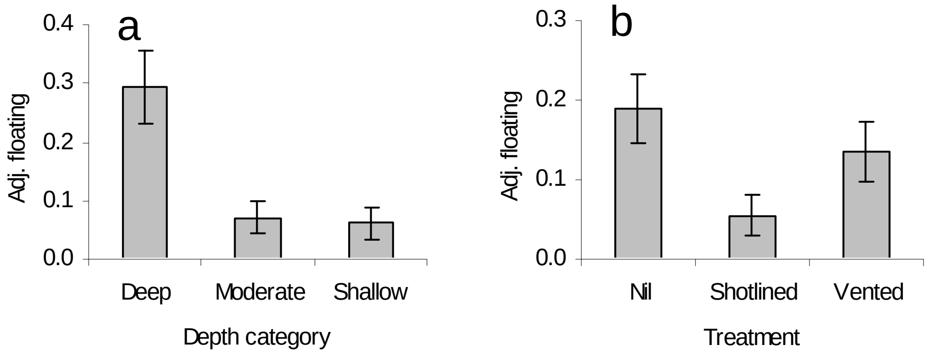

Figure 2-6. Adjusted mean proportions of fish that floated immediately on introduction into the experimental enclosures, in terms of their depth of capture (a) and treatment (b). Means and standard errors are shown.

Redthroat emperor

After pooling cells with insufficient observations for effective analysis, the raw experimental data indicate that the overall short-term survival rate for redthroat emperor was about 85%, but that, as with coral trout, survival rates appeared to vary considerably as a result of the effects of certain factors or covariates (Table 2-8). There was some considerable difference in survival, as indicated from the raw data tabulation, between the two treatments (76% and 92% for shotline release and venting respectively). However the survival of untreated fish was intermediate between that of the two treatments (88%). The initial GLM analysis tested the effects of release condition, the environment of the experimental apparatus, barotrauma symptoms and treatment (Table 2-9), and showed that the only factor influencing the short-term survival of redthroat emperor was release condition (P = 0.001). As expected, the trend was for increasing levels of mortality amongst fish in poorer condition (i.e. increasing index values) (Figure 2-7). Despite the observed differences in the raw data, the modelled results indicated that treatment had no significant effect on survival (P = 0.39) (Table 2-9).

Table 2-8. Raw data results showing numbers of redthroat emperor in each class that survived, died or disappeared (missing), as well as the total and proportion that survived (% surv). For further explanation see caption to Table 2-4.

Variate	Class	Survived	Died	Missing	Total	% surv
Release condition	1	64	4	4	72	94.12
	2	57	8	15	80	87.69
	3	22	11	43	76	66.67
	4*	2	2	16	20	50.00
Depth	Deep	96	10	7	113	90.57
	Shallow	53	16	73	142	76.81
Surface interval	1	48	7	13	68	87.27
	2	87	16	39	142	84.47
	3	12	2	19	33	85.71
	4*	3	1	9	13	75.00
Length	Large	68	11	27	106	86.08
	Small	80	15	53	148	84.21
Hook location	Shallow*	131	22	68	221	85.62
	Deep*	3	2	4	9	60.00
	Foul	8	2	4	14	80.00
Barotrauma	Nil	39	16	61	116	70.91
	Swollen	104	8	19	131	92.86
	Extreme*	7	2	0	9	77.78
Treatment	Nil	55	7	26	88	88.71
	Shotline	47	9	20	76	83.93
	Vented	48	10	34	92	82.76
Environment	Normal	70	4	3	77	94.59
	Shark	42	7	35	84	85.71
	Washout	38	15	42	95	71.70

The follow-up analysis identified barotrauma symptoms as being the only significant factor contributing to the survival of redthroat emperor (P < 0.001; Table 2-10). Curiously, the adjusted mean survival rate among fish exhibiting no obvious external signs of barotrauma was not significantly different from that of fish with ‘extreme’ symptoms of gut extrusion and exophthalmia (71 and 77% respectively). Moreover the highest modelled survival rate (92%) was among fish exhibiting the classic sign of bloating or expansion of the body cavity (Table 2-11).

Table 2-9 Results of analysis of deviance testing the effects of release condition, environment, barotrauma signs and treatment on the survival of redthroat emperor.

Source	d.f.	Deviance	Mean Deviance	Deviance Ratio	Approx Chi prob.
Release condition	3	15.5027	5.1676	5.17	0.001
Environment	2	4.5639	2.2819	2.28	0.102
Barotrauma	2	3.757	1.8785	1.88	0.153
Treatment	2	1.8774	0.9387	0.94	0.391
Residual	160	116.2740	0.7267		
Total	169	141.9749	0.8401		

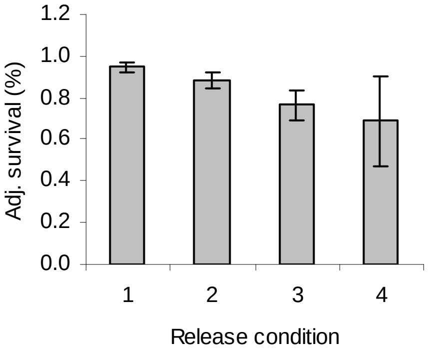

Figure 2-7 Adjusted mean survival rates for redthroat emperor recorded with different release condition categories. Condition index ranges from 1 (excellent) to 4 (moribund).

Table 2-10. Analysis of deviance table showing the effects of a suite of factors on short-term survival of redthroat emperor.

Source	d.f.	Deviance	Mean Deviance	Deviance Ratio	Approx Chi prob.
Barotrauma	2	16.2705	8.1353	8.14	<0.001
Depth	2	0.2334	0.1167	0.12	0.890
Hook Location	2	1.8084	0.9042	0.90	0.405
Surface interval	1	0.2093	0.2093	0.21	0.647
Length	1	0.0515	0.0515	0.05	0.820
Treatment	2	1.3265	0.6632	0.66	0.515
Residual	155	124.1994	0.8013		
Total	165	144.0990	0.8733		

The GLM was re-run with depth and barotrauma fitted in reverse order, in an attempt to find an explanation for the unexpected barotrauma-related trend. While each contributed to explaining survival, barotrauma had by far the stronger effect. Because of the very low sample numbers in some barotrauma/depth combinations the results of these exploratory analyses were inconclusive.

Fifty (91%) of the 55 fish showing no barotrauma symptoms were captured from the shallow depth range. Only nine fish exhibited 'serious' barotrauma signs (exophthalmia or gut extrusion, individually or in combination), and these were all from intermediate or deep depth ranges (Table 2-12). All five fish from moderate depths survived, but only 2 of the 4 (50%) from the deepest areas survived. There was a good spread of samples across capture depth ranges where barotrauma was evident as swelling or bloating of the body cavity, although the greatest numbers were observed from intermediate depths. While the differences were non-significant, it is of interest that the highest adjusted survival rate (88%) was associated with the intermediate depth category, with somewhat lower estimates for fish caught in the deepest and shallowest areas (86% and 82% respectively).

With the effects of depth, barotrauma, hook location, surface interval and body size accounted for, differences in survival between treated and control fish (ranging from 82 to 89%; Table 2-11) were not statistically significant (P = 0.52).

Table 2-11 Mean survival estimates and associated approximate standard errors for redthroat emperor adjusted for a range of variates. Those with superscripts beside the adjusted means were significant at the 95% level; superscripts with different alphabetic characters denote significant pairwise differences.

Variate	Class	Adj. mean	s.e.
Barotrauma	Nil	0.7132^a	0.0918
	Bloat	0.918^b	0.0298
	Serious	0.7715^a	0.1494
Depth	Deep	0.8580	0.0752
	Moderate	0.8768	0.0533
	Shallow	0.8151	0.0549
Hook location	Deep	0.5930	0.2196
	Foul	0.8923	0.0788
	Shallow	0.8566	0.0294
Surface interval	0.1	0.8697	0.0567
	0.5	0.8566	0.0319
	1.0	0.8389	0.0440
	1.5	0.8196	0.0968
	2.0	0.7988	0.1625
Length	Large	0.8407	0.0442
	Small	0.8592	0.0365
Treatment	N	0.8923	0.0397
	S	0.8319	0.0512
	V	0.8253	0.0501

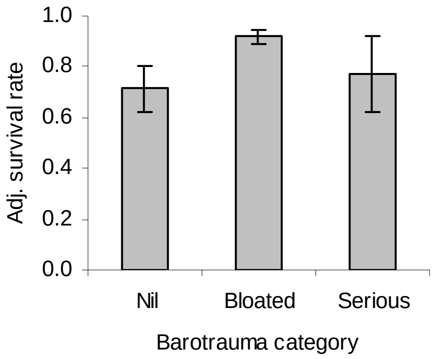

Figure 2-8. Effects of barotrauma severity on the short-term survival rate of redthroat emperor. Adjusted means are shown, and the error bars are s.e.

Table 2-12 Unadjusted survival rate (%) of redthroat emperor caught from three depth ranges and showing three levels of visible barotrauma signs. Sample sizes are shown in parentheses.

	Barotrauma		
Depth	Nil	Bloated	Serious
Shallow	74 (50)	84 (19)	- (0)
Intermediate	0 (1)	93 (74)	100 (5)
Deep	50 (4)	100 (18)	50 (4)

Crimson snapper

Probably still more widely known amongst Queensland anglers as smallmouth nannygai, the crimson snapper *Lutjanus erythropterus* showed a survival rate of about 84%, similar to that of the redthroat emperor. As with the previous two species, the observational data summaries (Table 2-13) revealed substantial differences in survival rate between classes in a number of variates or factors, particularly release condition and hook location. Again, barotrauma treatment appeared to have little effect on survival.

The primary GLM analysis (Table 2-14) showed release condition as being the dominant statistically significant factor ($P < 0.001$) influencing the short-term post-release survival of crimson snapper. The status of the experimental enclosure ('environ'), barotrauma symptom category and treatment failed to approach significance at the 0.05 level. As expected, fish reported as being in excellent or very good condition at release into the experimental enclosure (condition indices 1 or 2) survived considerably better than those with condition index 3 (Figure 2-9). Only 10% of fish reported as being in very poor condition at release (index = 4) survived.

Removing release condition and substituting all other potentially contributing factors (hook location, surface interval, barotrauma, body size, bleeding and treatment) showed hook location to be the only significant factor ($P < 0.001$; Table 2-15). The following 2-way interaction terms were trialed in the model: surface interval x hook location, surface interval x barotrauma, and barotrauma x hook location.

However as none of these interactions was statistically significant, they were dropped from the final model which revealed hook location still to be the dominant term (<0.001), although the effect of barotrauma category was of marginal significance (0.059) and is therefore of interest.

Adjusted means from the GLM analysis (Table 2-16) revealed that shallow-hooked crimson snapper survived better (96%) than those hooked in the throat or gut (deep-hooked; 35%) (Figure 2-10a). Pairwise t-tests showed no difference statistically between the survival of shallow-hooked and foul-hooked fish, as indicated by the superscripts in Table 2-16. Crimson snapper with no visible signs of barotrauma fared slightly better than those with distended stomachs (bloated), and in turn these showed a higher survival rate than fish with parts of the alimentary canal protruding form the mouth or gill area, or exhibiting exophthalmia (Figure 2-10b). While these differences spanned a relatively modest range (from 86% to 99%) the standard errors suggest that there might be a real effect.

Table 2-13. Raw data results showing numbers of crimson snapper in each class that survived, died, or disappeared (missing), as well as the total and proportion that survived (% surv). For further explanation see caption to Table 2-4.

Variate	Class	Survived	Died	Missing	Total	% surv
Release condition	1	35	1	3	39	97.22
	2	134	12	3	149	91.78
	3	36	11	3	50	76.60
	4*	3	17	5	25	15.00
Surface interval	1	110	19	5	134	85.27
	2	99	17	8	124	85.34
	3	8	4	0	12	66.67
	4*	7	3	2	12	70.00
Length	Large	92	17	5	114	84.40
	Small	130	26	10	166	83.33
Hook location	Shallow*	207	21	13	241	90.79
	Deep	7	21	2	30	25.00
	Foul	11	1	0	12	91.67
Barotrauma	Nil	5	1	0	6	83.33
	Swollen	133	24	9	166	84.71
	Extreme*	86	17	6	109	83.50
Treatment	Nil	69	14	8	91	83.13
	Shotline	82	13	4	99	86.32
	Vented	74	16	3	93	82.22
Bleeding	Heavy	3	3	0	6	50.00
	Light	7	4	2	13	63.64
	None	215	36	13	264	85.66
Floater	0	220	33	8	261	86.96
	1	5	10	7	22	33.33
Environ	Normal	155	32	6	193	82.89
	Shark	19	1	1	21	95.00
	Washout	51	10	8	69	83.61

Table 2-14. Results of analysis of deviance testing the effects of release condition, environment, barotrauma signs and treatment on the survival of crimson snapper.

Source	d.f.	Deviance	Mean Deviance	Deviance Ratio	Approx Chi prob.
Release condition	3	61.6674	20.5558	20.56	<.001
Environment	2	0.6176	0.3088	0.31	0.734
Barotrauma	2	0.3502	0.1751	0.18	0.839
Treatment	2	2.8402	1.4201	1.42	0.242
Residual	237	153.3065	0.6469		
Total	246	218.7819	0.8894		

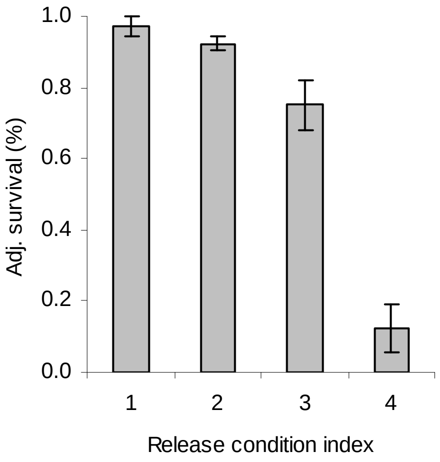

Figure 2-9. Adjusted mean survival rates for crimson snapper recorded with different release condition categories. Condition index ranges from 1 (excellent) to 4 (moribund).

Table 2-15. Analysis of deviance table showing the effects of a suite of factors on short-term survival of crimson snapper.

Source	d.f.	Deviance	Mean Deviance	Deviance Ratio	Approx Chi prob.
Hook location	2	60.5563	30.2781	30.28	<.001
Surface interval	1	1.7423	1.7423	1.74	0.187
Barotrauma	2	5.6591	2.8296	2.83	0.059
Bleeding	2	1.6636	0.8318	0.83	0.435
Length	1	0.6131	0.6131	0.61	0.434
Treatment	2	0.4044	0.2022	0.20	0.817
Residual	251	160.0133	0.6375		
Total	261	230.6522	0.8837		

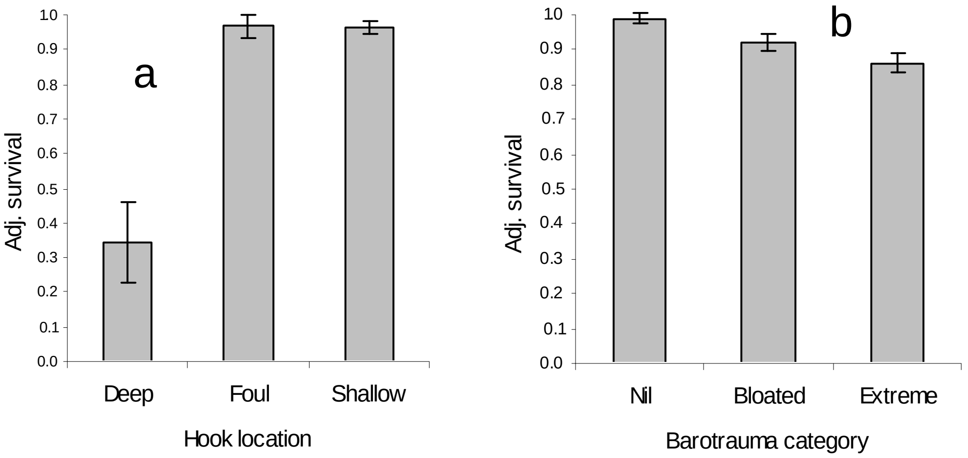

Figure 2-10. Effect of (a) hook location and (b) barotrauma on the short-term survival rate of crimson snapper adjusted for all other terms in the model.

Table 2-16. Mean survival estimates and associate approximate standard errors for crimson snapper adjusted for a range of variates. Those with superscripts beside the adjusted means were significant at the 95% level; superscripts with different alphabetic characters denote significant pairwise diffrences.

Variate	Class	Adj mean	s.e.
Hook location	Deep	0.3457^a	0.1168
	Foul	0.9664^b	0.0364
	Shallow	0.9629^b	0.0165
Barotrauma	Bloat	0.9207	0.0226
	Extreme	0.8626	0.0290
	Nil	0.9903	0.0167
Length	Large	0.9107	0.0240
	Small	0.8917	0.0251
Bleeding	Heavy	0.7668	0.1252
	Light	0.8923	0.0543
	Nil	0.8359	0.0185
Treatment	Nil	0.8988	0.0274
	Shotline	0.9080	0.0260
	Vented	0.8907	0.0283
Surface interval	0.0	0.8995	0.0220
	0.5	0.8483	0.0173
	1.0	0.7702	0.0377
	1.5	0.6532	0.0967
	2.0	0.5007	0.1712
	2.5	0.3393	0.2157
	3.0	0.2040	0.2015
	3.13	0.1758	0.1899

During the experiment 22 (8%) of the 283 fish caught and placed into the vertical enclosures were recorded as being ‘floaters’. Seven (32%) of these disappeared or escaped, compared to 15 (68%) of the non-floaters. Of the 268 fish that remained in the enclosures until the end of the experiment, 10 (67%) of the floaters died, compared to just 13% of the non-floaters (Table 2-17). The fact that there was such a disparity in mortality rate between floaters and non-floaters makes it of interest to investigate the possible causes. This was done by repeating a set of GLM analyses, but with ‘floater’ as the (binary) response variate. Terms used in the model were FLCat, HookLocCat, BtCat, SurfInt, Treatment and BtCat·Treatment, but none was significant. In other words, (i) floaters were far more likely to have escaped (either actively or as a result of washing out) than non-floaters; (ii) floaters that remained in the enclosure were much more likely to die than non-floaters, (iii) neither the extent of barotrauma symptoms, treatment, or their interaction was influential in determining whether or not the fish floated.

Table 2-17 Numbers of floating and non-floating crimson snapper that escaped or were lost from the vertical enclosures, and the survival statistics of those that remained throughout the experiment.

Status	Floaters	Non-floaters	Total
Disappeared	7	8	15
Remained - died	10	33	43
Remained - survived	5	220	225
Remained - total	15	253	268
Disappeared + remained	22	261	283

Saddletail snapper

Table 2-18 shows the observed results of the short-term experiments on saddletail snapper (*Lutjanus malabaricus*), probably more widely known as large-mouth nannygai. Unlike its congener the crimson snapper, saddletail snapper were more susceptible to the immediate effects of capture, handling and release, with an overall survival rate only marginally above 50%. A number of variates including release condition, floating status, hook location and perhaps surface interval appear to be influential in determining short-term survival.

An initial GLM to test the effects of release condition, enclosure environment, barotrauma signs, treatment and some potentially important interactions showed that release condition, enclosure environment and treatment were significant determinants of short-term survival of saddletail snapper (Table 2-19). As with the previous species examined, the survival rates of fish recorded as being in good condition when released were significantly greater than for those with poor release condition estimates (Figure 2-11a). Similarly to crimson snapper, survival of saddletail snapper was reduced to about 10% when release condition was lowest (category 4).

The physical environment of the experimental apparatus appeared to have a much greater impact on survival of saddletail snapper than it did on crimson snapper, even though the two species were caught together at the same site and kept in the same enclosures (Figure 2-11b). Survival of fish in enclosures damaged by sharks or laid over by strong currents was somewhat less (63% and 66% respectively) than among those in unaffected enclosures, where the adjusted mean survival rate was 72%.

Treatment was also a significant factor in this analysis (P = 0.028; Table 2-19). The overall survival rate for saddletail snapper was comparatively low, at around 50%, but without treatment the adjusted mean indicates that only 44% of the fish survived. Shotline release appears to offer an improved survival prospect at 55%, but the greatest benefit appears to relate to venting, which gave an adjusted mean survival rate of 60% (Figure 2-11c).

Table 2-18. Raw data results showing numbers of saddletail snapper in each class that survived, died, or disappeared (missing), as well as the total and proportion that survived (% surv). For further explanation see caption to Table 2-4.

Variate	Class	Survived	Died	Missing	Total	% surv
Release condition	1	7	2	4	13	77.78
	2	35	9	1	45	79.55
	3	21	16	10	47	56.76
	4*	5	34	17	56	12.82
Surface interval	1	46	39	20	105	54.12
	2	20	27	13	60	42.55
	3	3	2	0	5	60.00
Length	Large	38	33	10	81	53.52
	Small	32	34	23	89	48.48
Hook location	Shallow*	63	44	26	133	58.88
	Deep	5	18	7	30	21.74
	Foul	2	4	0	6	33.33
Barotrauma	Swollen	41	35	16	92	53.95
	Extreme*	29	32	17	78	47.54
Treatment	Nil	17	25	15	57	40.48
	Shotline	27	24	8	59	52.94
	Vented	26	19	10	55	57.78
Bleeding	Bleeding*	4	6	2	12	40.00
	No	66	62	31	159	51.56
Floater	0	67	41	18	126	62.04
	1	2	27	15	44	6.90
Environment	Normal	18	14	5	37	56.25
	Shark	15	17	9	41	46.88
	Washout	37	37	19	93	50.00

Table 2-19. Results of analysis of deviance testing the effects of release condition, environment, barotrauma signs and treatment on the survival of saddletail snapper.

Source	d.f.	Deviance	Mean Deviance	Deviance Ratio	Approx Chi prob.
Release condition	3	45.607	15.202	15.2	<.001
Environment	2	13.446	6.723	6.72	0.001
Treatment	2	7.187	3.593	3.59	0.028
Barotrauma	1	0.155	0.155	0.16	0.693
Residual	119	110.551	0.929		
Total	127	176.945	1.393		

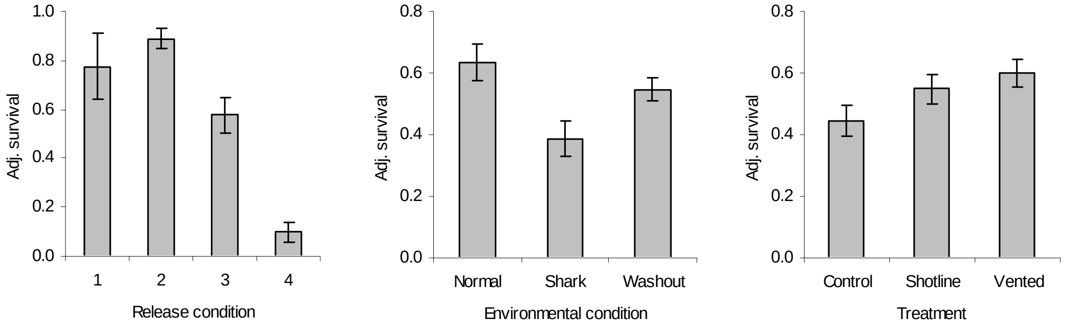

Figure 2-11. Adjusted mean survival rates for saddletail snapper recorded with different release condition indices, enclosure environment categories and treatments.

In the following analyses release condition was dropped from the model and replaced with as many potentially contributing factors as was possible, subject to the limitations of the data. Terms used in the model were hook location, surface interval, barotrauma category, bleeding category, treatment, fork length, enclosure environment and barotrauma x treatment (Table 2-20). As the interaction term was not significant (P = 0.71) this was dropped from the model, which then showed hook location to be the only factor of significance (P = 0.01), although surface interval also had a weak effect (P = 0.077).

Table 2-20. Analysis of deviance table showing the effects of a suite of factors on short-term survival of saddletail snapper.

Source	d.f.	Deviance	Mean Deviance	Deviance Ratio	Approx Chi prob.
Hook location	2	9.623	4.811	4.81	0.008
Surface interval	1	3.123	3.123	3.12	0.077
Barotrauma	1	2.850	2.850	2.85	0.091
Bleeding	1	0.626	0.626	0.63	0.429
Treatment	2	2.511	1.255	1.26	0.285
Length	1	0.213	0.213	0.21	0.644
Environment	2	0.849	0.425	0.42	0.654
Residual	122	164.395	1.347		
Total	132	184.189	1.395		

Although the effect of surface interval was not significant at the 0.05 level, the trend in decreasing survival with increasing surface interval appears convincing (Figure 2-12 *b*). For this reason the means in Table 2-21 and Figure 2-12 *a* and *c* have been adjusted to a surface interval of zero. This was done to more closely reflect the situation where anglers would release their undersize fish immediately, rather than hold them in a deck tank for varying periods as was usually necessary in these experiments.

Hook location was the major determinant of short-term survival in saddletail snapper. The estimated mean survival rate of shallow-hooked fish (73%) was nearly twice that of fish hooked in the gut or throat (38%) (Table 2-21; Figure 2-12 *a*). The survival of foul-hooked fish (48%) was intermediate between that of deep-hooked and shallow-hooked individuals. Although not statistically significant, the differences in survival among the three treatment categories closely reflected the (significant) trend shown previously in the 'condensed' model (Figure 2-11), with venting and shotline releasing resulting in slightly improved survival rates.

Table 2-21. Mean survival estimates and associate approximate standard errors for saddletail snapper adjusted for a range of variates. Those with superscripts beside the adjusted means were significant at the 95% level; superscripts with different alphabetic characters denote significant pairwise differences.

Variate	Class	Adj mean	s.e.
Hook location	Deep	0.3776^a	0.1385
	Foul	0.4777^a	0.2230
	Shallow	0.7339^b	0.0708
Barotrauma	Bloat	0.7227	0.0808
	Extreme	0.5971	0.0886
Environment	OK	0.7229	0.0995
	Shark	0.6297	0.1087
	Washout	0.6585	0.0783
Bleeding	Bleed	0.5607	0.1713
	NoBleed	0.6746	0.0721
Length	Large	0.6863	0.0845
	Small	0.6449	0.0780
Treatment	N	0.5938	0.1013
	S	0.6699	0.0848
	V	0.7274	0.0814
Surface interval	0	0.6661	0.0712
	0.5	0.4919	0.0432
	1	0.3165	0.0914
	1.15	0.2698	0.1028

Of the 44 fish reported to have floated on release into the enclosures, 15 (34%) disappeared, presumably as a result of being washed out of the top of the enclosure during rough weather (Table 2-22). This compares to a loss rate of a mere 6% among those that were able to swim down from the surface. There was also a disparity in the survival rate of those that remained in the enclosures depending on whether or not they floated on release. Twenty-seven (93%) of the remaining 29 floaters died, compared to 40 (37%) of the remaining non-floaters (Table 2-22).

To further investigate the possible causes of this disparity in survival, the data were re-analysed with a repeat set of GLM analyses, but with ‘floater’ as the (binary) response variate. Terms used in the model were Treatment, SurfInt, BtCat, HookLocCat, FLCat, and BtCat x Treatment. The final model showed that surface interval and the interaction between barotrauma signs and treatment were both significant determinants ($P = 0.035$ and < 0.001 respectively) of whether or not released saddletail snapper would float. Fish that showed the classic sign of moderate barotrauma (bloating) were most likely to float if they had received no barotrauma-relief treatment (0.16), less so if they had been released by shotlining (0.08) and least if they had been vented (0.04) (Figure 2-13). Shotline releasing, on the other hand, appeared to work best where the fish were suffering more extreme barotrauma symptoms – particularly everted stomachs, which occurred very frequently in this species. In fact none of the 29 ‘extreme’ barotrauma cases floated after release by shotline (which accounts for the absence of a relevant histogram bar in

Figure 2-13). About 38% of the untreated fish floated, as did 22% of those that had been vented prior to release.

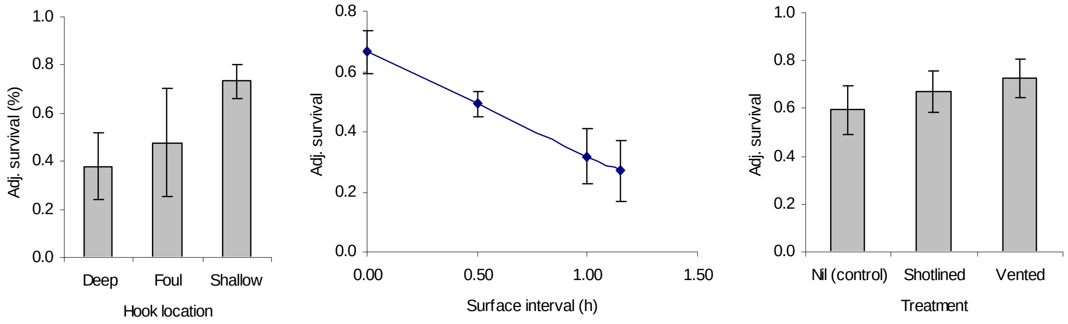

Figure 2-12. Effect of hook location, surface interval and treatment on the short-term survival rates of saddletail snapper. Means for hook location and treatment have been adjusted to zero surface interval (see text for explanation). Vertical bars are standard errors.

Table 2-22. Numbers of floating and non-floating saddletail snapper that escaped or were lost from the vertical enclosures, and the survival statistics of those that remained throughout the experiment.

Status	Floaters	Non-floaters	Total
Disappeared	15	8	33
Remained - died	27	40	67
Remained - survived	2	67	69
Remained - total	29	107	136
Disappeared + remained	44	125	169

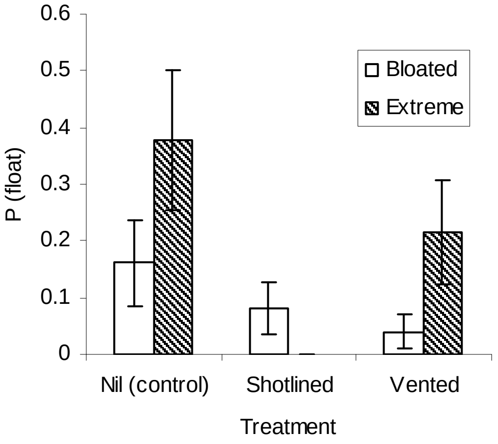

Figure 2-13. Probability of a released saddletail snapper floating after release, given its barotrauma condition and treatment. Adjusted means from GLM analysis and corresponding standard errors are shown.

Spangled emperor

The data for spangled emperor are particularly sparse. It was always considered by the project team (and the members of the Steering Committee) that this species would be the most difficult to deal with, given its patchy distribution and nocturnal behaviour. Fishing for spangled emperors is carried out most effectively at night in relatively shallow, isolated reef-enclosed lagoons with a sandy sea-floor. Consultation with commercial reef-line fishers with a significant and consistent logged catch of spangled emperor (from the Department's CFISH database) led to the identification of Gould Reef as the best location for the experimental work. The reef encloses a lagoon of just sufficient depth to moor the experimental enclosures, and has an opening of sufficient size to allow the passage of the RV *Tom Marshall*. However commercial line-fishers have advised that such locations are frequented by large sharks (e.g. tiger sharks) which could present a danger to fishers working from small boats at night, as well as to the experimental enclosures. Consequently most of the spangled emperor fishing was done from the *Tom Marshall.*

Unfortunately, 48 (71%) of the 67 spangled emperor captured at Gould Reef were lost as a result of major damage to the enclosures by large sharks. Including the five individuals captured at Heron Island (6-9 Mar '05) this left a sample of only 24 for statistical testing. It is not known whether some of the fish in the socks were dead or moribund when the sharks attacked, or whether the sharks were simply attracted by the live fish. It is of interest that even when an enclosure was damaged with large tears and holes in the mesh, not all the fish escaped, suggesting that the enclosure was acting as a *de facto* habitat.

The raw data tabulation (Table 2-23) shows that release condition appeared an important predictor of survival, with fish having the poorest release condition (4+) showing the lowest survival rate (25%), while all the fish classed as 2 or 3 survived. Those in the best condition at release appeared to suffer low survival, but the small sample size (n = 4) makes this observation highly unreliable. With the exception of floating status, it seemed unlikely that many of the other factors listed in Table 2-23 would emerge as influential in spangled emperor survival because of the inadequate numbers of observations in some of the combinations.

The initial GLM analysis tested the effect of release condition, barotrauma signs and treatment on survival. The condition of the enclosure ('environ') could not be tested as there was effectively only one category – that relating to shark attack. Of the three factors tested only release condition was significant (P = 0.005; Table 2-24 and Figure 2-14), again pointing to the surprising reliability with which the observation of an experienced angler can predict the likelihood of a fish surviving, simply from its appearance and behaviour when released.

The follow-up analysis (Table 2-25) examined the effects of barotrauma, body size, surface interval, treatment and the barotrauma x treatment interaction on survival, but none of these terms approached statistical significance. While it must be stressed that the differences are not significant, the modelled adjusted mean survival rates are nevertheless provided in Table 2-26, as a check on whether the general trends are consistent with expectations and the results of tests on the other species. The effects of barotrauma and surface interval trend in counter-intuitive directions, with higher survival rates at longer surface intervals and when the barotrauma signs were apparent (Table 2-26). There was relatively little difference in adjusted survival rate between treatments or between length classes; given the magnitude of the associated standard errors, it is not surprising that the differences were not significant.

Table 2-23. Raw data results showing numbers of spangled emperor in each class that survived, died, or disappeared (missing), as well as the total and proportion that survived (% surv). For further explanation see caption to Table 2-4.

Variate	Class	Survived	Died	Missing	Total	% surv
Release condition	1	1	2	1	4	33.33
	2	6	0	20	26	100.00
	3	11	0	17	28	100.00
	4*	1	3	10	14	25.00
Surface interval	1	9	3	15	27	75.00
	2	10	2	28	40	83.33
	3*	0	0	4	4	
Length	Large	9	3	20	32	75.00
	Small	10	2	27	39	83.33
Hook location	Shallow*	17	3	43	63	85.00
	Deep*	0	1	2	3	0.00
	Foul	2	0	3	5	100.00
Barotrauma	Nil	3	1	8	12	75.00
	Swollen	14	4	37	55	77.78
	Extreme*	2	0	3	5	100.00
Treatment	N	4	1	16	21	80.00
	S	6	2	18	26	75.00
	V	9	2	13	24	81.82
Injury	J	1	0	4	5	100.00
	N	18	5	44	67	78.26
Floater	0	17	2	41	60	89.47
	1	0	2	5	7	0.00
Environment	Shark	17	5	48	70	77.27
	Washout	2	0	0	2	100.00

Table 2-24. Results of analysis of deviance testing the effects of release condition, barotrauma signs and treatment on the survival of spangled emperor.

Source	d.f.	Deviance	Mean Deviance	Deviance Ratio	Approx Chi prob.
Release condition	2	10.5293	5.2647	5.26	0.005
Barotrauma	2	1.1634	0.5817	0.58	0.559
Treatment	2	1.4132	0.7066	0.71	0.493
Residual	17	11.4575	0.6740		
Total	23	24.5635	1.068		

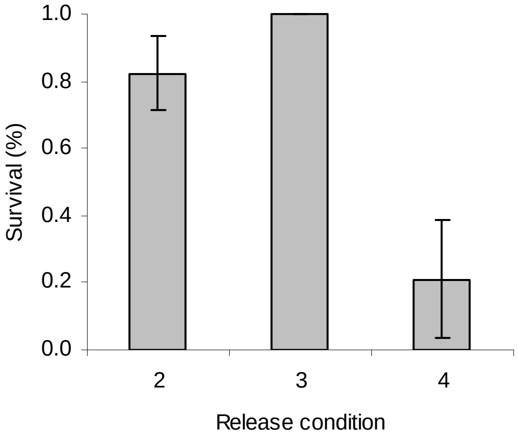

Figure 2-14. Effect of release condition on short-term survival of spangled emperor.

Table 2-25. Analysis of deviance table showing the effects of a suite of factors (excluding non-significant interactions) on short-term survival of spangled emperor.

Source	d.f.	Deviance	Mean Deviance	Deviance Ratio	Approx Chi prob.
Barotrauma	2	0.994	0.497	0.50	0.608
Length	1	0.309	0.309	0.31	0.578
Surface interval	1	0.328	0.328	0.33	0.567
Treatment	2	0.271	0.135	0.14	0.873
Residual	17	22.661	1.333		
Total	23	24.564	1.068		

About 10% of the 67 spangled emperor released into the experimental enclosures floated after release, and 71% of those were lost (Table 2-27), primarily as a result of serious damage to the enclosures by sharks or by direct predation. Tears in the apparatus mesh were large enough to allow all of the contained fish to escape, and it is perhaps surprising that any fish remained at all. Only two of the fish recorded as floating remained captive, and neither survived. In contrast, 17 of the 19 non-floaters survived the experimental period. Clearly post-release floating status had a major effect both on subsequent survival and escapement, but because of data limitations the possible contributing effects of factors such as barotrauma, hook location and injury could not be evaluated. For example, only four of the retained fish were without any barotrauma symptoms, and only two were reported with everted gut and/or exophthalmia. Chi-square tests such as the GLM analyses of deviance used here cannot be expected to produce reliable results with cell samples of this small size.

Table 2-26. Mean survival estimates and associate approximate standard errors for spangled emperor adjusted for a range of variates. None of the differences between adjusted means were significant at the 95% level.

Variate	Class	Adj mean	s.e.
Barotrauma	Nil	0.7024	0.2876
	Bloat	0.7869	0.1019
	Serious	0.9997	0.0068
Length	Large	0.7316	0.1370
	Small	0.8495	0.1029
Treatment	Nil	0.7751	0.2076
	Shotline	0.7334	0.1692
	Vented	0.8392	0.1123
Surface interval	0.2	0.7103	0.1685
	0.4	0.7735	0.0875
	0.6	0.8271	0.0962
	0.8	0.8707	0.1304

Table 2-27. Numbers of floating and non-floating spangled emperor that escaped or were lost from the vertical enclosures, and the survival statistics of those that remained throughout the experiment.

Status	Floaters	Non-floaters	Total
Disappeared	5	41	46
Remained - died	2	2	4
Remained - survived	0	17	17
Remained - total	2	19	21
Disappeared + remained	7	60	67

2.4.6 Release capsule trials

During field operations at Davies Reef and Heron Island we re-submerged a number of fish (mainly coral trout and redthroat emperor) with the release capsule to gain some idea of its ease of operation and effectiveness. The fish were caught in 15-20 m of water, and released in a similar range of depths a slight distance from their point of capture. Our observations revealed that the device has a number of valuable attributes in comparison with the two release methods tested during the Project. Firstly, it requires less handling of the fish, which can be placed back in the water as soon as it is disengaged from the hook. Venting typically takes up to 30 sec or so, during which time the fish is out of the water, prevented as much as possible from moving, and subject to an invasive procedure. Attaching a struggling fish to the shot weight can be difficult, and a good deal of care is needed in placing the fish together with the weight back in the water in such a way as to avoid the fish 'falling off' the (barbless) hook. There is a potential element of danger in dealing with syringe needles and hooks – even barbless – when the fish are active and the operating platform (usually the seat of a small boat) is far from stable. From this point of view the release capsule has certain distinct advantages. We found that with the species observed, the fish showed little signs of struggling or distress while being lowered in the capsule, usually being gently forced up against the soft mesh at the top of the device (Figure 2-15, left). Apart from a couple of instances where the teeth ofa coral trout were momentarily caught in the mesh of the capsule, there appeared no impediment to the ability of the fish to swim out the bottom of the device (Figure 2-15, right).

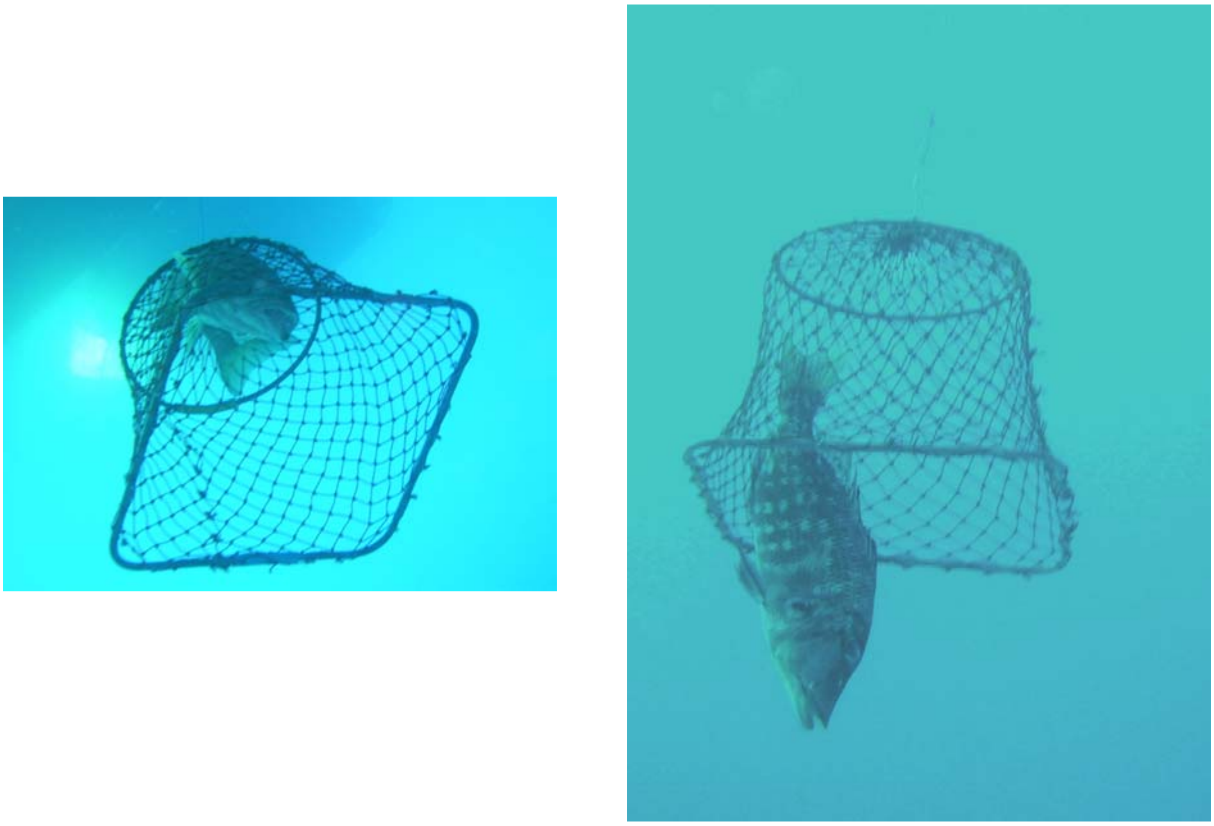

Figure 2-15. Release capsule being lowered with a common coral trout (left), and stationary at depth (~15 m) showing a redthroat emperor swimming out of the bottom.

2.5 DISCUSSION

As anticipated, the effects of a range of factors and covariates on the short-term survival prospects of the five species examined in our experiments (coral trout, redthroat emperor, crimson snapper, saddletail snapper and spangled emperor) differed greatly between species (Table 2-28). In the initial generalised linear model (with survived/not survived as the binary response variate) the term ‘release condition’ was included, to represent the combined effects of all the factors that might have influenced the survival rates of the fish during their capture, handling on board, and treatment. In all species release condition was by far the dominant effect, even though the condition index was a qualitative appraisal (on a 1-5 scale) subject to a certain amount of inter-angler variability. The condition or environment of the experimental apparatus (i.e. whether subjected to currents strong enough to lay the apparatus over at an angle or to damage to the mesh from shark bites) was significant only in the case of saddletail snapper, where fish in enclosures suffering shark damage survived less well than those where the enclosures were unaffected by shark damage or currents. Only in saddletail snapper (previously known as largemouth nannygai) did barotrauma treatment appear to have a significant effect on survival when the effects of capture and handling were expressed in terms of release condition.

Table 2-28. Summary of probability values derived from the initial and follow-up GLM analyses for each. Factors significant at the 0.05 level are shown in bold, while those of lower significance but still of interest are surrounded by parentheses. Missing cells indicate factors not included because of aliasing or insufficient data contrast.

Model	Coral trout	Redthroat emperor	Crimson snapper	Saddletail snapper	Spangled emperor
Condensed					
Release condition	**<0.001**	**0.001**	**<0.001**	**<0.001**	**0.005**
Environment	0.213	0.102	0.734	**0.001**	
Barotrauma signs	0.755	0.153	0.839	0.693	0.559
Treatment	0.159	0.391	0.242	**0.028**	0.493
Expanded					
Hook location	**0.005**	0.405	**<0.001**	**0.008**	
Capture depth	**<0.001**	0.89			
Surface interval	0.918	0.647	0.187	(0.077)	0.567
Barotrauma signs	0.331	**<0.001**	(0.059)	0.091	0.608
Size (FL)	**0.002**	0.82	0.434	0.644	0.578
Bleeding			0.435	0.429	
Environment				0.654	
Treatment	0.743	0.515	0.817	0.285	0.873

In the set of models in which release condition was replaced by whatever contributing effects could be included (given the limitations of the data), certain trends emerged although there were considerable differences between taxonomic groupings. The most consistently significant term was hook location. In coral trout and the two snapper species (crimson and saddletail) hook location was significant at least at the 0.05 level. All deep-hooked fish (i.e. where the hook was lodged in the throat, gullet or gut) showed a poorer survival rate than shallow-hooked fish (where the hook was lodged in the lip or mouth). This finding is consistent with many other studies examining the effects of hooking damage (Muoneke and Childress 1994, Cooke and Suski 2004). Our experimental protocol for deep-hooked fish was to leave the hook in place by cutting the line close to the fish's mouth (according to best-practice procedures), so we had no way of testing whether leaving the hook *in situ* has a beneficial effect on survival. Even if we had included a randomised procedure for testing this effect, it would ultimately have suffered from lack of contrast in the data, since very few fish used in our experiments had been hooked in the throat or gut.

Depth of capture significantly influenced the survival rate of coral trout, but not redthroat emperor, which was the only other species where there was sufficient contrast in the data to enable the statistical comparison. This was the case regardless of their barotrauma symptoms or the treatment administered. The adjusted mean survival rates for coral trout taken from shallow and intermediate depths were twice those in fish captured from deep water.

We refer to the length of time between capture and release into the experimental apparatus as the surface interval. Although not usually accounted for in studies of this nature, Lyle *et al.* 2006 found a significant effect of surface interval on the short-term survival of dusky flathead (*Platycephalus fuscus*) in south-east Queensland. However in the case of our reef species, the elapsed time between capture and release (which averaged 45.7 ± 1.06 minutes and occasionally exceeded 3 hours) was not a major determinant of survival, and its effect approached significance only in saddletail snapper.

The presence or otherwise of externally visible signs of barotrauma was of significance to short-term survival only in redthroat emperor where (interestingly) bloated fish had by far the highest adjusted mean survival rate (nearly 92%). Survival differences between fish with no visible barotrauma signs and those with serious symptoms (extruded gut or exophthalmia) were not significantly different. The small sample size and high standard error associated with the mean for seriously affected fish probably swamped any real difference with the no-symptom group. However the latter group was well represented (n = 116) and the anomalous result cannot be attributed to an insufficiently large sample. It is consistent with the result for the effect of capture depth, in that the lowest survival rate was amongst fish from the shallowest depths, where one would expect the incidence of barotrauma signs to have been least.

In only one species (coral trout) was body size a significant predictor of short-term survival, with large fish surviving slightly better (78%) than small fish (65%). We have no immediate explanation as to why this should be the case, but it may have something to do with the development of the gonads limiting the expansion of the swim bladder within the body cavity of large, more mature fish. Alternatively there may be an allometric relationship between swim bladder size and fish length, such that the swim bladder volume decreases relative to the size of the fish, and so its susceptibility to the effects of barotrauma decrease with size.

When the experimental work commenced we had not included in the experimental protocol any capacity for including observations on the fish immediately after they had been released, apart from the subjective release condition index. However towards the end of the second of the two Heron Island experiments that accounted for nearly all the redthroat emperor, field staff realised that it could be useful to note whether the released fish remained floating at the surface or returned to the surface after briefly submerging. It was found that shotline-released fish would sometimes 'jump off the shot' either just below the surface, or before they reached their equilibrium depth. Also, it is possible that regardless of the amount of care taken in venting a fish there is always a possibility that not all the excess gas is released to enable the fish to submerge immediately of its own accord (see comments below on coral trout). There are insufficient data for redthroat emperor to test the effect of floating status in this species, but coral trout, crimson snapper and saddletail snapper all registered floating as having a highly significant ($P < 0.001$) effect on survival. In all three species fish that submerged immediately on release showed much higher survival rates than those that remained floating on the surface. Not unexpectedly there was a greater proportion of floaters amongst bloated control fish (i.e. those showing the usual swollen body-cavity, a common visible sign of barotrauma but had not been vented or shotline-released) than other combinations of barotrauma sign and treatment. It is possible that the lack of sufficient depth in the enclosures may have contributed to the fact that some fish floated after being released on the shotline.

The effect of barotrauma treatment was statistically significant in saddletail snapper (in the condensed model) but not in any of the other species examined. Although not significant in the expanded saddletail snapper model, the adjusted treatment means showed similar trends to those estimated from the condensed model, and suggest that treating this species prior to release will enhance its ultimate survival. In terms of their ability to submerge after release, coral trout appeared to benefit from the shotline treatment but not from venting. This probably results from the fact that if the coral trout's very membranous swimbladder ruptures on ascent, the escaping gases form numerous pockets in and around the mesenteries. Traditional venting procedures are unable to access all these gas pockets, with the result that venting is less effective than might be expected, and evidently fails to confer any survival advantage over nil treatment. It may be that the same applies to serranids in general, as it is often said that reef-associated cods belonging to the same family as the coral trout are very difficult to vent and release successfully. Re-pressurisation by releasing the fish with a shotline or release capsule (see Bruesewitz *et al.* 1993), will (unlike venting) overcome the buoyancy problem and improve the individual's survival chances. In a related and as yet unpublished project investigating the mechanical strength of the swimbladders of coral trout, red emperor and redthroat emperor, Bittar *et al.* (James Cook University, Townsville, unpublished data) noted that although the swimbladder wall of coral trout is mechanically quite strong, the capture depth from which it would be expected to rupture is little more than 10 m. These authors also found that the coral trout's membranous swimbladder was much more difficult to isolate from the surrounding tissues than were the much stouter-walled swimbladders of the red emperor and redthroat emperor.

The spawning behaviour of coral trout on the Great Barrier Reef, first described by Samoilys and Squire (1994), suggests that this species may be able to tolerate rapid changes in pressure. Spawning behaviour comprises a series of 'spawning rushes' during which a male and female fish from a seasonal spawning aggregation swim rapidly toward the surface in close proximity, release their gametes, then immediately swim back down to their original depth. Samoilys and Squire (1994) describe the height of these 'rushes' as being from 2 to at least 12 m, and from varying initial depths. Why the swimbladders of these fish are not damaged in the process is problematical. It may be that the fish are physically prepared for the anticipated pressure change, and have tensed the abdominal musculature to the extent that it does not allow the swimbladder to expand to the point of rupture. Because the rushes are so rapid, this muscular control may only have to be maintained for a few seconds. It is also possible that the increasing swimbladder volume associated with the reduction in ambient pressure may squeeze the gonads and helps ensure the maximum extrusion of gametes in a tightly circumscribed volume of the water column over a very brief time period. In other words, the swimbladder may be an integral component of the mechanics of spawning in this species.

When a hooked fish is being brought to the surface, however, the time duration is usually much longer and the fish may not have the capacity to maintain its abdominal tension, particularly if it has become exhausted as a result of struggling. On many occasions project staff observed fish that had been brought to the surface bloat and in some instance produce gas bubbles (presumably from the swimbladder) after they had been placed in the holding tank. This may have been the result of a gradual involuntary relaxation of the abdominal wall, which allowed the swimbladder to expand (causing bloating) or even rupture (causing gas bubble release). After decompression of largemouth bass *Micropterus salmoides* as a result of having been brought to the surface, Feathers and Knable (1983) observed that some time (approx. 5 min) elapsed before bloating occurred. Lee (1992) found the same species to be better able to re-submerge if returned to the water immediately after capture, presumably because 'delayed' bloating had not fully occurred. These observations are consistent with the hypothesis of muscular control, although there is also a possibility that when air temperatures are higher than the ambient water temperature at capture depth there may also be a simple heat-related expansion effect.

Our analyses indicated that surface interval was not a significant predictor of short-term survival in any of the species examined in this Project, and was evident as a weak (non-significant) signal only in saddletail snapper. In terms of the observations of 'delayed bloating' described above, it is understandable that surface interval showed no effect, as the process of tagging, venting (where necessary) and holding the experimental fish in the deck tank meant that in only a very few instances would the elapsed time between capture and 'release' into the experimental enclosure have been short enough for the effect to have become apparent. Rapid release of captured fish is traditionally recommended for obvious reasons, principally to avoid prolonged time out of water and reduce potential UV damage to the fish's eyes. While rapid release may be achievable in a basic c&r fishery where de-hooking devices are used, there could be issues in tag-and-release operations, where the time taken to measure and tag the fish increases the likelihood of delayed bloating occurring.

For the remaining species (crimson snapper, redthroat emperor and spangled emperor), there was little apparent benefit to be derived from shotline release or venting the fish over simply releasing them without treatment. This comes as a surprise, as conventional wisdom amongst anglers is that fish showing signs of barotrauma (bloating, swelling, gut extrusion and exophthalmia) should at least be vented to assist them to return to their equilibration depth. This finding is curious, as there was an extremely strong effect of post-release floating on survival, and it would have been expected that either shotline release or venting would assist a reasonable proportion of bloated fish to return to depth. It may be that these fish, regardless of how they had been treated and the degree of barotrauma evident externally, have suffered some degree of internal damage that affected their ability to survive the three-day experimental period. Alternatively, as has been suggested in a number of other studies, the process of treating the fish may have caused some damage. It may also be that fish are just as likely to die (for different reasons) from the effects of an inability to submerge as from the adverse effects of barotrauma treatment.

Our experiments showed that of the five species examined, saddletail snapper was the most susceptible to the short-term effects of c&r and will benefit from either venting or shotline release. Shotlining is more effective when barotrauma symptoms are serious than when they are moderate. Survival of coral trout and perhaps other serranids will also benefit from treatment with either method, though probably more from shotline release if the fish are very large. While there was no compelling evidence of a survival advantage to be gained from treating the other species, our experiments showed that there were no significant adverse effects of treatment. There is little doubt that both venting and shotline releasing help overcome the buoyancy problems associated with barotrauma, but the effects were not consistent and not always translated into improved short-term survival. We recognise that these experiments, while providing estimates of absolute mortality or survival, only extended for three days, and there is a strong likelihood that the effects of capture, handling, tagging, and release may not become evident for weeks or even months after the event. The short-term experiments also effectively protected the fish from surface predation, which may well have been an additional source of mortality amongst bloated fish (Bruesewitz *et al*. 1993). Chapter 4 relates to the long-term survival component of this project, and provides evidence which assists in determining the extent to which delayed effects from c&r are apparent in the species of interest.

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CHAPTER 3. EFFECT OF HOOK PATTERN AND SIZE ON CATCH RATE, HOOKING LOCATION, INJURY AND BLEEDING FOR A NUMBER OF TROPICAL REEF FISH SPECIES.[1]

A. Mapleston, D.J. Welch, G. Begg, M. McLennan, D. Mayer, and I.W. Brown

3.1 ABSTRACT

The Queensland Great Barrier Reef line fishery in Australia is regulated via a range of input and output controls including minimum size limits, daily catch limits and commercial catch quotas. As a result of these measures a substantial proportion of the catch is released or discarded. The fate of these released fish is uncertain, but hook-related mortality can potentially be decreased by using hooks that reduce the rates of injury, bleeding and deep hooking. There is also the potential to reduce the capture of non-target species though gear selectivity. A total of 1053 individual fish representing five target species and three non-target species were caught using six hook types including three hook patterns (non-offset circle, J and offset circle), each in two sizes (small 4/0 or 5/0 and large 8/0). Catch rates for each of the hook patterns and sizes varied between species with no consistent results for target or non-target species. When data for all of the fish species were aggregated there was a trend for larger hooks, J hooks and offset circle hooks to cause a greater number of injuries. Using larger hooks was more likely to result in bleeding, although this trend was not statistically significant. Larger hooks were also more likely to foul-hook fish or hook fish in the eye. There was a reduction in the rates of injuries and bleeding for both target and non-target species when using the smaller hook sizes. For a number of species included in our study the incidence of deep hooking decreased when using non-offset circle hooks, however, these results were not consistent for all species. Our results highlight the variability in hook performance across a range of tropical demersal finfish species. The most obvious conservation benefits for both target and non-target species arise from using smaller sized hooks and non-offset circle hooks. Fishers should be encouraged to use these hook configurations to reduce the potential for post-release mortality of released fish.

3.2 INTRODUCTION

Hook and line fishing gear are commonly used in many tropical reef finfish fisheries world wide. The Great Barrier Reef (GBR), off the east coast of Australia, is the largest coral reef ecosystem in the world and supports important commercial, recreational and charter line fisheries. The commercial fishery has an annual value of about AU$60-100 million, primarily supplying common coral trout (*Plectropomus leopardus*) for the live food fish trade in Asia. The commercial sector each year harvests around 3000 tonnes (*t*) of demersal reef fish, with large quantities also harvested by recreational (2000 *t*) and charter (300 *t*) sectors (Begg *et al*., 2005). The main target species for all sectors of the fishery are common coral trout (*Plectropomus leopardus*) and redthroat emperor (*Lethrinus miniatus*), with the importance of other species such as red emperor (*Lutjanus sebae*), saddle tailed and crimson snapper (*L. malabaricus and L. erythropterus*) and serranids other than coral trout varying among sectors and regions (Mapstone *et a*l., 1996; Higgs, 2001). This multi-sector, multi-species fishery is regulated through a variety of management strategies including spawning closures, minimum and maximum size limits for all sectors, total allowable commercial catches, and recreational and charter bag limits. Fish caught by recreational and commercial

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fishers are not always retained, either because of fisheries regulations (i.e. quotas, size and bag limits), poor eating quality, damage caused by attacks from other fish or sharks during capture, recreational catch-and-release fishing and/or ethical reasons. The number of fish released by recreational fishers as a proportion of the total catch varies between species, (e.g. red emperor, 68.1%; coral trout, 35.3%; Henry and Lyle, 2003). The number of fish released by the commercial sector varies between regions and species, and may be influenced by high-grading, particularly in the live food fish fishery for common coral trout. An important goal identified by managers and stakeholders of line fisheries in Australia is to increase the survival of released fish (McLeay *et al*., 2002). One factor contributing to injuries and mortality of released or discarded fish from line fishers is hook type (Diggles and Ernst, 1997; Ayvazian *et al*., 2002; Falterman and Graves, 2002; Bacheler and Buckel, 2004). A number of recent studies have investigated differences in catch rates, hooking location and rates of injury when using circle hooks and J hooks for both recreational (Prince *et al*., 2002; Skomal *et al*., 2002; Cooke *et al*., 2003) and commercial line fisheries (Falterman and Graves, 2002; Bacheler and Buckel, 2004). These studies have been prompted on the basis of the perceived conservation benefits of using circle hooks, which include reduced post-release mortality, fish frequently hooked in the jaw facilitating easier hook removal, reduced gut hooking, and reduced catch of non-target species. Although some evidence supports these claims, the effectiveness of circle hooks is not consistent across all fisheries or species (Cooke and Suski, 2004). The wide variety of sizes and configurations produced by hook manufacturers adds to the difficulty of making general statements about the effects of hooks. Hook size has been found to be important when considering issues such as selectivity and hooking location (Ralston, 1990; Otway and Craig, 1993; Bacheler and Buckel, 2004,), and variation in the degree of offset (deviation of the hook point relative to the shank) can also alter the effectiveness of circle hooks (Prince *et* al., 2002; Ostrand *et al*., 2005).

Our objective was to determine the effect of circle hook configurations on the survival prospects of key species in the GBR line fishery. Circle hooks have provided conservation benefits through reduced deep hooking and reduced mortality for a number of other fisheries. The applicability of circle hooks for the GBR line fishery has not previously been tested and the effects of popular hook types currently used in the fishery on factors affecting mortality are not known. Empirical data, therefore, are needed to determine the potential value of using circle hooks within this fishery as a strategy to reduce hook-related mortality. We examine catch rate, hooking location, incidence of bleeding and injury for six commonly used hook types including three patterns and two sizes for each pattern, across a range of target and non-target tropical fish species.

3.3 MATERIALS AND METHODS

Between 14 January and 19 October 2005 we conducted 19 dedicated fishing trips aboard fisheries research vessels to four separate locations off the east coast of Queensland (Figure 3-1). Suitable fishing locations were chosen following analysis of commercial and recreational catch records and consultation with local fishers regarding areas where consistent catches of harvested fin fish species could be expected. Common coral trout were targeted at Davies Reef in the central GBR in depths from 9 to 29 m. Crimson snapper and saddle tailed snapper were caught from a submerged wreck in Halifax Bay, in the central GBR at a depth of 20 m. Redthroat emperor were targeted offshore from Heron Island in the southern GBR at depths from 8 to 20 m. Red emperor were targeted offshore from Double Island Point in southern Queensland in depths from 45 to 50 m. Included in the catch were a number of non-target species of which the three most abundant species or species groups have been included in the analysis. These include blue spotted rock cod (*Cephalopholis cyanostigma*), blackblotch emperor (*Lethrinus semicinctus*) and a number of species of trevally (Family Carangidae) which have been aggregated into a single group for the purpose of analysis.

Fishing gear used for the hooking experiments included a rod (Penn Mariner medium action spin rod) and reel (Penn Powerspin 7000) spooled with 15 kg monofilament line and handline (Seahorse® 200mm Professional Caster Extra Strength) spooled with 25 kg monofilament line. These fishing gears were typical of those used by recreational and commercial fishers targeting demersal reef fish in the study areas. Commercial fishers typically use larger size (~8/0) J hooks with handlines and monofilament line (~25-30 kg). In contrast recreational and charter fishers use a greater diversity of hook sizes and patterns and are more likely to fish with rod and reel. For the purpose of our study a total of six hooks were used: size 4/0 and 8/0 J (both J hooks were Mustad 4190); 5/0 and 8/0 12° offset circle hooks; and 5/0 and 8/0 0° offset circle hooks. Except the modified 0° offset circle hooks, each hook pattern was recommended by recreational or commercial fishers and was available from local tackle shops. Recreational fishers preferred Gamakatsu Octopus circle hooks which are manufactured with thin-gauge wire and a 12° offset. For the purpose of this study the offset was removed by bending the hooks with pliers. The gape widths of the J hooks and circle hooks were similar within the small and large size classes. Fishing rigs consisted of a single hook tied to the end of the line with one or two size 4 (27 g) or 5 (65 g) running ball sinkers. These rigs are consistent with those used by both recreational and commercial fishers targeting demersal reef fish.

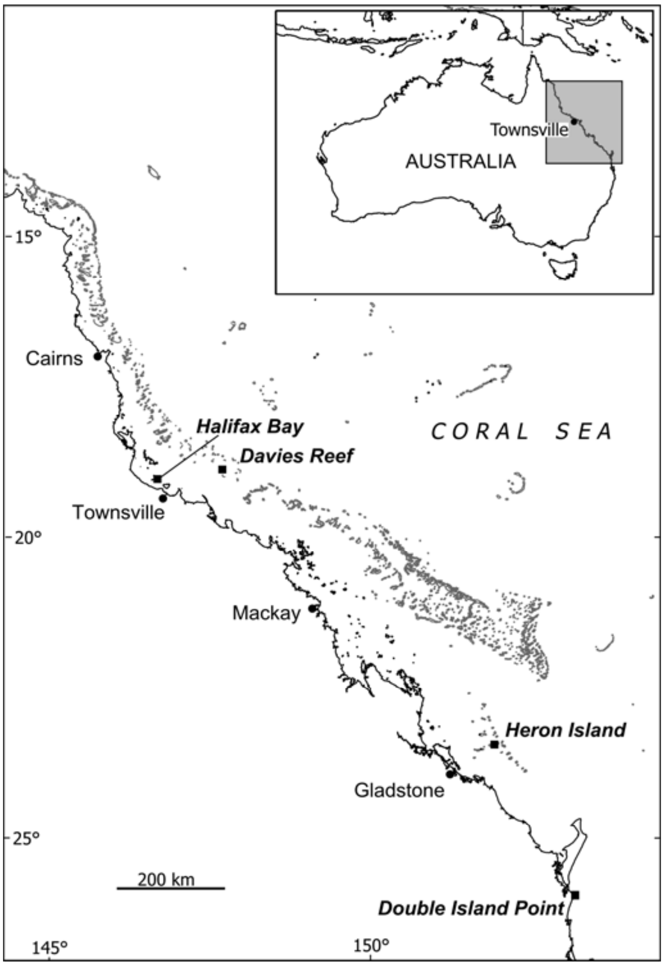

Figure 3-1. Map of fishing locations for hooking studies.

Research staff supervised between two and five fishers during each of the fishing trips. Fishing was structured so that each hooking trial equated to a three hour fishing session. Each fisher was randomly assigned one of the six hook types at the start of a fishing session and thereafter followed a sequential order. Fishing time was standardised to 30 min per hook type, which was termed a ‘hang’ as the vessel was anchored in one spot during this time. Each fishing session was divided into six half-hour hangs. The vessel was moved to a new location at the end of a 30 minute hang if no fish were caught or catch rates were low. Frozen pilchards (*Sardinops sp.*) were used as bait (~150-170 mm total length) and baits were cut to be proportional to the size of the hook. When fish were landed the following information was recorded: 1) species; 2) fork length (mm); 3) either anatomical hooking location (lip, mouth, throat, gut, eye), or foul hooked if the hook lodged outside the mouth; 4) injuries sustained (pierced eye, damage to either the gills or jaw); and 5) bleeding (yes, no). Injury data were aggregated into two categories (injured or not injured), and hooking location was aggregated into three categories for analysis (shallow, lip and mouth; deep, throat and gut; other, eye and foul hooked). The grouping of hooking location is consistent with other studies which have shown a correlation between mortality and deep hooking in the gills, oesophagus or throat (Muoneke and Childress, 1994; Diggles and Ernst, 1997; Millard at al., 2003). Fish were unhooked using pliers or de-hookers, then tagged with unique identifiable dart tag and released. If a fish was gut-hooked, the hook was left *in situ* by cutting the line close to the fish's jaw.

Data were analysed under the generalized linear model framework (McCullagh and Nelder 1989), using GenStat (2005). Binary responses (proportions of fish injured or bleeding) were analysed assuming the Binomial distribution with the logit link, and count data (catch rates and aggregate hooking locations) were analysed with the Poisson distribution and a log link. In both models, the dispersion was estimated from the residual mean deviance. Model terms included trip and fisher (as fixed main effects), hook pattern and hook size along with their interaction, and fish size. Common coral trout were divided into two size classes on the basis of their minimum legal size (MLS) of 380 mm TL (total length), while the remaining species were divided into two size classes on the basis of their sample median sizes. The resultant mean proportions and rates were thus balanced and adjusted for all the other terms in the model. Where the overall treatment effect was shown to be significant ($P < 0.05$), least-significant difference (LSD) testing was conducted between the respective means. These analyses were conducted for each species separately, as well as for all species aggregated.

3.4 RESULTS

3.4.1 Catch statistics

Following 25 fishing sessions a total of 1053 fish representing five target species and three non-target species were captured in sufficient numbers to be included in the analysis (Table 3-1). All of the red emperor (average fork length 314 ± 40 mm s.d.) were below the MLS of 550 mm TL and more than 98% of the catch of crimson sea perch and saddle tailed sea perch (average fork length 305 ± 29 mm and 326 ± 29 mm, respectively) were below the MLS of 400 mm TL. Twenty three percent of the common coral trout landed (average fork length 406 ± 71 mm) and 11.54% of the redthroat emperor (average fork length 419 ± 62 mm) were below the MLS of 380 mm TL. There are no size limits for trevally (average fork length 391 ± 127 mm), but all of the blue spotted rock cod (average total length 245 ± 21 mm) and 6.1% of the blackblotch emperor (average fork length 245 ± 13 mm) were below the MLS of 380 mm TL and 250 mm TL, respectively.

Table 3-1. Numbers of target and non-target species included in the analysis.

Common name	Scientific name	Total
Target species		
Crimson sea perch	*Lutjanus erythropterus*	403
Common coral trout	*Plectropomus leopardus*	161
Saddle tailed sea perch	*Lutjanus malabaricus*	136
Redthroat emperor	*Lethrinus miniatus*	53
Red emperor	*Lutjanus sebae*	49
Non-target species		
Trevally	*Carangid spp.*	95
Blackblotch emperor	*Lethrinus semicinctus*	83
Blue spotted rock cod	*Cephalopholis cyanostigma*	73

3.4.2 Catch rates

When data were aggregated across hook types the greatest number of fish of any one species landed during any hang was 24 crimson snapper (mean 7.75 ± 6.11 S.D.). The maximum number of individuals of any of the other seven species landed in any hang ranged from 5 to 12 (mean 2.81 ± 2.21). The effect of hook size on catch rate was significant for only crimson snapper ($P < 0.001$) and blackblotch emperor ($P < 0.001$), with small hooks producing higher catch rates than large hooks. In addition, hook pattern had a significant effect on catch rates of blackblotch emperor ($P = 0.003$) but none of the other species (Table 3-2). Catch rates were higher when using smaller hooks except for common coral trout and redthroat emperor (Table 3-2). When the data were aggregated across species it was apparent that hang ($P < 0.001$), fisher ($P < 0.001$) and hook size ($P < 0.001$) all had a significant effect on catch rates. There was no significant effect of hook pattern when data were aggregated ($P = 0.075$).

Table 3-2. Mean catch rates (per half hour hang) by hook pattern and size for individual species and aggregated data including all species. Significant differences are indicated by superscripts - within rows and hook treatments, means with a common letter are not significantly different ($P < 0.05$).

	Hook Pattern				Hook Size		
	Offset circle	J	Non-offset circle	s.e.	Large	Small	s.e.
Common coral trout	1.11	1.68	1.06	0.29	1.39	1.18	0.27
Redthroat emperor	0.42	0.27	0.24	0.07	0.34	0.28	0.06
Crimson sea perch	2.27	2.04	2.62	0.32	1.87^a	2.74^b	0.27
Saddle tailed sea perch	0.88	0.6	0.82	1.31	0.74	0.79	1.31
Red emperor	0.95	0.57	0.78	0.31	0.65	0.9	0.31
Blue spotted rock cod	0.85	0.96	0.7	0.22	0.73	0.77	0.17
Blackblotch emperor	1.15^a	0.39^b	1.41^a	0.26	0.54^a	1.42^b	0.23
Trevally	0.73	0.58	0.9	1.27	0.62	0.85	1.26
All species	2.54	2.28	2.81	0.18	2.18^a	2.90^b	0.14

3.4.3 Injury and bleeding

Hook-related injuries were observed in 6% of the fish captured. Of these injuries, 42% were associated with the hook piercing the eye, 33.3% with torn flesh around the jaw and 24.7% with damage to the gills. These categories were aggregated for analysis into injured or not injured. Hook pattern had a significant effect of on injury rate in crimson snapper ($P = 0.012$) and saddletail snapper ($P = 0.008$). Offset circle and J hooks were more often associated with injuries than non-offset circle hooks (Table 3-3). Hook size had a significant effect on injury rates of common coral trout ($P = 0.003$). Larger hooks consistently caused more injuries than smaller hooks for all species, except trevally (Table 3-3). Except for common coral trout, small fish were more likely to be injured than large fish. When data were aggregated across species, hook pattern ($P = 0.023$) and size ($P < 0.001$) had a significant effect on injury rate.

Overall, 8.5% of fish landed were bleeding as a result of hooking. Bleeding was more often associated with shallow hooking (71.7%) than deep (14.2%) or other hooking (14.2%). Hook size affected bleeding for saddletailed snapper ($P < 0.001$), with larger hooks causing more bleeding. Larger hooks consistently caused more bleeding in all species (Table 3-4).

Table 3-3. Percentage of fish caught which were injured, by hook pattern, hook size and fish size for individual species and aggregated data including all species. Significant differences are indicated by superscripts – within rows and hook treatments, means with a common letter are not significantly different ($P < 0.05$)

Species	Hook Pattern				Hook Size			Fish size		
	Offset circle	J	Non-offset circle	s.e.	Large	Small	s.e.	Large	Small	s.e.
Common coral trout	4.56	4.69	2.56	2.71	8.44^{a}	0.00^{b}	1.66	4.50	2.30	2.13
Crimson sea perch	14.4^{a}	13.28^{a}	4.69^{b}	2.66	14.60	8.82	2.40	9.82	11.87	2.21
Saddletail sea perch	0.00^{a}	0.00^{a}	8.42^{b}	1.23	6.20	1.00	2.05	2.42	4.07	2.05
Red emperor	3.25	0.57	0.00	73.05	3.22	0.00	49.24	0.00	2.44	37.3
Blue spotted rock	4.75	7.16	4.52	4.61	9.35	2.03	3.59	2.93	7.35	3.55
Blackblotch emperor	0.00	5.08	0.00	1.39	4.27^{a}	0.00^{b}	1.75	0.00	2.60	1.08
Trevally	0.00	14.67	0.00	2.62	5.50	2.87	3.15	3.70	4.71	3.24
All species	6.90^{a}	7.81^{a}	3.69^{b}	4.58	8.98^{a}	3.91^{b}	0.95			

Table 3-4. Percentage of fish caught displaying bleeding, by hook pattern, hook size and fish size for individual species and aggregated data including all species. Significant differences are indicated by super-scripts – within rows and hook treatments, means with a common letter are not significantly different ($P < .05$).

Species	Hook Pattern				Hook Size			Fish size		
	Offset circle	J	Non-offset circle	s.e.	Large	Small	s.e.	Large	Small	s.e.
Common coral trout	2.36	11.18	11.85	3.69	12.79	4.85	3.11	10.53	2.75	2.75
Redthroat emperor	7.10	0.00	0.00	2.07	6.53	0.00	2.84	0.00	7.10	3.08
Crimson sea perch	15.41	14.89	16.98	3.18	16.73	15.21	2.72	17.31	14.34	2.59
Saddletail sea perch	11.29	8.95	10.79	4.64	20.62^{a}	2.72^{b}	3.74	11.17	9.72	3.80
Red emperor	2.81	0.00	0.47	46.71	2.96	0.00	59.47	3.25	0.00	65.42
Trevally	4.37	9.99	4.36	4.53	2.35	9.80	9.23	6.66	5.34	3.97
All species	7.77	8.79	8.91	1.31	10.08	7.34	1.10			

3.4.4 Hooking location

Fish were more likely to be shallow hooked (88.0%) than deep hooked (3.9%) or hooked at ‘other’ locations (8.1%). For the eight species, deep hooking ranged between 2.0% and 9.6% (Table 3-5). Hook size was a significant factor affecting hooking location for crimson snapper ($P < 0.001$; Figure 3-2) and blackblotch emperor ($P = 0.011$; Figure 3-3) small hooks being more often associated with shallow hooking and larger hooks with ‘other’ hooking locations. When data were aggregated across species there was a significant effect of hook size ($P = 0.019$) on hooking location (Figure 3-4). Small hooks were more likely to be associated with shallow hooking and larger hooks with hooking in ‘other’ locations. There was no effect of hook pattern on hooking location.

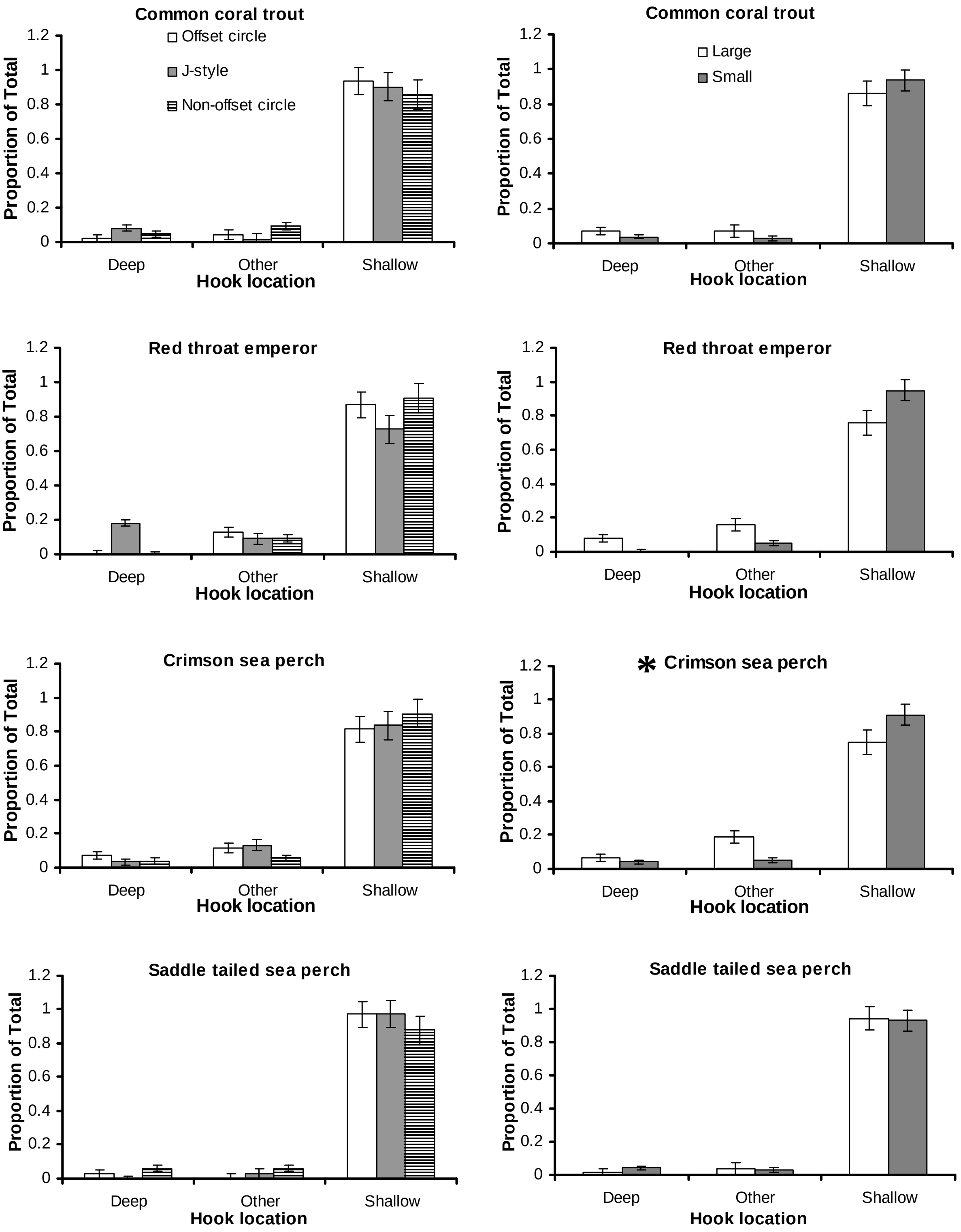

Figure 3-2. Effect of hook pattern (left panels) and hook size (right panels) on the anatomical hook location in coral trout, redthroat emperor, crimson snapper and saddletail snapper. Adjusted mean proportions ± s.e. are shown, asterisks highlighting species in which the effect was significant at P < 0.05.

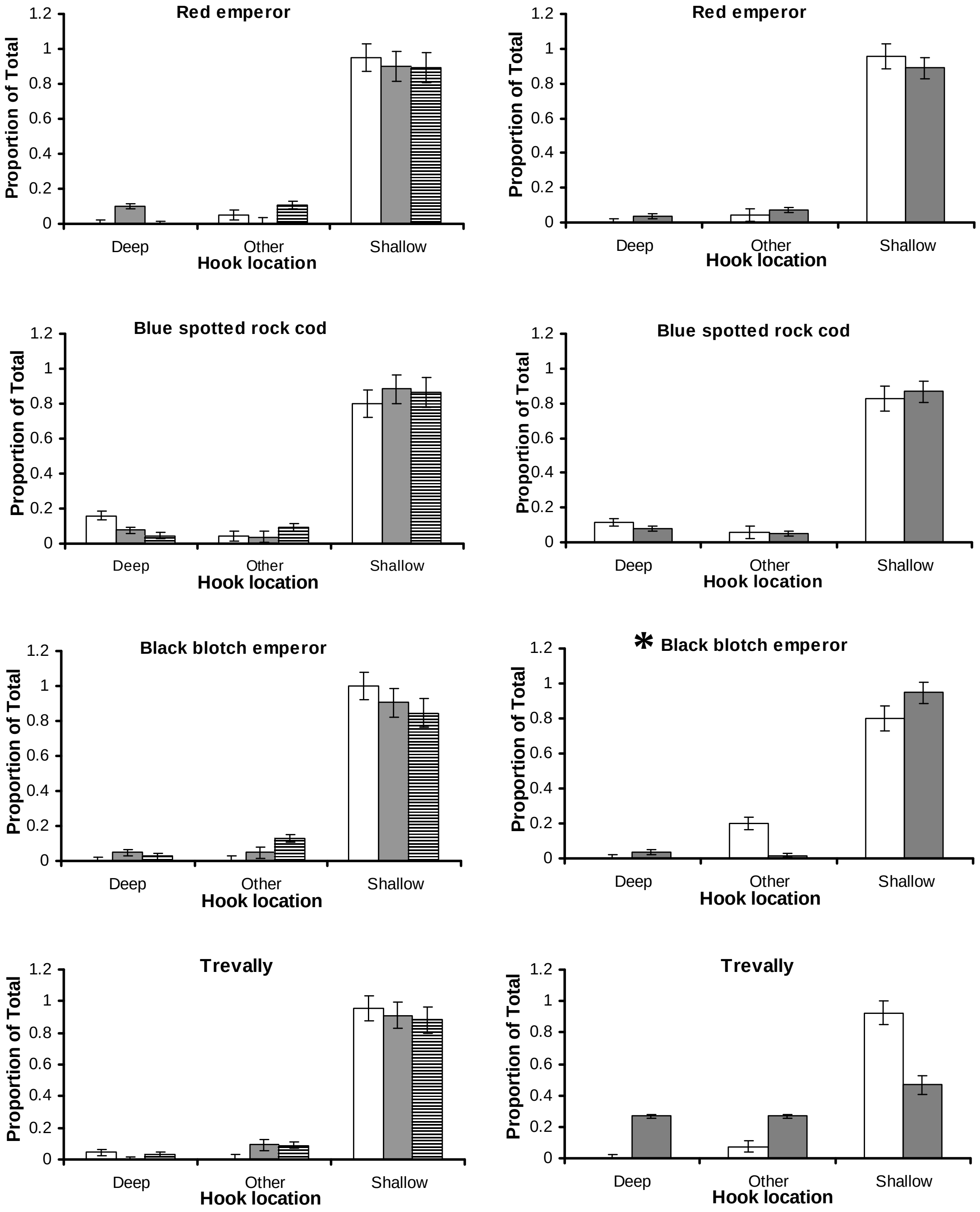

Figure 3-3. Effect of hook pattern (left panels) and hook size (right panels) on anatomical hook location in red emperor, blue-spotted rock cod, blackblotch emperor and trevally. Adjusted mean proportions ± s.e. are shown, asterisks highlighting species in which the effect was significant at $P < 0.05$.

Table 3-5. Hook location data for each species, showing the percentage of records within each category.

Species	Hook location		
	Deep	Other	Shallow
Common coral trout	5.00	4.38	90.63
Redthroat emperor	5.66	9.43	84.91
Crimson sea perch	4.77	10.30	84.92
Saddletail sea perch	4.41	3.68	91.91
Red emperor	2.04	6.12	91.84
Blue spotted rock cod	9.59	5.48	84.93
Blackblotch emperor	2.41	7.23	90.36
Trevally	2.20	5.49	92.31

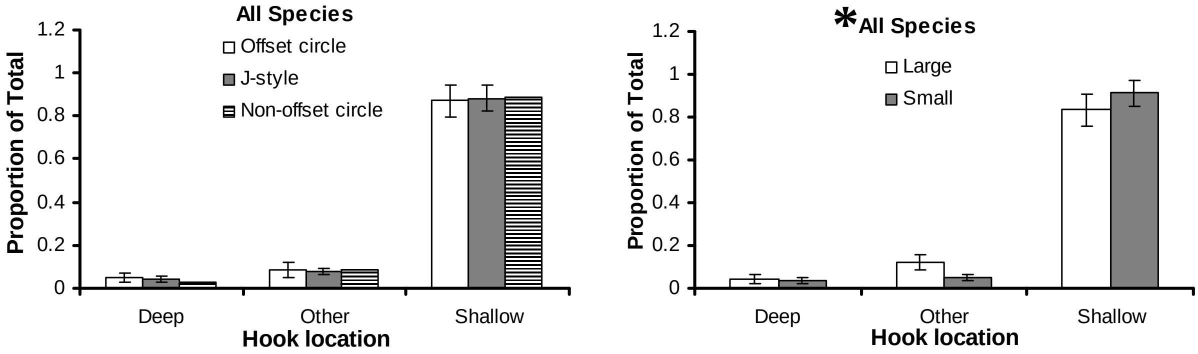

Figure 3-4. Effect of hook pattern (left panels) and hook size (right panels) on the anatomical hook location in all species pooled. Adjusted mean proportions ±s.e. are shown, asterisks highlighting effects significant at P <0.05.

3.5 DISCUSSION

3.5.1 Catch statistics

The species included in our study represent a broad range of target and non-target species caught in the GBR line fishery. The results highlight the variability in effectiveness of different hook types within a multi-species fishery and provide some evidence for the promotion of smaller hooks and non-offset circle hooks as a means of reducing hook-related mortality. The majority (> 98%) of saddle tailed and crimson snapper caught were below the MLS, as were all of the red emperors. All of these lutjanids share a similar life history, with juvenile fish schooling inshore and migrating offshore to deeper water with increasing age and size (Newman and Williams, 1996). For these species, fishing location will invariably affect the average size of fish caught, with more undersize fish likely to be caught on inshore grounds than offshore areas. Inshore grounds such as the one fished in our study are heavily utilised, particularly by recreational anglers either targeting these species or other species which use the same habitats. Therefore, the number of fish released from the catch may be very high for these species (Henry and Lyle, 2003).

3.5.2 Catch rates

There were few differences in the influence of the three hook patterns (non-offset circle, J and offset circle) or hook sizes (small 4/0 or 5/0 and large 8/0) on catch rates. No consistent trend was evident in the catch rate of any hook pattern for either the target or non-target species. Circle hooks did not always have the highest catch rates for target species. In fact J hooks caught the most common coral trout, the primary target species of the fishery, and for some species offset circle hooks out-fished non-offset circle hooks. Results from our study as in other studies, have shown that the effects of circle hooks on capture efficiency are not consistent across species (Cooke and Suski, 2004).

In only two species (crimson snapper and blackblotch emperor) was there an effect of hook size on catch rate, with smaller hooks yielding higher catch rates. However, the majority of crimson snapper and blackblotch emperor were small fish, which could have affected the efficiency of the larger hooks. The smaller gape size of crimson snapper and blackblotch emperor may also explain why hook size was a factor affecting the catch rates for these species. The relationship between gape size and hook efficiency appears to be important for both of these species, with larger hooks also being more likely to foul-hook fish or hook fish in the eye suggesting that the larger hooks were not working effectively.

Currently, larger J hooks are more commonly used by commercial line fishers targeting common coral trout within the GBR line fishery. Results from our study indicate the use of larger J hooks within the commercial sector may be maximising the catch of common coral trout, but not limiting the harvest of non-target species such as blue spotted rock cod. These two serranids are not gape limited, being able to easily swallow the largest hooks used in this experiment. Similar results with regard to hook size have been reported for other serranid groupers caught in North Carolina (Bacheler and Buckel, 2004) and for hapuupuu (*Epinephelus quernus)* from the Hawaiian deep-sea handline fishery (Ralston, 1982). In both studies changes in hook size did not affect the number of serranids caught. Catch rates of blue spotted rock cod and other large-gape non-target species within the GBR multi-species line fishery are therefore unlikely to be affected by moderate changes in hook size.

3.5.3 Injury and bleeding

There was a consistent trend for larger hooks to cause more injuries for all species. Except for trevally, larger hooks were also responsible for a higher incidence of bleeding. When data were aggregated, J hooks and offset circle hooks were more likely to cause injuries than non-offset circle hooks. Both bleeding and injury are reliable predictors of post-release mortality in a number of fish species (Ayvazian *et al.,* 2002; Malchoff *et al*., 2002; Domeier *et al*., 2003). The use of larger J hooks within the fishery, particularly by fishers targeting common coral trout, could be contributing to a greater rate of injury and bleeding among undersize and non-target fish being caught and released. There appears to be a trade-off, between the slight increases in catch rates of coral trout by using larger J hooks, and the substantial increase in injuries and bleeding for undersize and non-target species when using these hooks. The results from our study suggest that to maximise the conservation benefits for the fishery the use of smaller sized hooks will provide the greatest gain.

Injuries were more likely to occur to smaller fish which are likely to be released due to MLS regulations. There is a need to focus on reducing the rate of hook-related injury of smaller fish, particularly for the lutjanid species as discard rates for these species can be high (>50%) (Henry and Lyle, 2003). The discard rates for the three lutjanid species included in our study (>98%) are probably indicative of the inshore grounds which are fished primarily by recreational fishers either targeting these species or catching them as bycatch when targeting other species. The use of smaller hooks or non-offset circle hooks should be encouraged when fishing these grounds to reduce the incidence of injury and bleeding as well as foul hooking for these species.

3.5.4 Hooking location

There was a great deal of variation in the hook location across the different fish species, with no consistent trends for either target or non-target species. The results from our study contrast with other studies which have shown a clear relationship between circle hooks and hooking location, particularly for pelagic species such as billfish and tuna (Prince *et al*., 2002; Domeier *et al*., 2003; Kerstetter and Graves, 2006). It is likely there is a relationship between hooking location, hook type and the techniques and gears used in the fishery. Typically within recreational billfish fisheries there are specific techniques associated with the use of circle hooks. Prince *et al*. (2002) noted that J hooks were set by jerking the rod vertically, while circle hooks were set by simply reeling the line tight as the fish swam away from the boat increasing the resistance to allow the hook to rotate and set. Within the GBR reef line fishery the application of this hook setting technique, particularly while fishing on or around reefs where there is an abundance of structure for fish to swim into and snag gear, may not be applicable given the current gear and targeting behaviour. Where the fishery operates in more open water the use of circle hooks should be encouraged, as the associated hook setting techniques may be more applicable.

Diggles and Ernst (1997) concluded that hooking location was the most important factor affecting mortality of two small reef fish species, wire netting cod (*Epinephelus quoyanus)* and yellow stripey (*Lutjanus carponotatus*) caught from the GBR. Hook location has also been a significant factor affecting survival of striped bass (*Morone saxatilis)* and chinook salmon (*Oncorhynchus tshawytscha*), with deep-hooked fish more likely to die than lip-hooked fish (Grover *et al*., 2002; Millard *et al*., 2003). The rates of deep hooking observed in our study varied between fish species, hook patterns and hook sizes. Although non-offset circle hooks resulted in a reduced rate of deep hooking when data were aggregated, this was not always the case for individual species. If shallow hooking is considered a positive outcome, with regard to hook location, there were no instances where non-offset circle hooks out performed the other hook patterns. This highlights the variability in the effectiveness of circle hooks across different species within this fishery.

Bacheler and Buckel (2004) reported that, compared to J hooks, circle hooks reduced the rate of gut hooking for grouper. However, results from our study showed no trend in the rate of deep hooking among similar serranids. The highest deep-hooking rates were associated with J hooks in common coral trout and offset circle hooks for blue spotted rock cod. For both these species there was a reduction in the rate of deep hooking when using non-offset circle hooks, although there was a higher rate of non-offset circle hooks lodging in ‘other’ hooking locations. The fishing gears and techniques used in our study were different to those used by Bachelor and Buckel (2004), and this could have reduced the effectiveness of circle hooks and contributed to the high incidence of ‘other’ hooking.

Hook size had an effect on hooking location for both crimson snapper and blackblotch emperor, with small hooks more often associated with shallow hooking and large hooks with ‘other’ hooking locations. These results are similar to those for catch rates where smaller hooks resulted in a higher catch rate for both species. It is likely that the smaller gape size of these species reduce the effectiveness of larger hooks leading to a greater rate of foul hooking or hooking in the eye. Other studies have shown that there is a strong correlation between hooking location and hook size with larger hooks more likely to hook fish in injurious locations. Cooke and Suski (2004) make the point that to work correctly, the entire circle hook needs to be ingested by the fish prior to setting the hook. Results from our study suggest that within a multi-species fishery such as the GBR line fishery it is more beneficial to use smaller sized hooks which will be more effective across a wider size range and for a greater number of species. The relationship between hook size and gape size appear to be important considerations when optimising the performance of hook patterns for conservation benefits (Cooke *et al*. 2005).

3.5.5 Conclusions

The rate of discarding and possibility of hook-related mortality remain a key concern for stakeholders in the GBR line fishery. Our results highlight the variability in performance of six hook types for a range of target and non-target demersal reef fish species, using gear and techniques consistent with the recreational and commercial fishery. The most consistent and obvious conservation benefits for the fishery resulted from using smaller hooks and non-offset circle hook patterns. As has been shown in other studies, there appears to be little benefit in promoting the use of offset circle hooks with no evidence of any beneficial effects for the sustainability of the fishery over and above those of non-offset circle hooks. However recreational fishers preferred to use a circle hook pattern which has an offset. Fishers should be encouraged to use other circle hook patterns which do not have an offset, or alternately the hook can be bent to remove the offset prior to fishing.

We have shown that using smaller hooks could provide a positive benefit across the fishery by reducing the incidence of injury and bleeding of released fish for a number of target and non-target species. The conservation benefits of non-offset circle hooks within the GBR line fishery although apparent are not as clear as they have been for other fisheries and this is likely to be related to the gear and targeting behaviour of the fishers. The techniques used when setting circle hooks are different from those employed when using J hooks. Within the GBR line fishery there may be situations, other than targeting common coral trout and redthroat emperor in shallow waters around reefs which will suit the application of these hook setting techniques and circle hooks more readily.

3.6 ACKNOWLEDGEMENTS

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CHAPTER 4. A COMMUNITY-BASED ASSESSMENT OF THE EFFECTS OF HOOKING DAMAGE AND RELEASE METHODS ON LONG-TERM SURVIVAL OF KEY GREAT BARRIER REEF FISH SPECIES.

W. Sumpton, I. Brown, D. Mayer, M. McLennan, A. Mapleston, D. Welch, W. Sawynok, and G. Begg.

4.1 ABSTRACT

Over 9,000 individuals of eight species of coral reef fish (coral trout (*Plectropomus leopardus.*), "other*" coral trout (Plectropomus spp),* redthroat emperor (*Lethrinus miniatus)*, grass emperor (*Lethrinus laticaudis),* spangled emperor *(Lethrinus nebulosus)*, red emperor (*Lutjanus sebae),* saddletail snapper (*Lutjanus malabaricus)* and crimson snapper (*Lutjanus erythropterus)*), were tagged by researchers and members of the Australian National Sportsfishing Association in Queensland between 2003 and 2007 as part of an experiment to determine the effects of barotrauma relief procedures on survival of line caught tropical reef fish. Two types of barotrauma relief procedures were tested: venting using a hollow needle, and shot-line release. Other potential mortality-inducing factors including injury, bleeding, hooking location, hook removal and depth of capture were also assessed. Subsequent recapture rates were analysed using generalized logistic regression models to determine factors likely to impact on release survival. Release condition was overall found to be the most important factor affecting the subsequent recapture rate of all species. Saddletail snapper suffered the most from the effects of barotrauma with the recapture rate of vented and shotlined fish approximately 40% higher that of untreated fish (although these differences were not statistically significant). Crimson snapper was unusual in being the only species where fish that had obvious barotrauma symptoms had higher recapture rates than fish that had no such symptoms. We attribute this result partly to the more careful recording of symptoms by researchers who tagged large numbers of fish at a location that received considerable fishing effort by recreational fishers, thereby biasing the result.

Capture depth was a significant factor in all species apart from crimson snapper and redthroat emperor, the general trend being for reduced survival with increasing capture depth, at least for depths greater than about 15 m. Where the data were adequate, there was a general trend for recapture rates of fish hooked in either the lip or mouth to be significantly higher than for those hooked in the throat or gut. Body size was also an important factor affecting recapture rate in coral trout and crimson snapper. While larger coral trout survived better than smaller trout, the opposite was the case for crimson snapper.

While in only three species (crimson snapper, saddletail snapper and redthroat emperor) did the modeled results indicate a significant benefit from treating fish for barotrauma, we recommend treating all the species we investigated, with the exception of red emperor. The results for red emperor were not statistically significant but the recapture rate of untreated fish was about 50% higher than treated fish. More red emperor were caught in deep than shallow water, but the species exhibited fewer barotrauma symptoms than any of the others examined.

The difficulty in distinguishing between small individuals of crimson snapper and saddletail snapper is a further reason for recommending treatment of these two species, despite some differences in their barotrauma response. Although the differences were not statistically significant, there was some evidence that shotlining increased survival more than venting in most species apart from crimson snapper, with more shotlined than vented fish recaptured.

We believe that the results of these long-term tagging experiments show that there is benefit in promoting shotlining and other less invasive forms of barotrauma relief within the recreational fishing community as well as the traditional treatment of venting.

4.2 INTRODUCTION

In recent years the desire to enhance release survival of line caught fish has been prompted by documented high rates of discarding (Higgs 1998, Higgs 2000) as management changes of increased size limits and reduced bag limits (Anon. 2003) have increased the numbers of fish released by both commercial and recreational anglers. In recognition of the importance of release survival, Australia has developed a national strategy for enhancing the survival of released line caught fish (McLeay *et al.* 2002), an initiative which co-ordinated a series of projects examining release survival issues on groups of priority species. The research being presented here is part of that strategy. The main objectives of the research being reported here were to examine factors influencing both the short term survival (presented in Chapter 2) and long term survival (this chapter) and also to test whether barotrauma relief procedures had an impact on the release survival of fish. The short term survival of fish was examined over a three day period (See Chapter 2) whereas the series of experiments described in this chapter investigate the survival of fish over periods of weeks and months where infection and the chronic effects of capture and release are more likely to be manifest.

Efforts to improve the release survival of line caught fish have involved the use of different hooks (Diggles and Ernst 1997, Cooke and Suski 2004), and fishing methods as well as codes of handling and release practice. In Chapter 3 of this report we examine the impacts of various hook types on the damage caused to our species of interest. In many fisheries, barotrauma is also a major issue, particularly those that take place in relatively deep water (Harden Jones 1951, Harden Jones and Scholes 1985, Parrish and Moffitt 1993, Wilson and Burns 1996, St John and Syers 2005, Parker *et al.* 2006,) where pressure change and associated expansion or bursting of swimbladder can cause catastrophic physiological damage (Rummer and Bennett 2006).

In order to reduce these barotrauma effects, and to allow the fish to swim away from the water surface, many fishers either vent the fish or attach a weight that drags the fish from the surface (shot-lining). Venting a fish refers to puncturing the fish's swim bladder with a sharp object, preferably a cannula. Shot-lining is generally done by inserting a weighted, unbarbed hook (attached to a normal fishing line) into the mouth and allowing it to drag the fish to an appropriate depth. When the fish reaches this depth, the line is prevented from running off the spool and the fish falls or swims off the hook before the hook and weight are retrieved via the attached line. The practice of venting is fairly widespread amongst recreational anglers and commercial anglers routinely vent coral trout that are to be marketed in the live fish trade. In Queensland shotlining is not a widespread practice among recreational taggers although in Western Australia and elsewhere it is being widely promoted as a method of ameliorating the effects of barotrauma.

Australian National Sportfishing Association (ANSA) anglers in Queensland have actively been involved in collaborative research to assist in the sustainable management of fish stocks by assisting researchers tag large numbers of fish (Begg *et al.* 1997; McPhee *et al.* 1999, Sumpton *et al.* 2003). Prior to the start of this current research many ANSA anglers were experienced in tagging and venting tropical reef species that were the subject of this research (i.e. coral trout (*Plectropomus spp.*), redthroat emperor (*Lethrinus miniatus)*, grass emperor (*Lethrinus laticaudis),* spangled emperor (*Lethrinus nebulosus*), red emperor (*Lutjanus sebae*), saddletail snapper (*Lutjanus malabaricus)* and crimson snapper (*Lutjanus erythropterus).* These ANSA anglers were therefore considered to be an experienced and well-equipped group to assist in experiments on tropical reef species.

Results of the analysis of the large Queensland Suntag recreational tagging database to determine some of the factors affecting post release survival of common tropical reef species are presented in Chapter 5. Based on analysis of the data up to 2003 it was noted that venting appeared to enhance the survival of both *Lutjanus sebae* and *Lutjanus malabaricus,* although it was noted that venting was conducted by only a small subset of anglers and there were inconsistencies in the information recorded by anglers. As a result of that previous analysis and the need to improve the quality of information collected by ANSA anglers, a number of changes were made to the tagging data recording protocols. In this experiment we use a select group of skilled recreational anglers to test whether barotrauma relief procedures (shotlining and venting) had any impact on the recapture rate of the key target species in the demersal reef line fishery over the longer term. We also investigate the factors likely to have influenced the survival of these species. We use recapture rate of the various treatment classes of tagged fish as an estimate of relative survival rate, but because many factors play a role in determining rates of fish capture, tag recapture rates should not be used as principal indicators of differences in post-release survival between species.

4.3 MATERIALS AND METHODS

4.3.1 Field Operations

A group of over fifty ANSA anglers who were experienced in tag and release procedures were recruited throughout Queensland to assist in experiments to determine the effects of two barotrauma relief procedures (shotlining and venting) on the long-term survival of line caught tropical reef fish. Fishing was conducted throughout Queensland but most activity was centred in the Great Barrier Reef Marine Park (GBRMP). The exception to this was red emperor which were tagged in large numbers between Noosa Heads and the southern part of the GBRMP.

Shot line devices were constructed using a 0.45 kg lead “tear drop” sinker to which had been attached a barbless Mustad size 8/0 J style hook. Venting tools were 16 gauge hypodermic needles as recommended by the Florida Sea Grant Program (www.flseagrant.org/science/venting/).

Anglers were individually contacted by Project staff and trained in the use of the barotrauma relief procedures, although most already had considerable experience with the use of venting tools and “best practise” fish handling techniques. When venting fish, anglers were advised to insert the needle under a scale at an angle of 45° to the side of the body, directly below the 4th dorsal spine and in line with the top of the pectoral fin. Project staff also maintained regular contact with the recreational anglers, stressing the need to adhere to the experimental protocols when releasing tagged fish.

Between September 2003 and September 2007 over 12,700 coral trout (*Plectropomus spp.*), redthroat emperor (*Lethrinus miniatus*), grass emperor (*Lethrinus laticaudis*), spangled emperor *(Lethrinus nebulosus)*, red emperor (*Lutjanus sebae),* saddletail snapper (*Lutjanus malabaricus)* and crimson snapper (*Lutjanus erythropterus)* were tagged as part of the experiment.

All fish were caught by hook and line, and most handled using a moist cloth to minimise injury during hook removal and tagging. Fish were measured (± 1 cm), tagged and released generally within 30 seconds of capture. Where fork lengths were recorded these were converted to total lengths using morphometric relationships available from previous studies (McPherson *et al.* (1992) for the lutjanids , Brown and Sumpton (1998) for *Lethrinus miniatus*,) and others were taken from unpublished reports and FishBase (Froese and Pauly 2006). Location (in some cases recorded as GPS coordinates) and dates of capture were also recorded.

Some fish were not treated, and these served as controls. Others were treated either by venting the swim bladder with a hollow needle, or releasing the fish using a shot line device. The experimental design required anglers to use each of the treatments and a control on consecutive fish so that there would be a balanced design across treatments (i.e. approximately equal numbers of vented, shotlined and control releases). Individually numbered tags marked with the words ’record date place length’ and a 24-hr toll free telephone number, were inserted in the dorsal musculature and locked between the pterygiophores below the dorsal fin rays. Anchor tags (Hallprint TM; 75 x 2 mm) and dart tags (Hallprint TM; 91 x 2 mm) were used, depending on the size of fish tagged.

Barotrauma symptoms were recorded as one or more of the following categories:- No visible sign of barotrauma, swim bladder inflated and stomach hard, gut protruding from mouth and/or anus, exophthalmia (eyes bulging).

Hooking location, bleeding and injury were categorised as shown in the table below and anglers were provided with diagrams to aid in the objective recording of hooking location and injury data.

Hooking location	Bleeding	Injury
Lip or jaw	No bleeding	No damage
Inside mouth but not as far as throat	Light bleeding	Hooked in eye
Throat or gill hooked but hook visible	Copious dark red blood	Gill damage
Gut hooked with hook not visible		Jaw damage
Foul hooked (not in the mouth)		Moderate scale loss
		Heavy scale loss

The size and type of hook as well as depth of capture were also recorded. Release condition was assessed subjectively as one of five categories according to the following criteria:

1: No obvious damage from capture/handling, minimal time out of water, swam away strongly
2: Some hook or handling damage, short time out of water, swam away well
3: Moderate damage from hooking or handling, moderate scale loss, slow to swim away
4: Long time out of water, major scale loss, long recovery time, fish turned upside down
5: No sign of recovery on release, floated away on surface or taken by a predator

There were many instances where a fish was recaptured several times and released each time. These fish were only assumed to have been caught once in determining recapture rates, subsequent recaptures being excluded from the analyses.

4.3.2 Data analysis

Binomial generalised linear regression models (GLMs) with logit link function were used in GenStat (2007) to test the effect of various factors on recapture rate, with each fish species being analysed individually. Two GLMs are presented for each species. The first was used to test whether release condition and tagger affiliation (recreational vs. research) were important contributing factors to the overall recapture rate of tagged fish. Release condition was confounded by the influence of other factors and could be regarded as encapsulating the combined effects of factors such as barotrauma symptoms, injury and other capture variables. To account for this, a second GLM was run with release condition replaced by contributing factors such as bleeding, hooking location, body size and injury. Two-way interaction terms were also fitted but aliasing and lack of data coverage across all categories resulted in only main effects models being presented for some species. In general, data coverage was too limited to consider higher order interactions.

Depth was categorized into three depth classes (< 15m, 15-30 m, and > 30 m) for presentation of the raw data summaries, but capture depth was treated as a second-degree polynomial variable in all models, apart from saddletail snapper. All other factors were analysed as categorical variables. In some cases data were pooled when the numbers of observations in various categories were low. These groupings are described for each species in the results that follow but in all cases the barotrauma signs category of ‘extreme’ represents the aggregation of all fish displaying symptoms other than ‘none’ and ‘swollen’ and included those individuals that had signs of exophthalmia and/or gut extrusion from mouth or anus. Likewise, hooking location was classified into three groups with the aggregation of fish hooked in the mouth and jaw being grouped into a ‘shallow’ hooking group and the remainder (other than those foul hooked outside the mouth) being grouped as ‘deep’ hooked. Body size was categorized into two groups, usually separated on the basis of minimum legal size.

4.4 RESULTS

4.4.1 General data summary

Over the four years in which the experiment was conducted 12761 fish were tagged and released by researchers and recreational anglers (Table 4-1). The contribution made by community based anglers varied dramatically among species with the greatest contribution being made to the tagging of "other" coral trout, red emperor and grass emperor. Other coral trout comprised species such as chinese footballer (*Plectropomus laevis*), barcheek coral trout (*P. maculatus*) and passionfruit trout *(P. aerolatus* By midway through the Project it became apparent (from interim analyses of the tag-recapture data provided by Infofish Services) that, while the anticipated number of tagged and released fish was well within (and in some species exceeding) expectation, the releases with appropriate treatment were seriously lagging. This was due to a variety of factors, including increased fuel costs and poor weather (limiting the number of tagging trips), and the impact of the GBRMPA re-zoning process and spawning closures which limited available fishing areas and times. It was also clear, however, that many of the collaborating anglers were rarely using both treatments, and in some cases they were not using either treatment at all. This was despite regular liaison with individual anglers and groups, the provision of numerous additional tags, venting tools and shotline release weights, and the release of a number of progress reports, presentations and press articles urging anglers to observe the scientific protocols (at the risk of jeopardising the whole experiment). As a result, Project staff made a special attempt, within the constraints of existing financial resources, to increase the number of released tagged and treated fish, predominately in areas where the highest numbers of recaptures might be expected. Consequently, the 'research' releases complying with experimental protocols accounted for 21% of the total releases (over 40% of the total coral trout and redthroat emperor releases), and to something like 57% of the usable treated releases over all species. Some of the additional data were attributable to releases from the hooking trials reported in Chapter 3, but a large part was due to specially-organised tagging operations. Table 4-1 to Table 4-4 show the numbers of each species that were tagged and recaptured as well as the overall recapture rate of these fish. These tables only include fish that were treated by researchers and anglers that were part of the experiment and do not include releases by non-participating anglers. In some analyses that follow these data sets have been further restricted to eliminate data from anglers that appeared to have a biasing influence on results due to misreporting or data inconsistencies. For example, anglers that tagged large numbers of fish in one area and who regularly fished the same grounds and recorded disproportionately high catches from certain treatments were eliminated from subsequent analysis. The tables provide some evidence of the benefits of treating species such as saddletail snapper and crimson snapper for barotrauma but suggest that red emperor may not warrant treatment. The detailed models presented in the results that follow further explore the effects of barotrtauma treatment , injury and other factors on recapture rate.

Table 4-1 The numbers of fish tagged by researchers, ANSA anglers and other anglers between October 2003 and September 2007.

Species	Individuals	Charter	ANSA club	Research	Total	% Research
Common coral trout	38	104	310	678	1130	60.00
"Other" coral trout	9	11	165	20	205	9.76
Redthroat emperor		5	527	486	1018	47.74
Crimson snapper	40	66	1237	725	2068	35.06
Saddletail snapper	14	120	1132	304	1570	19.36
Red emperor	65	2105	2042	270	4482	6.02
Grass emperor	26	165	1737	25	1953	1.28
Spangled emperor	5	34	78	128	245	52.24
Total	197	2610	7228	2636	12671	20.80

Table 4-2 Numbers of the various tropical line caught species that were experimentally treated by researchers and ANSA anglers between October 2003 and September 2007.

Species	Not treated	Shot-lined	Vented	Total
Common Coral trout	361	179	422	962
"Other" coral trout	73	18	31	122
Redthroat emperor	456	153	231	840
Crimson snapper	821	171	365	1357
Saddletail snapper	651	99	248	998
Red emperor	3004	151	191	3346
Grass emperor	1112	18	58	1188
Spangled emperor	113	40	49	202
Total	6591	829	1595	9015

Table 4-3 Numbers of recaptures of tropical line caught species tagged and treated as part of the long term release survival experiment between October 2003 and September 2007.

Species	Not treated	Shot-lined	Vented	Total
Common Coral trout	29	17	25	71
"Other" coral trout	4		3	7
Redthroat emperor	5	6	5	16
Crimson sea perch	116	31	69	216
Saddletail sea perch	65	16	32	113
Red emperor	355	11	13	379
Grass emperor	51		3	54
Spangled emperor	2			2
Total	627	81	150	858

Table 4-4 Recapture rate of tropical line caught species that were either shotlined, vented or not treated (controls) by researchers and ANSA anglers between October 2003 and September 2007.

Species	Not treated	Shot-lined	Vented	Total
Common Coral trout	8.0	9.5	5.9	7.4
"Other" coral trout	5.5	0.0	9.7	5.7
Redthroat emperor	1.1	3.9	2.2	1.9
Crimson sea perch	14.1	18.1	18.9	15.9
Saddletail sea perch	10.0	16.2	12.9	11.3
Red emperor	11.8	7.3	6.8	11.3
Grass emperor	4.6	0.0	5.2	4.5
Spangled emperor	1.8	0.0	0.0	1.0
Total	9.5	9.8	9.4	9.5

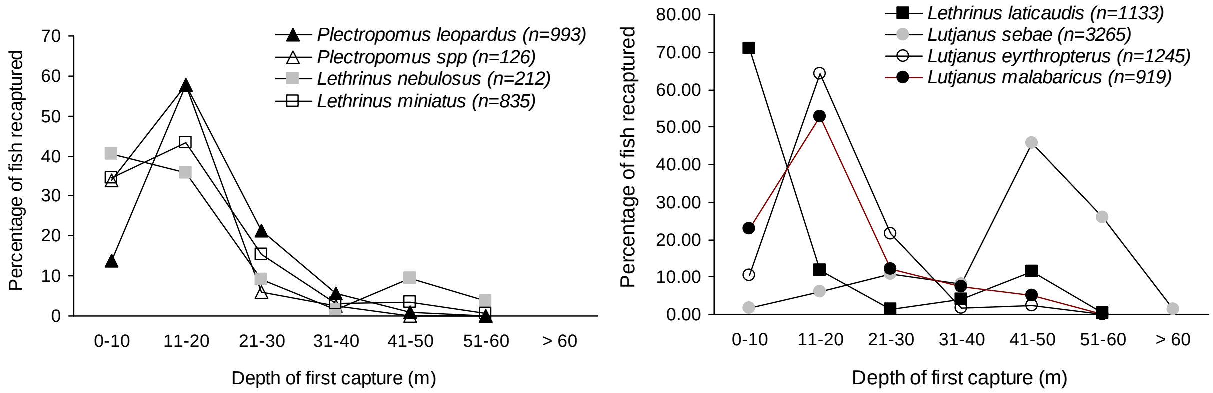

Figure 4-1 Percentage of fish that were first captured at a range of different depths and subsequently tagged by researchers or ANSA anglers.

Apart from red emperor, all species tended to be targeted in waters less than 40 m depth (Figure 4-1) where over 80% of tagging and release took place. In contrast, most red emperor were caught in depths greater than 30 m. In fact most fish apart from red emperor and grass emperor were caught in 10 to 20 m of water. Grass emperor was the only species where most of the catch came from depths less than 10 m.

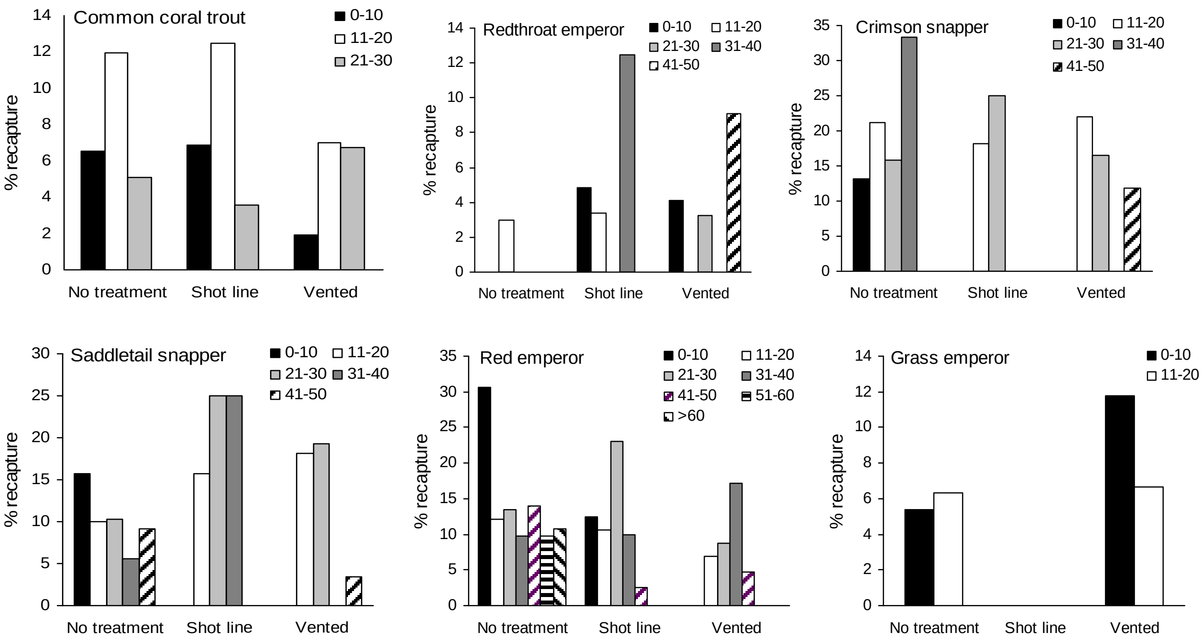

Figure 4-2 Proportion of recaptures by treatment (vented, shot lined or control) and capture-depth interval.

Unadjusted recapture rates of fish related to depth of first capture are shown in Figure 4-2 which again highlights the narrow depth range over which some of the species were caught. These data do not show the distribution of tagging effort related to depth which is discussed more in subsequent sections where the impact of depth is investigated using generalised linear models.

Most tagged and released fish were below minimum legal size (Figure 4-3), presumably because anglers would frequently retain larger specimens for consumption. Grass emperor was the exception, where more legal-sized fish than undersized were tagged and released. The three lutjanid species were those that were least likely to be released if they were caught above their MLS. The high proportion of large coral trout and redthroat emperor tagged and released is due to the greater contribution by researchers, who tagged all line-caught species regardless of size.

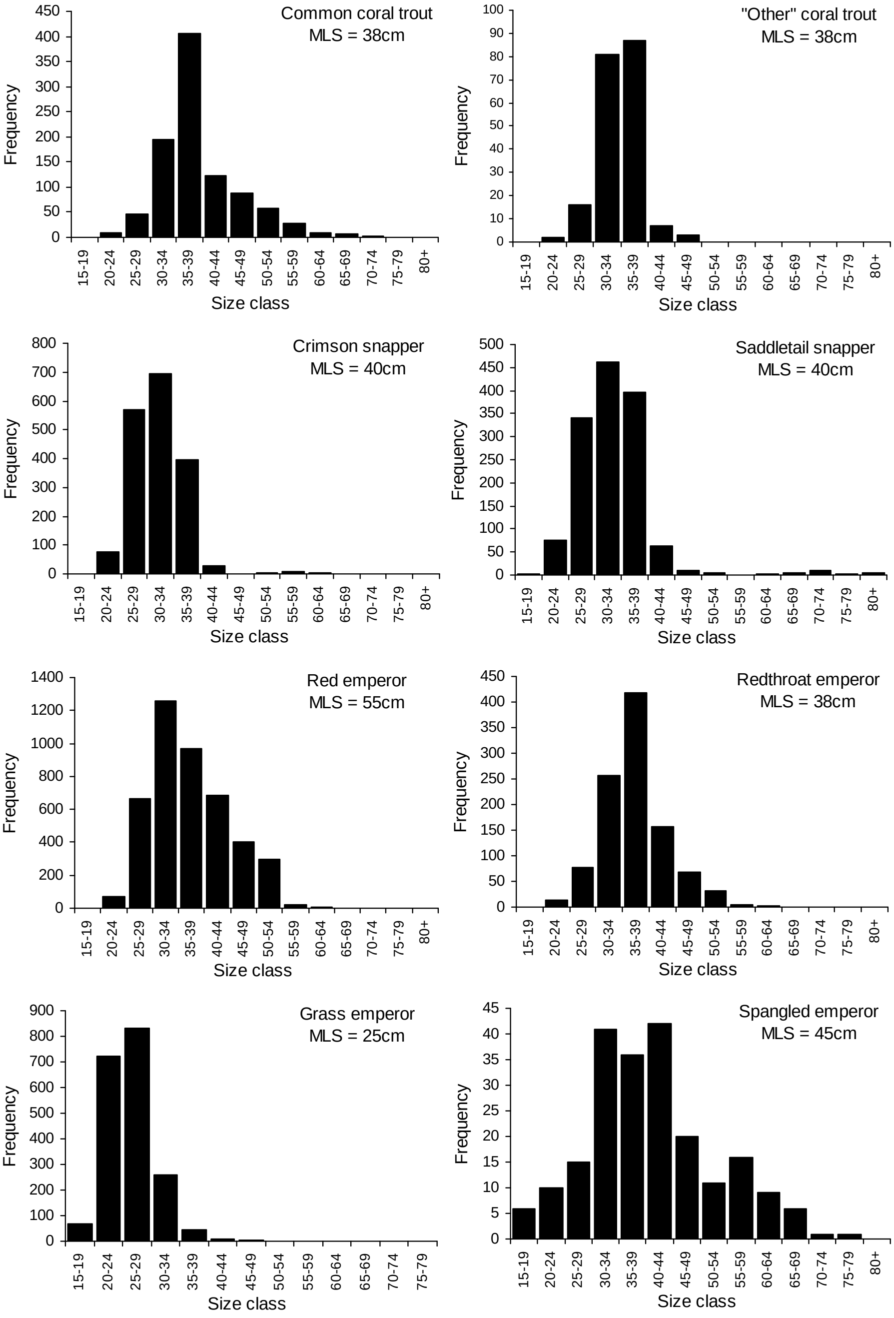

Figure 4-3. Size distribution (TL, cm) of tropical coral reef fish species tagged and released between October 2003 and September 2007, including releases by Project staff as well as recreational anglers, pooled across treatments and times.

4.4.2 Coral trout (*Plectropomus leopardus*)

The summarised unadjusted data for coral trout (Table 4-5) highlights a number of surprising results, particularly the mixed results regarding treatment. Also noted were the high recapture rates of fish that were foul hooked (19%) and those in which the hooks had been left in after tagging and released (17.7%), although sample sizes were low. The recapture rate of large coral trout (> 37cm) was also more than twice that of those below the minimum legal size.

Table 4-5. Raw data summary results showing the numbers of coral trout tagged and recaptured by anglers and researchers between October 2003 and September 2007. Results are presented in relation to a number of observed factors and treatments likely to have influenced the probability of recapture. Large fish were those equal to or exceeding the MLS of 38 cm.

Variate	Class	No. recaptured	No. Tagged	% Recaptured
Release Condition	1	41	691	5.93
	2	26	216	12.04
	3	6	66	9.09
	4	1	50	2.00
	5		4	0.00
Treatment	None	29	361	8.03
	Shotline	17	179	9.50
	Vented	25	422	5.92
Tagger affiliation	Club	16	336	4.76
	Research	53	598	8.86
Depth of Capture (m)	<15	20	267	7.49
	15 - 29	46	541	8.50
	30+	2	85	2.35
Hook removed	Yes	74	1151	6.43
	No	3	17	17.65
Bleeding	Heavy	3	49	6.12
	Light	2	78	2.56
	None	67	867	7.73
Injury category	Eye	1	17	5.88
	Gill		10	0.00
	Jaw		7	0.00
	None	69	920	7.50
Body size	Large	46	439	10.48
	Small	21	536	3.92
Hooking location	Deep	4	50	8.00
	Foul	3	16	18.75
	Shallow	63	909	6.93
Barotrauma signs	Nil	13	257	5.06
	Swollen	51	622	8.20
	Extreme	1	36	2.78

The results of the GLM which tested the effects of release condition on recapture of coral trout is presented in Table 4-6. As none of the two-way interactions were significant for this model (P > 0.24) they were removed and the resultant main effects model showed that release condition and barotrauma signs were significant. Recapture rates declined with poorer condition of release although release condition 2 had the overall highest recapture rate, a result that was also reflected in the unadjusted summary results. Fish classified as displaying extreme symptoms of barotrauma were recaptured less frequently than those displaying no symptoms or less severe symptoms (Figure 4-4). Despite the fact that the unadjusted recapture rates of researcher-released fish were twice as high as those of angler-released fish (8.9 and 4.8% respectively), the effect of angler affiliation was no longer significant.

Table 4-6. Analysis of deviance table showing the effect of release condition, barotrauma signs, tagger affiliation and treatment on the recapture rate of line caught common coral trout.

Source	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Release condition	4	14.8987	3.7247	3.72	**0.005**
Barotrauma signs	2	7.6537	3.8269	3.83	**0.022**
Tagger affiliation	5	2.0786	0.4157	0.42	0.838
Barotrauma treatment	2	3.579	1.7895	1.79	0.167
Residual	845	427.3	0.5057		
Total	858	455.51	0.5309		

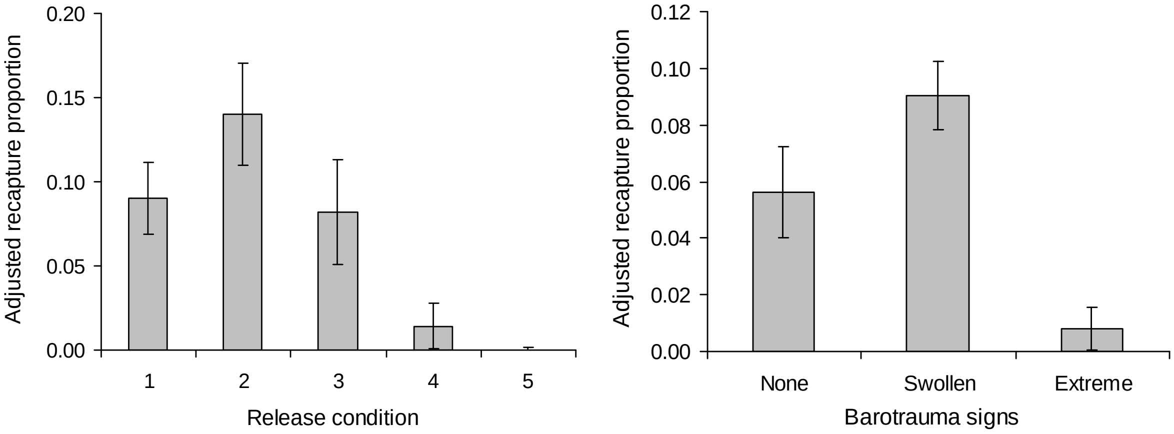

Figure 4-4. Adjusted mean recapture rate (± s.e.) for line caught coral trout for a range of release condition and barotrauma signs categories.

A range of potential contributing factors to the overall probability of recapture were selected for further analysis on the basis of preliminary modeling. Barotrauma treatment was tested as an interaction term with barotrauma signs as well as body size but as none of these interactions were significant (P>0.1) they were removed from the final model, the results of which are presented in Table 4-7. Coral trout were divided into large and small on the basis of their minimum legal size (38 cm). The effect of barotrauma signs was not included in the final model as it was noted that fish that were not classified in terms of these signs had a disproportionately high recapture rate and therefore model predictions would have been biased if this effect was included. Both depth and body size contributed significantly (P<0.05) to the recapture probability of coral trout with larger fish above the minimum legal size more likely to be recaptured than smaller fish (Figure 4-5).

Table 4-7. Effects of body size, depth, hook removal, bleeding and barotrauma treatment on the recapture rate of common coral trout.

Source	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Body size	1	12.1444	12.1444	12.14	**<.001**
Depth (polynomial)	2	6.7504	3.3752	3.38	**0.034**
Hook removed	1	3.1541	3.1541	3.15	0.076
Bleeding	3	4.8726	1.6242	1.62	0.181
Hooking location	3	2.4442	0.8147	0.81	0.485
Barotrauma treatment	3	2.263	0.7543	0.75	0.52
Residual	802	407.1192	0.5076		
Total	815	438.7479	0.5383		

Table 4-8. Mean recapture proportions (rates) and standard errors for coral trout adjusted for the influence of a range of variates. Variates that were statistically significant are identified by asterisks.

Variate	Class	Adj. mean	s.e.
Body size *	Large	0.1226	0.0215
	Small	0.0534	0.0129
Depth *	<5	0.0455	0.0261
	5	0.0508	0.0253
	15	0.0899	0.0123
	25	0.0647	0.0145
	35	0.0178	0.0139
	45	0.0017	0.0034
	>50	0.0001	0.0004
Hook removed	Yes	0.0857	0.0133
	No	0.3540	0.1629
Bleeding	Heavy	0.0768	0.0463
	Light	0.0211	0.0205
	None	0.0915	0.0144
Barotrauma treatment	Control	0.1032	0.0211
	Shotline	0.0943	0.0274
	Vented	0.0717	0.0163

Recapture rates amongst fish caught in shallow and intermediate depths (< 30 m) were significantly greater (8%) than those caught in deeper areas (~1%) (Figure 4-5). The adjusted means of the other factors included in the model are shown in Table 4-8, and although they were not statistically significant they generally support the observed patterns in the raw data (Table 4-5).

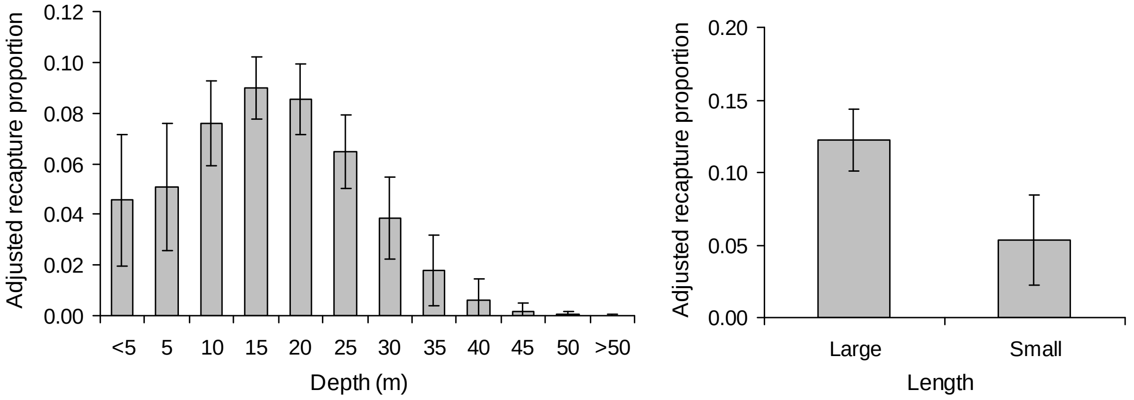

Figure 4-5. Adjusted mean proportions (± s.e.) of line caught coral trout for a range of depths and lengths (body size).

4.4.3 Redthroat emperor (*Lethrinus miniatus*)

The low recapture rate of redthroat emperor of only 1.9% greatly reduced the statistical power to detect differences in the effects of the various factors and barotrauma treatments on recapture rate. Only fish categorized as having release condition 1 and 3 were recaptured during the 4 years of the experiment. There were too few fish of this species caught that showed any signs of bleeding, injury or hooking damage to allow these factors to be tested effectively in any models. An unexpected result was the higher recapture rate of fish that were foul hooked (7.1%) as opposed to shallow hooked fish (1.8%), but this was based on just two recaptures of foul-hooked fish, and so cannot be considered a reliable result.

The initial GLM tested the effects of release condition, barotrauma signs and barotrauma treatment (Table 4-10) and showed that release condition was the only significant factor (P = 0.004) influencing the recapture of this species. None of the interactions were significant for redthroat emperor and so they were not included in the final model. The modeled pattern (Figure 4-6) reflected the observed data but did not fit the expected pattern of declining recapture rate with increasingly poorer release condition. A surprising result was the lack of any recaptures of the 253 fish assessed as having release condition 2. When the raw data were checked to see if there were any biases in categorizing release condition 2 fish there were no obvious discrepancies in terms of recording practices of individual anglers or areas fished etc. The only major difference between this subset of data and the overall dataset for this species was that researchers had only tagged 15% of release condition 2 fish as opposed to the overall average tagging rate for this species by researchers which was 48%. Models that included the affiliation of the tagger failed to show any significant effect (P > 0.05) with recapture rate of researcher tagged fish and ANSA angler tagged fish being 19.3% and 16.2% respectively.

When release condition was removed from the model and other factors likely to have impacted on recapture rate were included the only main effect approaching statistical significance was treatment (P = 0.055). Of the interactions originally fitted there was a highly significant interaction between depth and barotrauma treatment (P = 0.008) although none of the other factors was significant. When the adjusted mean recapture rates for the depth x treatment interaction were plotted (Figure 4-7) it was clear that there were insufficient data for control (untreated) fish across the range of depths to allow conclusions to be drawn from this interaction. Consequently a main effects model was fitted (Table 4-11), with adjusted means shown in Table 4-12.

The fact that treatment had only a marginally significant effect on recapture rate was probably due in part to the comparatively low numbers of recaptures (5-6 per treatment). However the total numbers of releases (153–456) was considered reasonable. Despite the low overall recapture rates, treatment had a positive effect – venting resulting in a 59% increase in recapture rate over the controls, and shotlining a 163% increase. The counterintuitive trend in recapture rates with increasing depth (Figure 4-8) was probably driven by a (possibly chance) recapture of just two tagged fish. Had this been 1 recapture, the observed rate would have halved, with a result much more in line with the expected.

Table 4-9. Raw data summary results showing the numbers of redthroat emperor tagged and recaptured by anglers and researchers between October 2003 and September 2007. Results are presented in relation to a number of observed factors and treatments likely to have influenced the probability of recapture. Large fish were those greater than the MLS of 38cm.

Variate	Class	No recaptured	No. Tagged	% Recaptured
Release condition	1	12	582	2.06
	2	0	253	0.00
	3	4	58	6.90
	4	0	26	0.00
Barotrauma treatment	Control	5	456	1.10
	Shotlined	6	153	3.92
	Vented	5	231	2.16
Tagger affiliation	Club	5	433	1.15
	Research	11	379	2.90
Depth of capture (m)	<15	8	325	2.46
	15 - 29	6	315	1.90
	30+	2	55	3.64
Hook removed	Yes	15	1037	1.45
	No	1	11	9.09
Bleeding	Heavy	0	13	0.00
	Light	1	20	5.00
	None	15	773	1.94
Injury category	Eye	0	5	0.00
	Gill	0	5	0.00
	Jaw	0	3	0.00
	None	13	644	2.02
Body size	Large	14	683	2.05
	Small	2	349	0.57
Hooking location	Deep	1	30	3.33
	Foul	2	28	7.14
	Shallow	13	720	1.81
Barotrauma signs	Nil	7	500	1.40
	Swollen	8	220	3.64
	Extreme	0	9	0.00

Table 4-10 Analysis of deviance table showing the effect of release condition, barotrauma signs, tagger affiliation and barotrauma treatment on the recapture rate of line caught redthroat emperor.

Source	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Release condition	5	19.5532	3.9106	3.91	**0.002**
Barotrauma signs	3	6.7556	2.2519	2.25	0.080
Tagger affiliation	3	2.7937	0.9312	0.93	0.425
Barotrauma treatment	3	3.4571	1.1524	1.15	0.326
Residual	1033	133.0206	0.1288		
Total	1047	165.5801	0.1581		

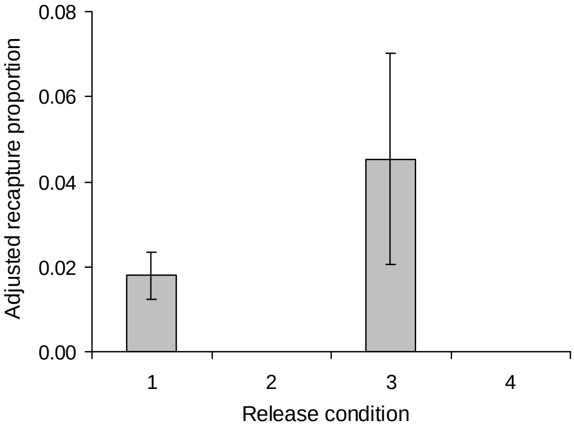

Figure 4-6. Adjusted mean recapture rates (± s.e.) for line caught redthroat emperor for a range of release condition categories.

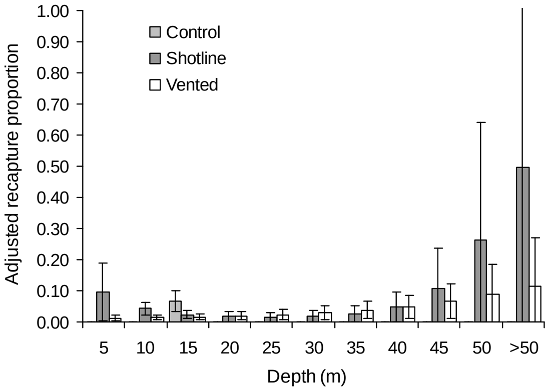

Figure 4-7. Adjusted recapture rate (as a proportion of fish tagged and released) ± s.e., of redthroat emperor treated for barotrauma injury and caught at different depths.

Table 4-11. Analysis of deviance table showing the effect of depth, body size, barotrauma signs and barotrauma treatment on the recapture rate of line caught common redthroat emperor.

Source	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Body size	2	4.3785	2.1892	2.19	0.112
Barotrauma signs	3	4.5621	1.5207	1.52	0.207
Depth (polynomial)	2	2.6588	1.3294	1.33	0.265
Barotrauma treatment	3	7.588	2.5293	2.53	**0.055**
Residual	1037	146.3927	0.1412		
Total	1047	165.5801	0.1581		

Table 4-12. Mean recapture proportions or rates (± s.e.) for redthroat emperor adjusted for the influence of a range of variates. Asterisks denote effects significant at P ~ 0.05.

Variate	Class	Adj. mean	s.e.
Body size	Large	0.0181	0.0054
	Small	0.0056	0.0041
Barotrauma signs	None	0.0094	0.0037
	Swollen	0.0236	0.0087
	Extreme	0.0000	0.0004
Depth of capture (m)	5	0.0112	0.0052
	15	0.0146	0.0044
	25	0.0187	0.0077
	35	0.0233	0.0115
	45	0.0284	0.0214
	>50	0.0334	0.0426
Barotrauma treatment*	Control	0.0114	0.0054
	Shotline	0.0337	0.0142
	Vented	0.0184	0.0086

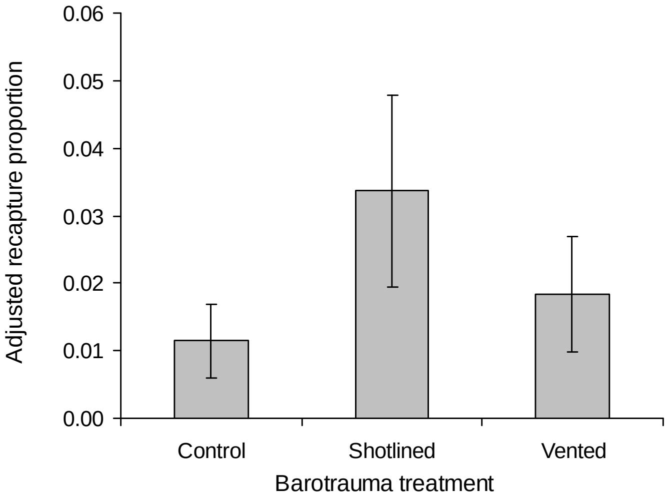

Figure 4-8. Adjusted recapture rate (as a proportion of fish tagged and released) ± s.e., of redthroat emperor treated for barotrauma injury.

4.4.4 Crimson snapper (*Lutjanus erythropterus*)

The raw crimson snapper data (Table 4-13) highlights the high recapture rate of this species in comparison to both coral trout and redthroat emperor. There were relatively large numbers of recaptures in the various factor and treatment categories for this species which increased the precision of model outputs. Deeply hooked fish were recaptured less frequently than either shallow or foul-hooked fish. The data also showed a strong release condition effect with recapture rate of crimson snapper declining with poorer release condition. There was also a relatively high recapture rate of fish that were suffering from barotrauma. Over 30% of fish with extreme signs of barotrauma were recaptured compared with only around 13% of fish which did not display any symptoms of barotrauma.

Table 4-13. Raw data summary results showing the numbers of crimson snapper tagged and recaptured by anglers and researchers between October 2003 and September 2007. Results are presented in relation to a number of observed factors and treatments likely to have influenced the probability of recapture. Large fish were those greater than 35cm (MLS is 40cm).

Variate	Class	No. recaptured	No. tagged	% Recaptured
Release condition	1	143	783	18.26
	2	31	281	11.03
	3	5	56	8.93
	4	1	27	3.70
Barotrauma treatment	Control	116	821	14.13
	Shotlined	31	171	18.13
	Vented	69	365	18.90
Depth of capture (m)	<15	23	176	13.07
	15 - 29	174	867	20.07
	30+	0	37	0.00
Tagger affiliation	Club	56	689	8.13
	Research	157	661	23.75
Hook removed	Yes	194	993	19.54
	No	3	53	5.66
Bleeding	Heavy	21	72	29.17
	Light	10	69	14.49
	None	166	905	18.34
Injury category	Eye	6	29	20.69
	Gill	6	28	21.43
	Jaw	16	47	34.04
	None	167	922	18.11
Body size	Large	23	276	8.33
	Small	106	854	12.41
Hooking location	Deep	6	73	8.22
	Foul	10	35	28.57
	Shallow	178	910	19.56
Barotrauma signs	Nil	37	287	12.89
	Swollen	140	604	23.18
	Extreme	15	47	31.91

The GLM analysis that included release condition (Table 4-14) showed all factors included in model to be very highly significant (P < 0.001) contributors to the recapture rate of crimson snapper. One of the two way interactions was also statistically significant (barotrauma signs x barotrauma treatment; P < 0.001) but as these two factors were confounded by the greater application of relief procedures to fish that displayed barotrauma symptoms, the final model presented includes only the main effects. Recapture rate declined dramatically with poor release condition (Figure 4-9). Release condition 1 fish had more than twice the recapture rate of fish in poorer release condition (2, 3 or 4).

Unexpectedly, fish suffering the obvious effects of barotrauma had significantly higher recapture rates than did fish that had no obvious signs of barotrauma (Figure 4.9) when they were first caught and tagged. The modeled results also confirmed the observation from the raw data that crimson snapper with signs of barotrauma were more likely to be recaptured, and again the recapture probability was almost double that of fish that had no signs of barotrauma.

Treatment was also shown to have a very highly significant (P < 0.001) effect on recapture rate as treated fish were more likely to be re-caught than were the controls. The influence of tagger affiliation was also a much stronger effect for this species than it was for either coral trout or redthroat emperor. Fish tagged and released by researchers were twice as likely to be recaptured as those tagged and released by recreational anglers.

Table 4-14. Analysis of deviance table showing the effect of release condition, barotrauma signs, tagger affiliation and barotrauma treatment on the recapture rate of line-caught crimson snapper.

Source	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Barotrauma signs	3	75.2948	25.0983	25.1	**<0.001**
Tagger affiliation	4	63.4942	15.8736	15.87	**<0.001**
Release condition	5	19.4513	3.8903	3.89	**0.002**
Barotrauma treatment	3	18.5876	6.1959	6.2	**<0.001**
Residual	2052	1481.609	0.722		
Total	2067	1658.436	0.8023		

Models that replaced release condition with other potentially contributing factors provided no significant two way interactions although the depth x treatment interaction was of marginal importance (P = 0.063). The main effects of body size, barotrauma signs and hooking location were statistically significant (Table 4-15) in explaining some of the deviance in recapture rate. As tagger affiliation was not a significant factor (P = 0.129) it was also removed from the final model.

The adjusted recapture proportions of the modeled factors are shown in Table 4-16 and significant factors are also illustrated in Figure 4-10. The recapture rate of small crimson snapper was almost 16% compared with less than 9% for larger fish. Deep hooked fish likewise had a significantly lower recapture rate compared with either shallow or foul hooked fish and the modeled data also highlighted the enhanced recapture rate of fish with barotrauma signs although the adjusted mean of fish that had no signs was closer to the other categories than in the raw data. The interaction between depth and treatment (Figure 4-11) confirmed the value of venting fish, which was most evident in depths greater than 25m. Shotlined fish were not treated in enough depth categories for this treatment to be adequately modeled relative to depth.

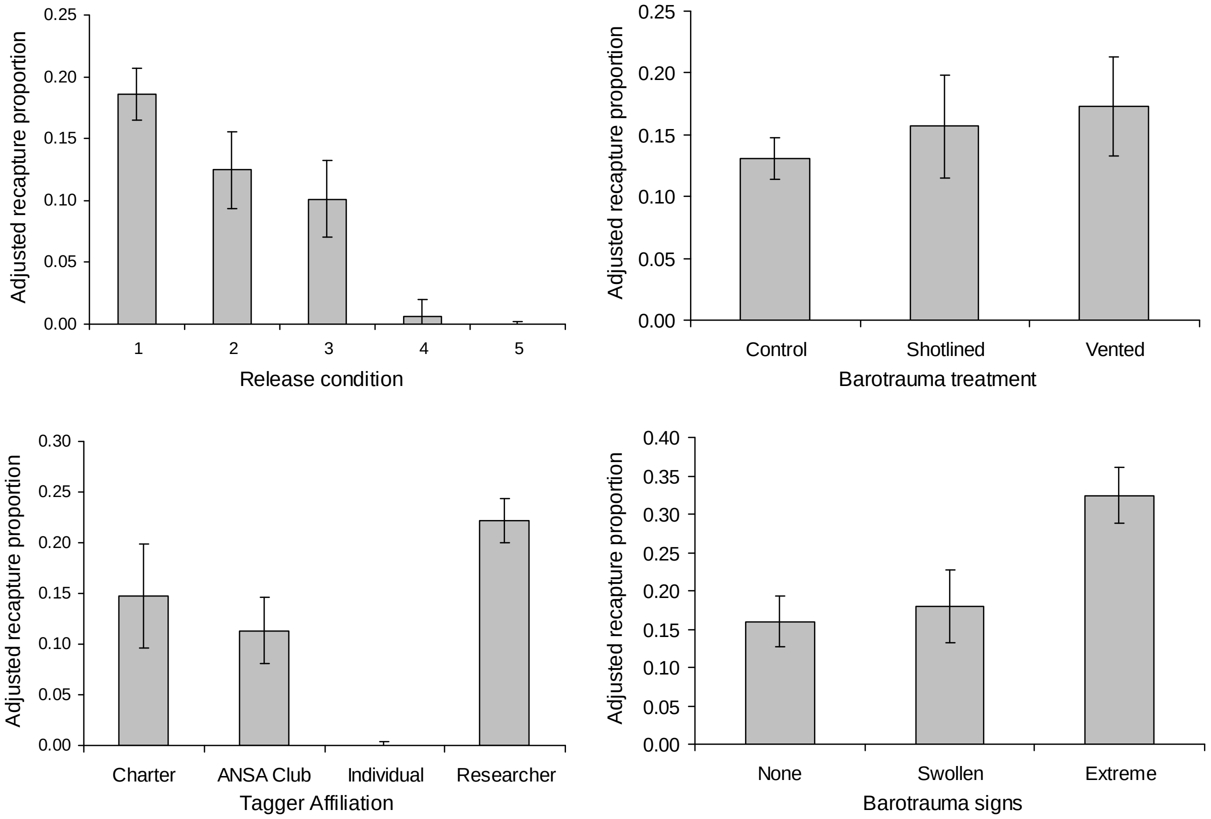

Figure 4-9. Adjusted mean recapture rate (± s.e.) for line caught crimson snapper for a range of release condition, barotrauma treatment, tagger affiliation and barotrauma signs categories.

Table 4-15. Analysis of deviance table showing the effect of body size, barotrauma signs, hooking location, depth and barotrauma treatment on the recapture rate of line caught crimson snapper.

Source	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Body size	2	68.7045	34.3522	34.35	**<0.001**
Barotrauma signs	3	35.7108	11.9036	11.9	**<0.001**
Hooking location	3	11.6803	3.8934	3.89	**0.009**
Depth (polynomial)	2	1.0059	0.5029	0.5	0.605
Barotrauma treatment	3	0.6501	0.2167	0.22	0.885
Depth x B. treatment	6	11.9445	1.9908	1.99	0.063
Residual	1113	944.7036	0.8488		
Total	1132	1074.4	0.9491		

Table 4-16. Mean recapture proportions (rates) and standard errors for crimson snapper adjusted for the influence of a range of variates. Asterisks denote variates significant at P = 0.05.

Variate	Class	Adj. mean	s.e.
Body size*	Large	0.0875	0.0213
	Small	0.1591	0.0164
Hooking location*	Deep	0.0737	0.0290
	Foul	0.2196	0.0639
	Shallow	0.1928	0.0151
Barotrauma signs*	None	0.1540	0.0291
	Swollen	0.2154	0.0181
	Extreme	0.2798	0.0625
Barotrauma treatment	Control	0.2026	0.0204
	Shotline	0.1261	0.0346
	Vented	0.1795	0.0215

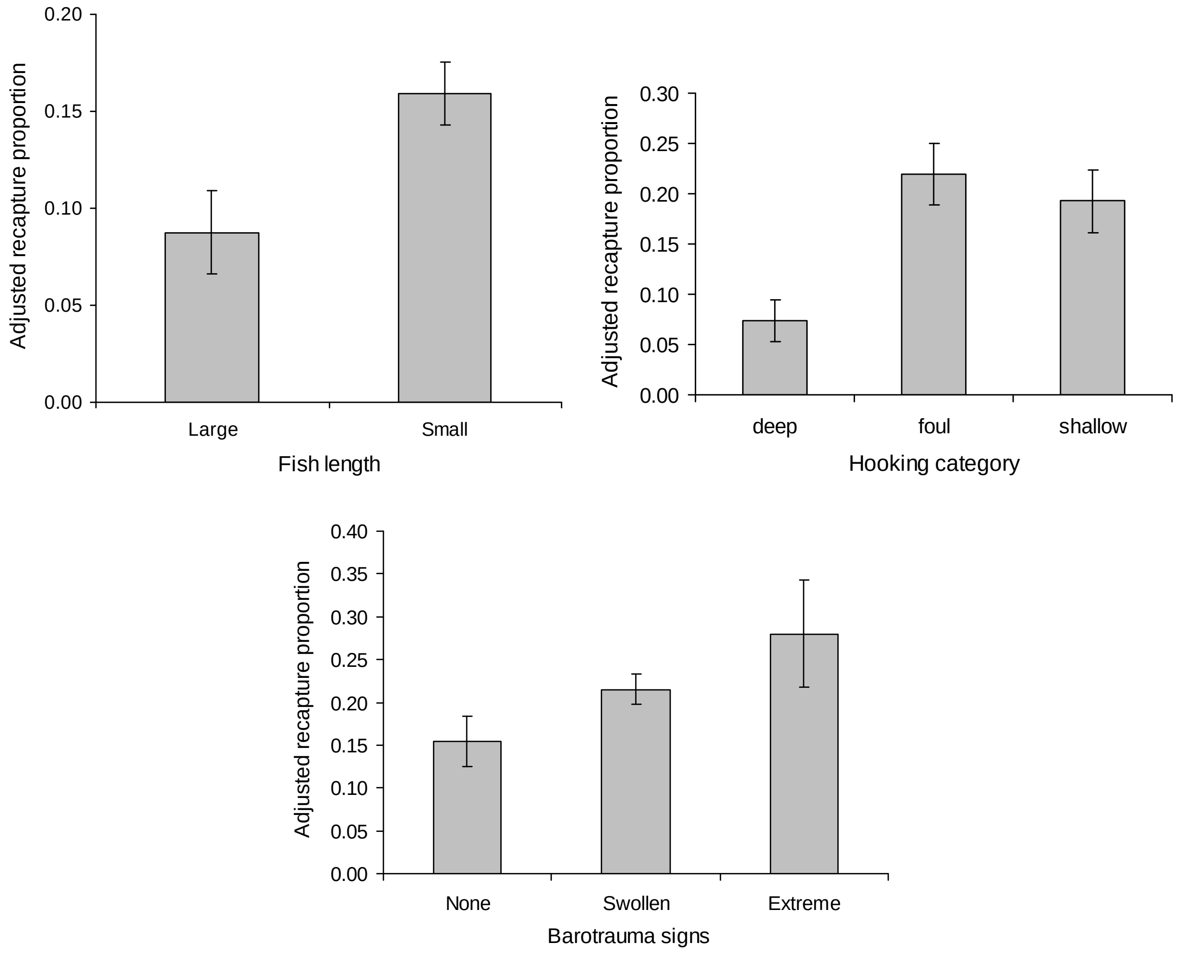

Figure 4-10. Adjusted mean recapture rate (± s.e.) for line caught crimson snapper for (a) small and large fish, (b) various hooking categories and (c) barotrauma signs.

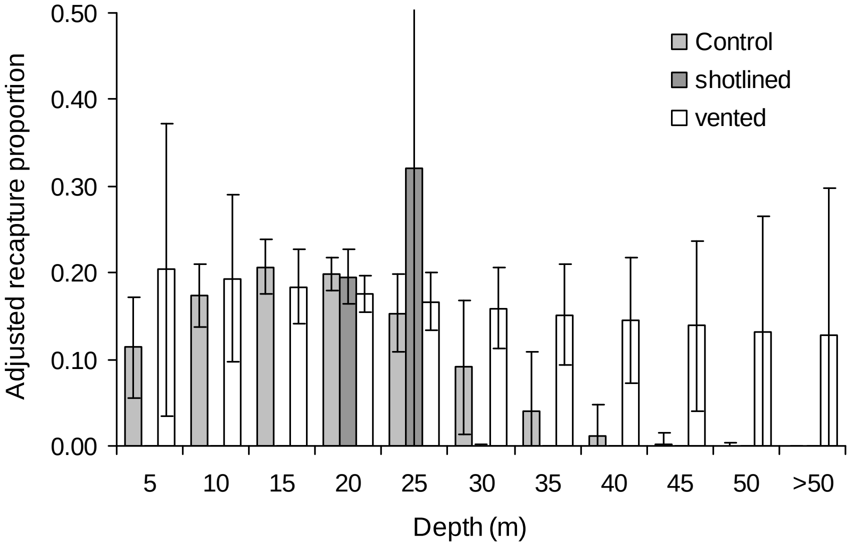

Figure 4-11. Adjusted mean recapture proportion (± s.e.) for barotrauma treated fish relative to depth of first capture.

4.4.5 Saddletail snapper (*Lutjanus malabaricus*)

Like crimson snapper, there were insufficient saddletail snapper greater than the MLS caught to divide the sample into large and small size classes based on this measure, so fish were divided at the same size as crimson snapper (35 cm). Of all the species examined this species had the highest proportion (>10%) suffering the extreme symptoms of barotrauma (Table 4-17). The raw data suggested benefit in treating fish as both shotlined and vented fish had recapture rates higher than control (untreated) fish. Given the large numbers of recaptures of fish that were classified in each of the barotrauma sign categories it was interesting that those classified with visible sign of barotrauma had a 17% recapture rate compared with those without signs of barotrauma (11% recapture rate).

Significant interactions between release condition and other factors are presented in Figure 4-12. Fish tagged and released by researchers showed the expected pattern of better survival with better overall subjective condition on release. The recapture rate of fish that had no barotrauma signs was apparently enhanced by venting compared with the other treatments although venting fish that had noticeable barotrauma symptoms had a negative effect on recapture rate when compared with either the controls or shot lined fish. Fish that had the obvious symptoms of barotrauma were more likely to be recaptured if they were shotline-released rather than vented.

Bleeding, barotrauma signs and tagger affiliation were significant main effects in the full model (Table 4-19) and after adjusting for non-significant interactions in the model and including important main effects, only one interaction was statistically significant (depth x barotrauma treatment). Depth and barotrauma signs were obviously correlated and changing the order of these terms resulted in the significance of these factors changing in the model outputs. Fish that were injured enough to bleed had a significantly ($P < 0.01$) lower probability of recapture than fish that were not bleeding as a result of line capture. Similarly researcher tagged and released fish had a higher recapture probability than those of non researchers (Table 4-20). Plotting the predicted means of the barotrauma signs x treatment interaction (Figure 4-13) highlighted the apparent benefit in shotlining fish that had signs of barotrauma. Unfortunately too few fish that did not display barotrauma signs were shotlined to adequately model that particular cell of the interaction but the high recapture rate of shotlined fish with extreme symptoms is grounds for encouraging this treatment to be used for saddletail snapper. An interesting result was the apparent enhanced survival of vented fish that did not display any signs of barotrauma.

Table 4-17. Raw data summary results showing the numbers of saddletail snapper tagged and recaptured by anglers and researchers between October 2003 and September 2007. Results are presented in relation to a number of observed factors and treatments likely to have influenced the probability of recapture. Large fish were those greater than 35cm (MLS is 40cm).

Variate	Class	No. recaptured	No. tagged	% Recaptured
Release condition	1	84	593	14.17
	2	8	212	3.77
	3	5	86	5.81
	4	2	44	4.55
	5	1	7	
Barotrauma treatment	Control	65	651	9.98
	Shotlined	16	99	16.16
	Vented	32	248	12.90
Depth of capture (m)	<15	38	307	12.38
	15 - 29	61	401	15.21
	30+	7	99	7.07
Tagger affiliation	Club	65	714	9.10
	Research	47	258	18.22
Hook Removed	Yes	105	919	11.43
	No	8	79	10.13
Bleeding	Heavy	1	12	8.33
	Light	6	62	9.68
	None	98	720	13.61
Injury category	Eye	0	4	0.00
	Gill	1	18	5.56
	Jaw	2	16	12.50
	None	100	756	13.23
Body size	Large	34	371	9.16
	Small	47	468	10.04
Hooking location	Deep	10	96	10.42
	Foul	1	13	7.69
	Shallow	93	681	13.66
Barotrauma signs	None	43	382	11.26
	Swollen	47	270	17.41
	Extreme	13	74	17.57

Table 4-18. Analysis of deviance table showing the effect of release condition, barotrauma signs, tagger affiliation and barotrauma treatment on the recapture rate of line caught saddletail snapper.

Source	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Release condition	3	31.3843	10.4614	10.46	**<0.001**
Tagger affiliation	1	17.0293	17.0293	17.03	**<0.001**
Barotrauma signs	3	13.9831	4.661	4.66	**0.003**
Barotrauma treatment	2	0.7661	0.383	0.38	0.682
R. condition x T. affiliation	3	18.4997	6.1666	6.17	**<0.001**
B. signs x B. treatment	6	15.6211	2.6035	2.6	**0.016**
Residual	979	607.72	0.6208		
Total	997	705.0038	0.7071		

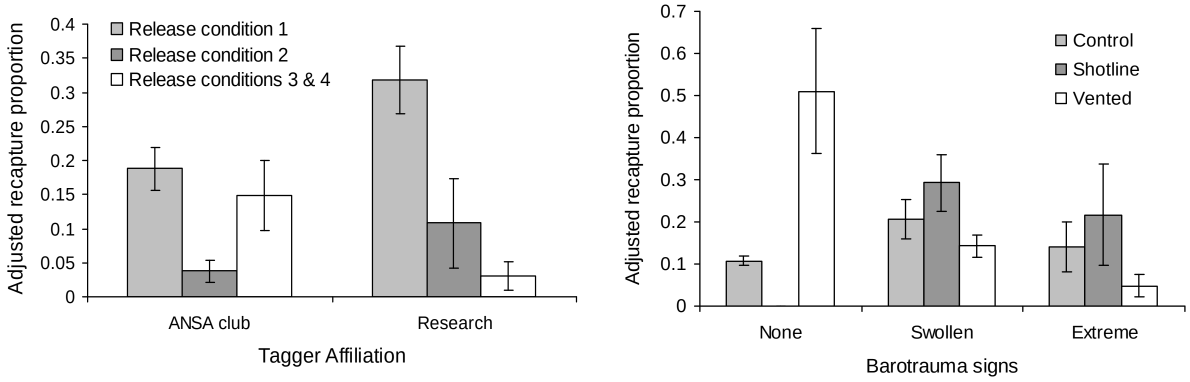

Figure 4-12. Adjusted mean recapture rates (± s.e.) for line saddletail snapper for a range of release condition categories, barotrauma signs and barotrauma treatments.

Table 4-19. Mean recapture proportions (rates) and standard errors for saddletail snapper adjusted for the influence of a range of variates.

Source	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Bleeding	2	9.6194	4.8097	4.81	**0.008**
Barotrauma signs	3	10.5434	3.5145	3.51	**0.014**
Tagger affiliation	1	4.2972	4.2972	4.3	**0.038**
Depth of capture	2	0.0507	0.0254	0.03	0.975
Body size	1	0.1566	0.1566	0.16	0.692
Hooking location	3	0.0848	0.0283	0.03	0.994
Barotrauma treatment	2	1.3457	0.6728	0.67	0.51
B. signs x B. treatment	6	15.611	2.6018	2.6	**0.016**
Residual	634	420.3214	0.663		
Total	654	462.0301	0.7065		

Table 4-20. Mean recapture proportions (rates) and standard errors for saddletail snapper adjusted for the influence of a range of variates. Asterisks denote effects significant at P = 0.05.

Variate	Class	Adj. mean	s.e.
Depth of capture	<15	0.1648	0.0324
	15 - 29	0.1347	0.0377
	30+	0.1504	0.2719
Hooking category	Deep	0.1239	0.0400
	Foul	0.1488	0.1388
	Shallow	0.1428	0.0215
Length	Large	0.1581	0.0278
	Small	0.1275	0.0235
Bleeding*	Bleeding	0.0573	0.0338
	None	0.1469	0.0212
Tagger affiliation*	Angler	0.1443	0.0219
	Research	0.2380	0.0536

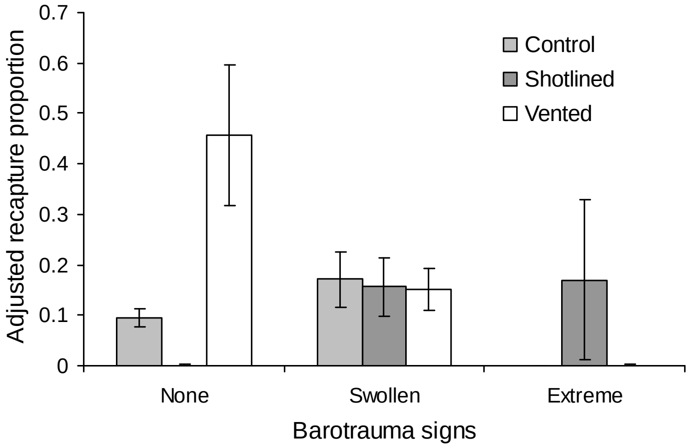

Figure 4-13. Adjusted mean recapture proportion (± s.e.) for treated and control saddletail snapper showing different barotrauma signs.

4.4.6 Red emperor (*Lutjanus sebae*)

During initial screening and checking of the red emperor data it was apparent that certain anglers were not adhering to the protocols of consecutively treating fish and as a result large sections of data were biased. The effect of this is seen in Table 4-21 which shows the significance of various factors on the recapture rate of red emperor when all data were analysed. Significant factors were release condition, barotrauma treatment and hooking location. These results were essentially caused by anglers who were tagging large numbers of fish but only selectively applying the barotrauma relief treatments. These anglers also recaptured many of their own fish as they were active taggers who applied disproportionately high effort to their local fishing spots and consequently obtained high recaptures in the one area. More than 2,000 records had to be removed from the dataset to eliminate these biases. Table 4-22 shows the results of analysing factors for the amended dataset. While release condition was still a dominant factor the importance of depth and the lack of significance of hooking location became apparent.

Table 4-21. Effects of release condition and other factors on the recapture rate of tagged red emperor (all experimental data).

Source	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Release condition	5	13.6639	2.7328	2.73	**0.018**
Depth (poly)	2	4.8019	2.4009	2.40	0.091
Barotrauma signs	5	6.1985	1.2397	1.24	0.287
Barotrauma treatment	3	8.7085	2.9028	2.90	**0.033**
Bleeding	3	2.4675	0.8225	0.82	0.481
Injury type	3	3.5170	1.1723	1.17	0.319
Hooking location	3	25.8036	8.6012	8.60	**<0.001**
Hook removed	1	0.0667	0.0667	0.07	0.796
Residual	3229	2288.9678	0.7089		
Total	3254	2354.1953	0.7235		

Table 4-22. Effects of release condition and other factors on the recapture rate of tagged red emperor (subset of data excluding records of biasing anglers).

Change	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Release condition	5	19.4274	3.8855	3.89	**0.002**
Depth (polynomial)	2	20.8978	10.4489	10.45	**<0.001**
Barotrauma signs	5	8.2156	1.6431	1.64	0.145
Barotrauma treatment	3	3.6127	1.2042	1.20	0.306
Bleeding	3	2.4185	0.8062	0.81	0.490
Injury type	3	3.5660	1.1887	1.19	0.312
Hooking location	3	5.5986	1.8662	1.87	0.133
Hook removed	1	0.1341	0.1341	0.13	0.714
Residual	1173	746.4197	0.6363		
Total	1198	810.2904	0.6764		

Summary of the raw data subset (Table 4-23) shows little difference in the recapture rate with respect to body size and a 50% increase in recapture rate of untreated fish over either of the two barotrauma treatments. There were insufficient data recorded for injury and bleeding categories for these factors to be included in any of the GLMs.

The initial GLM testing the effects of release condition and other factors yielded no significant ($P > 0.05$) two way interactions but release condition was highly significant in determining the recapture rate of red emperor. The pattern of higher recapture rate for better release condition fish was again clearly evident for this species (Figure 4-14). A higher recapture rate was observed for fish in very poor condition (class 4) but the large standard errors are indicative of a very small number of fish in this release condition category (2 recaptured of the 15 tagged).

When the overall model was fitted with factors other than release condition there were only two significant main effects – depth ($P < 0.001$) and hooking location ($P < 0.05$) – on recapture rate (Table 4-25) and no significant two-way interactions.

Table 4-23. Raw data summary results showing the numbers of red emperor tagged and recaptured by anglers and researchers between October 2003 and September 2007. Results are presented in relation to a number of observed factors and treatments likely to have influenced the probability of recapture. Large fish were those greater than 35cm (MLS for this species is 55cm).

Variate	Class	No. recaptured	No. tagged	% Recaptured
Release condition	1	100	829	12.06
	2	19	360	5.28
	3		37	0.00
	4	2	15	13.33
Barotrauma treatment	Control	103	993	10.37
	Shotlined	9	129	6.98
	Vented	11	160	6.88
Depth of capture (m)	<15	18	114	15.79
	15 - 29	54	402	13.43
	30+	42	573	7.33
Tagger affiliation	Club	114	1105	10.32
	Researcher	10	200	5.00
Hook Removed	Yes	121	1219	9.93
	No	2	63	3.17
Bleeding	Heavy	1	5	20.00
	Light	2	47	4.26
	None	91	837	10.87
Injury category	Gill		15	0.00
	Jaw	1	20	5.00
	None	89	829	10.74
Body size	Large	60	584	10.27
	Small	41	362	11.33
Hooking location	Deep	2	73	2.74
	Foul		11	0.00
	Shallow	99	871	11.37
Barotrauma signs	None	82	775	10.58
	Swollen	14	138	10.14
	Extreme	3	9	33.33

Table 4-24. Effect of release condition, tagger affiliation, barotrauma signs and barotrauma treatment on the recapture rate of line caught red emperor.

Change	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Release condition	5	28.8547	5.7709	5.77	**<0.001**
Barotrauma signs	3	7.2495	2.4165	2.42	0.064
Tagger affiliation	4	7.4866	1.8716	1.87	0.112
Barotrauma	3	2.7431	0.9144	0.91	0.433
Residual	2380	1334.569	0.5607		
Total	2395	1380.903	0.5766		

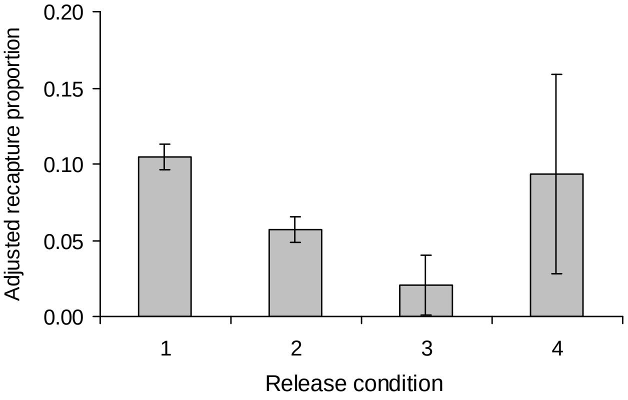

Figure 4-14. Adjusted mean recapture rates (± s.e.) of line-caught red emperor for a range of release condition categories.

Table 4-25. Analysis of deviance table showing the effects of depth, hooking location, body size, hook removal and barotrauma treatment on the recapture of tagged red emperor (data subset).

Change	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Depth (polynomial)	2	26.5506	13.2753	13.28	**<0.001**
Hooking location	2	8.7455	4.3728	4.37	**0.013**
Barotrauma signs	3	6.1515	2.0505	2.05	0.104
Body size	2	1.8166	0.9083	0.91	0.403
Hook removed	1	0.3864	0.3864	0.39	0.534
Barotrauma treatment	3	3.3794	1.1265	1.13	0.337
Residual	1185	763.2604	0.6441		
Total	1198	810.2904	0.6764		

Table 4-26. Mean recapture proportions (rates) and standard errors for red emperor adjusted for the influence of a range of variates. Asterisks denote effects significant at P = 0.05.

Variate	Class	Adj. mean	s.e.
Depth of capture (m)*	5	0.1762	0.0535
	15	0.1717	0.0265
	25	0.1431	0.0209
	35	0.1004	0.0165
	45	0.0581	0.0134
	55	0.0273	0.0125
Hooking location*	Deep	0.0154	0.0231
	Foul	0.0007	0.0049
	Shallow	0.1157	0.0143
Barotrauma signs	None	0.1083	0.0152
	Swollen	0.1266	0.0335
	Extreme	0.4906	0.1838
Treatment	Control	0.1151	0.0148
	Shotlined	0.0783	0.0266
	Vented	0.0738	0.0235
Body size	Large	0.1080	0.0138
	Small	0.1157	0.0185
Hook removed	Yes	0.1097	0.0126
	No	0.0771	0.0883

While not statistically significant, the modeled treatment effects were in broad agreement with the raw results (Table 4-23) which showed a higher recapture rate among control fish than in fish that had either been vented or shotlined. The adjusted mean recapture proportions for red emperor relative to depth and hooking location are shown in Figure 4-15, which shows a declining recapture rate trend with increasing depth. Fish only hooked in the lip or mouth (shallow hooking location) also had a significantly higher probability of recapture than did those that were either foul or deep hooked (Figure 4-15).

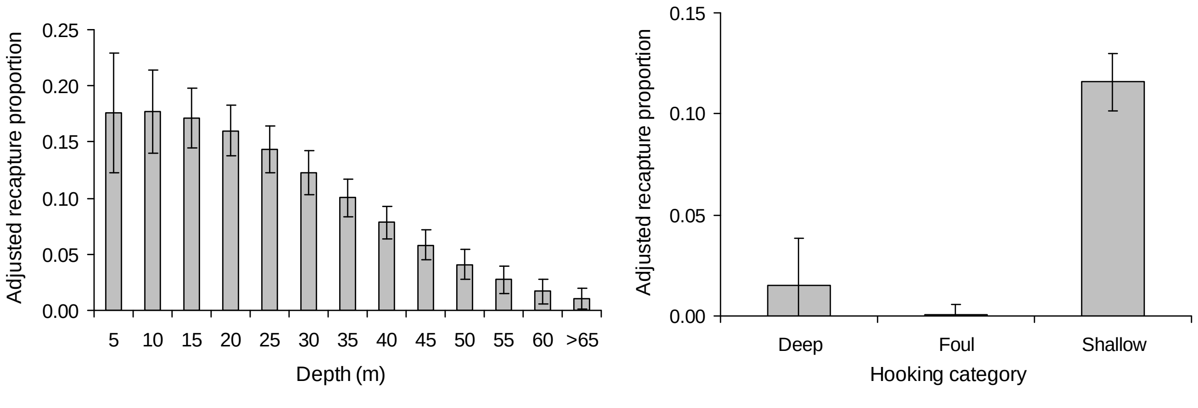

Figure 4-15. Adjusted mean recapture rate (± s.e.) for line caught red emperor over a range of depth of first capture categories (left) and hooking location categories (right).

4.4.7 Grass emperor (*Lethrinus laticaudis*)

Grass emperor was not originally included as a species to be assessed in this research but many of the recreational anglers that contributed to the tagging of the 6 main target species also tagged and released large numbers of this species. It was also included because spangled emperor were not targeted extensively by recreational anglers in Queensland and including grass emperor would increase the numbers of lethrinids tagged. Unfortunately this species was very poorly represented in terms of barotrauma treatment with only 18 fish being shot lined and 58 fish vented. Most of the fish tagged were however released in relatively good condition (index = 1 or 2).

Table 4-27. Raw data summary results showing the numbers of grass emperor tagged and recaptured by anglers and researchers between October 2003 and September 2007. Results are presented in relation to a number of observed factors and treatments likely to have influenced the probability of recapture. Large fish were those greater than the MLS of 25cm.

Variate	Class	No. recaptured	No. tagged	% Recaptured
Release condition	1	68	1347	5.05
	2	22	510	4.31
	3	0	11	0.00
	4	0	2	0.00
Barotrauma treatment	Control	51	1112	4.59
	Shotlined	0	18	0.00
	Vented	3	58	5.17
Depth of capture (m)	<15	49	900	5.44
	15 - 29	4	68	5.88
	30+	0	130	0.00
Tagger affiliation	Club	51	1113	4.58
	Research	3	23	13.04
Hook Removed	Yes	50	1073	4.66
	No	4	115	3.48
Bleeding	Heavy	0	0	
	Light	0	9	0.00
	None	51	968	5.27
Injury category	Eye	0	1	0.00
	None	51	976	5.23
Body size	Large	21	653	3.22
	Small	32	526	6.08
Hooking location	Deep	4	119	3.36
	Foul	0	15	0.00
	Shallow	46	827	5.56
Barotrauma signs	None	48	907	5.29
	Swollen	1	26	3.85
	Extreme	0	12	0.00

Table 4-28. Effect of release condition, barotrauma signs, tagger affiliation and barotrauma treatment on the recapture rate of line caught grass emperor.

Source	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Release condition	2	23.6527	11.8264	11.83	**<0.001**
Barotrauma signs	4	3.7155	0.9289	0.93	0.446
Tagger affiliation	3	2.4702	0.8234	0.82	0.481
Barotrauma treatment	3	0.716	0.2387	0.24	0.869
Residual	1228	419.7685	0.3418		
Total	1240	450.323	0.3632		

None of the two-way interactions in the release condition model was significant ($P > 0.1$) and release condition was the only significant main effect (Table 4-28 and Figure 4-16). The fact that most grass emperor tagged and released were classified as release condition 1 or 2 suggests that it copes with line capture and release better than many other species and also reflects the fact that most fishing for this species was undertaken in shallow water (Table 4-27) where the impact of barotrauma is less likely to be an effect.

The full model that included factors likely to contribute to release condition (Table 4-29) showed no significant interaction effects and depth as the only significant main effect ($P < 0.001$). Recapture rates were lower at depths greater than 15m (Table 4-30), but sample sizes were too low to provide definitive trends. While treatment was not significant statistically, the large number of controls ($n = 1112$; see Table 4-27) provide a good estimate of the overall recapture rate. As only 18 fish were released with shotline treatment, there can be little confidence in the zero recapture rate. However the sample size of released vented fish (58) was reasonable, indicating some improvement (12.6%) in adjusted recapture rate over the controls.

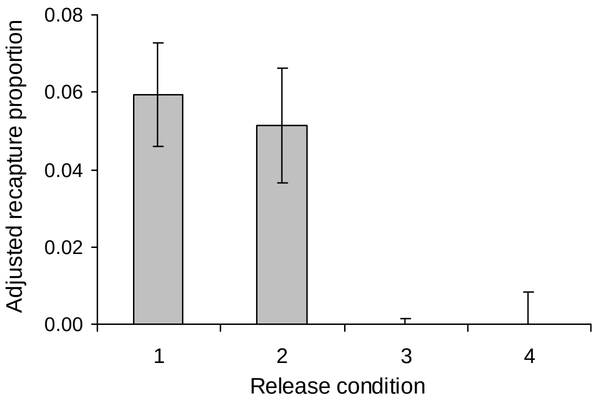

Figure 4-16. Adjusted mean recapture rates (± s.e.) of line-caught grass emperor for a range of release condition categories.

Table 4-29. Effect of depth, body size, hooking location, barotrauma treatment, barotrauma signs and hook removal on the recapture rate of line-caught grass emperor.

Source	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Depth (polynomial)	2	23.6527	11.8264	11.83	**<0.001**
Body size	2	4.3971	2.1986	2.2	0.111
Hooking location	3	3.0567	1.0189	1.02	0.383
Barotrauma treatment	3	2.5118	0.8373	0.84	0.473
Barotrauma signs	3	1.7775	0.5925	0.59	0.620
Hook removed	1	0.0893	0.0893	0.09	0.765
Residual	1226	414.8379	0.3384		
Total	1240	450.3230	0.3632		

Table 4-30 Mean recapture proportions (rates) and standard errors for grass emperor adjusted for the influence of a range of variates. Asterisks denote effects significant at P = 0.05.

Variate	Class	Adj. mean	s.e.
Depth category*	<5	0.1181	0.2001
	5	0.1511	0.1049
	10	0.1531	0.1032
	15	0.1216	0.1849
	20	0.0894	0.5929
	25	0.0528	1.7589
	30	0.0084	0.6413
	> 35	0.0003	0.0273
Body size	Large	0.0634	0.0178
	Small	0.1087	0.0340
Hooking location	Deep	0.0118	0.0083
	Foul	0.0000	0.0008
	Shallow	0.0931	0.0251
Treatment	Control	0.0851	0.0222
	Shotlined	0.0001	0.0017
	Vented	0.1391	0.0817
Barotrauma signs	None	0.0876	0.0233
	Swollen	0.0391	0.0521
	Extreme	0.0000	0.0004
Hook removed	Yes	0.0861	0.0225
	No	0.0533	0.0292

4.4.8 Other coral trout species (*Plectropomus spp.*)

‘Other’ coral trout consisted of a number of species including chinese footballer (*Plectropomus laevis*), barred-cheek coral trout (*P. maculatus*) and passionfruit trout *(P. aerolatus*) but too few were recaptured to enable a thorough the statistical analysis of the data. Even with the small number of fish tagged there was a disproportionately high recapture rate of large fish (28.6%) compared with smaller fish. Twenty percent of fish that were tagged and released displayed symptoms of barotrauma but overall the recapture of only12 fish precluded further analysis of these data. An initial model tested the effects of release condition on the recapture rate (Table 4-32) but revealed no significant effects, almost certainly a result of the low numbers of fish recaptured.

Table 4-31. Raw data summary results showing the numbers of "other" coral trout tagged and recaptured by anglers and researchers between October 2003 and September 2007. Results are presented in relation to a number of observed factors and treatments likely to have influenced the probability of recapture. Large fish were those greater than 38cm.

Variate	Class	No. recaptured	No. tagged	% Recaptured
Release condition	1	8	146	5.48
	2	4	47	8.51
	3	0	2	0.00
	4	0	0	0.00
Barotrauma treatment	Control	4	73	5.48
	Shotlined	0	18	0.00
	Vented	3	31	9.68
Depth of capture (m)	<15	1	58	1.72
	15 - 29	6	57	10.53
	30+	0	4	0.00
Tagger affiliation	Club	7	107	6.54
	Research	0	16	0.00
Hook removed	Yes	7	122	5.74
	No	0	0	0.00
Bleeding	Heavy	0	0	0.00
	Light	0	2	0.00
	None	6	116	5.17
Injury category	Eye	0	1	0.00
	Jaw	0	1	0.00
	None	6	115	5.22
Length	Large	2	7	28.57
	Small	4	106	3.77
Hooking location	Deep	0	1	0.00
	Foul	0	0	
	Shallow	6	117	5.13
Barotrauma signs	None	5	96	5.21
	Swollen	1	17	5.88
	Extreme	0	3	0.00

Table 4-32. Effect of release condition, tagger affiliation, barotrauma signs, tagger affiliation and barotrauma treatment on the recapture rate of line caught "other" coral trout species.

Source	d.f.	Deviance	Mean deviance	Deviance ratio	Chi prob.
Release condition	3	2.013	0.671	0.67	0.57
Tagger affiliation	4	6.5313	1.6328	1.63	0.163
Barotrauma signs	3	0.1986	0.0662	0.07	0.978
Barotrauma treatment	3	2.519	0.8397	0.84	0.472
Residual	191	80.136	0.4196		
Total	204	91.3979	0.448		

4.4.9 Spangled emperor (*Lethrinus nebulosus*)

Unfortunately too few spangled emperor were recaptured to determine the effects of the various barotrauma relief procedures on recapture probability (Table 4-33). Recreational anglers tagged very few individuals of this species, most (61%) having been tagged by researchers towards the end of the project period, leaving insufficient time to obtain enough recaptures to enable meaningful analysis.

Table 4-33. Raw data summary results showing the numbers of spangled emperor tagged and recaptured by anglers and researchers between October 2003 and September 2007. Results are presented in relation to a number of observed factors and treatments likely to have influenced the probability of recapture. Large fish were those greater than the MLS of 38cm.

Variate	Class	No. recaptured	No. tagged	Percentage recaptured
Release condition	1	3	138	2.17
	2	0	48	0.00
	3	0	29	0.00
	4	0	11	0.00
	5	0	5	0.00
Barotrauma treatment	None	2	81	2.47
	Shotlined	0	38	0.00
	Vented	0	47	0.00
Depth of capture (m)	<15	2	130	1.54
	15 - 29	0	27	0.00
	30+	0	35	0.00
Tagger affiliation	Club	1	77	1.30
	Research	1	122	0.82
Hook removed	Yes	1	165	0.61
	No	1	7	14.29
Bleeding	Heavy	0	1	0.00
	Light	0	7	0.00
	None	2	163	1.23
Injury category	Eye	0	1	0.00
	Gill	0	1	0.00
	Jaw	0	5	0.00
	None	2	154	1.30
			11	
Body size	Large	0	48	0.00
	Small	2	98	2.04
Hooking location	Deep	1	9	11.11
	Foul	0	5	0.00
	Shallow	1	158	0.63
Barotrauma signs	None	2	122	1.64
	Swollen	0	79	0.00
	Extreme	0	0	0.00

4.4.10 Effect of deep hooking and hook removal on recapture

Fish that were deep-hooked (in the throat or gut) sometimes had the hook removed by anglers whereas in other cases the hook was left lodged inside the gullet of the fish and the line cut prior to the fish being released (the current general best practice within the angling community). The notable trends here were the enhanced survival of coral trout that had hooks left in and the reverse situation with deep-hooked crimson snapper, which evidently survived better when hook was removed. Whether or not the hook was left *in situ* in deep-hooked saddletail snapper appeared to have no effect at all on subsequent recapture rates (a robust conclusion considering the sample sizes). In the remaining species (redthroat emperor, red emperor, grass emperor and spangled emperor) the release and/or recapture numbers were so small that there can be little confidence in any comparison of recapture rates between fish where the hook was left in and where it was removed.

Table 4-34. Number of tagged and recaptured fish that were deep-hooked but which either had their hooks removed or were left in on release. Numbers of fish subsequently recaptured are shown in parentheses.

Species	Number tagged (and recaptured)		Percentage recaptured	
	Hook removed	Hook left in	Hook removed	Hook left in
Coral trout	33 (1)	17 (3)	3.03	17.65
Redthroat emperor	19 (0)	11 (1)	0.00	9.09
Crimson snapper	27 (4)	56 (5)	14.81	8.93
Saddletail snapper	19 (2)	89 (9)	10.53	10.11
Red emperor	14 (0)	64 (2)	0.00	3.13
Grass emperor	4 (0)	138 (4)	0.00	2.90
Spangled emperor	2 (0)	7 (1)	0.00	14.29

4.5 DISCUSSION

The condensed models that included release condition explained more of the variability in the data than models that included the combination of other factors that would have impacted the overall probability of survival. This suggests that the best predictor of survival was the subjective assessment (open to interangler variation) of how the fish behaved when it was released back into the water. It is clear that many factors that cannot be easily quantified are impacting on the release survival of many of these species.

Two factors were consistently important in predicting the recapture rate of all species (Table 4-35) - depth and release condition. Even though release condition was a subjective qualitative assessment which would be expected to vary among anglers the trend was for most species to have a greater probability of recapture if they were released in better condition. Likewise the effect of depth was fairly consistent for all species with recapture probability generally decreasing with increasing depth although only half of the species tested showed a statistically significant effect. This is in line with many other studies that have demonstrated higher mortality or incidence of barotrauma symptoms of fish with depth (St John and Syers 2005, Hannah and Matteson 2007). One of the possible criticisms of this work was that insufficient fish were caught from a range of different depths to enable sufficient power to accurately model depth effects. Despite this, the involvement of a large number of ANSA fishers who are representative of the overall recreational fishing community should have insured that the fishing locations were typical of those fished by recreational anglers. In addition, the depth distribution shown is broadly reflective of the fishing grounds in the Great Barrier Reef Marine Park where most fishing is conducted around relatively shallow coral reefs in waters less than 30 m. We are therefore confident that the depth distribution covered broadly reflects the distribution of recreational fishing effort for these species, although we acknowledge that the behaviour of both fish and fishers may influence the recapture rates of fish at different locations.

Table 4-35. Summary of probability values derived from generalized linear models. Factors significant at the 0.05 level are shown in bold, while those of lower significance but still of interest are shown in parentheses. Missing cells indicate factors that were not included in the models due to aliasing, confounding or insufficient data contrast.

	Coral trout	Redthroat emperor	Crimson snapper	Saddletail snapper	Red emperor	Grassy emperor
Condensed model						
Release condition	**<0.005**	**0.002**	**0.002**	**<0.001**	**<0.001**	**0.001**
Barotrauma signs	**0.027**	0.080	**<0.001**	**0.003**	(0.064)	0.446
Tagger affiliation	0.838	0.425	**<0.001**	**0.001**	0.112	0.481
Treatment	0.167	0.326	**<0.001**	0.397	0.433	0.869
Signs x Treatment				**0.016**		
Condition x Tagger				**0.001**		
Expanded model						
Depth	**0.034**	0.265	0.500	0.975	**<.001**	**<0.001**
Barotrauma signs		0.207	**<0.001**	**0.014**	0.106	0.104
Hook removed	0.076				0.646	0.534
Body size	**<0.001**	0.112	**<0.001**	0.692	0.430	0.403
Bleeding	0.181			**0.008**		
Tagger affiliation				**0.038**		
Hooking category	0.485		**0.009**	0.994	**0.013**	0.383
Treatment	0.439	(0.055)	0.885	0.510	0.329	0.337
Depth x Treatment			(0.063)			
B. signs x Treatment				**0.016**		

Body size was only a significant factor for coral trout and crimson snapper and both showed opposite effects. The greater survival of larger coral trout was consistent with findings of the short term experiment (Chapter 2) and possible reasons for this are discussed in detail in that chapter. The apparent better survival of small crimson snapper is more difficult to interpret. Obviously many factors interact when a fish is hooked and subsequently landed by an angler. For some species larger individuals may take longer to land than smaller individuals due to their greater "fighting" ability. This could either increase the stress on the fish (due to lactic acid build up etc.) but it may allow for a greater period of time for the fish to self vent as it takes longer to ascend from depth. Alternatively, a quick retrieval of a small fish may cause the swimbladder to burst due to the rapid expansion of swimbladder gases that cannot be quickly compensated for by the fish. The fact that few fish greater than the current minimum legal sizes were tagged and released for most species does not diminish the value of these results as the size of fish released would be representative of the discards of the recreational sector. Commercial fishers are less likely to release fish above the MLS although due the quota restrictions on coral trout and the market premium paid for small live coral trout, large individuals of this species are sometimes released by commercial fishers.

While the results may not be statistically significant for saddletail snapper there does appear to be benefit in treating crimson snapper and saddletail snapper as both these species had appreciably higher recapture rates than the other species investigated when they were treated by either shotlining or venting. Anglers may also have difficulty in distinguishing between crimson snapper and saddletail snapper as they form mixed schools and small specimens below the minimum legal size are very difficult to identify to species level. It was clear that there was some misidentification of these species by anglers and at times researchers and experienced fishers had problems identifying small individuals in particular. It is further surprising that such closely related species should exhibit such a difference in physiological response to line capture and barotrauma although the literature contains examples of differences in barotrauma susceptibility among similar species within the same family (Lucy and Arendt 2002, Rummer and Bennett 2005, Hannah and Matteson 2007).

The interaction between barotrauma signs and treatment was not significant in most cases but this interaction is clearly important as it is expected that treatment for barotrauma symptoms should have the greatest impact when fish are suffering from its effects. Nonetheless, the fact that there were no dramatic ill effects shown from venting or shotlining fish means that treatment for barotrauma can be recommended regardless of the ability of anglers to accurately diagnose the condition. The exception to this is red emperor where there is evidence to recommend against treatment. Red emperor were caught predominantly in depths greater than 40 m whereas most of the other species were caught in shallower water. Of all the species examined, it also displayed the fewest effects of barotrauma. In the short term experiments (Chapter 1) we found no benefit in treating red emperor, which appears to be quite resilient to line capture even when brought to the surface from moderate depths (> 40 m). These long-term tagging experiments did however find that there was a declining recapture trend with increasing depth. This suggests that the species is still more prone to increased mortality with increasing depth of capture, regardless of treatment. An alternative explanation is that the deeper-water habitats might be more spatially diffuse, so that the chance of a particular deep release site being fished (and the tagged fish 're-sampled') is lower than at a well-identified shallow inshore 'mark' or fishing site. Spatial heterogeneity of fishing effort is identified as a particularly challenging issue to deal with in the analysis of tag-recapture data.

For most species there were too few deeply hooked fish to test the effect of hook removal on recapture rate but the results were not consistent across all species. Coral trout did benefit from cutting the line and leaving deeply lodged hooks in place prior to release. In contrast, recaptures of deeply hooked crimson snapper were higher if deep hooks were removed. Reasons for this differing result are speculative but could reflect different bait striking habits among the various species. For example, the 'ambush predatorial' coral trout may ingest the baited hook to an anatomical point where the hook's removal is likely to damage adjacent tissues and organs (e.g. heart, gills). On the other hand, the anatomy of the anterior alimentary canal of a crimson snapper may be such that, on balance, problems associated with gut obstruction by a hook left *in situ* may outweigh the risks of serious damage resulting from the hook's removal.

The poor recapture rate for redthroat emperor should not necessarily be interpreted as an indication that it suffers more from the effects of barotrauma or capture stress. Even though this species showed some effect of barotrauma treatment on recapture rate there are many things that could influence the ultimate recapture rate of the species examined in this study. Differential tag loss among species, may be responsible for impacting on the recapture rate of some species (McGlennon and Partington 1997) and there is little information on tag loss for any of the species studied here. In addition, recreational fishing effort is not uniform across fishing grounds for all species. This observation was most noticeable in the crimson snapper, saddletail snapper and red emperor data. Each of these species had relatively high recapture rates, most likely because they are heavily fished at well-known and accessible fishing locations. These factors therefore preclude any ranking of species susceptibility to release mortality based on recapture rate alone.

Observations by researchers during experiments, as well as comments by many of the ANSA taggers raised some doubts about the efficacy of shotlining as a barotrauma relief procedure for recreational anglers. During tagging experiments it was common for fish to become detached from the shotline shortly after their descent from the surface. It was noted that larger and more active fish were capable of violently shaking their head and becoming detached from the shotline before they reached a depth that would have enabled the alleviation of their symptoms. Experience with the technique no doubt reduces the probability of malfunction and anglers experienced in using this method report less of a problem. However, many experienced anglers who participated in the experiment were reluctant to use shotlining, reporting that it was more time consuming and prone to failure in release than venting for some species. Despite these difficulties, for some species shotlining still provided recapture rates comparable with, and often better than, venting. Venting is clearly a more invasive practice as it involves the puncturing of internal organs leading to the greater probability of infection and damage to other vital internal organs than would be expected by simply threading a barbless hook through the lip. Despite the reluctance of the recreational sector in Queensland to use shotlines, this method could be encouraged as a means of alleviating the effects of barotrauma for some species, particularly large individuals and species considered not to respond well to venting. There is also the risk that promoting either technique will result in injury to anglers. The use of sharp hooks, gaffs and knives as well as the handling of large powerful fish makes fishing an inherently risky activity but the use of both venting tools as well as holding fish on a hooked shotline increases the risk of injury to anglers than just simply releasing fish untreated. There may also be benefit in using other devices such as weighted cages placed over fish to return them to depth, as these may be even less damaging than shotlining. This is an area requiring further investigation as new devices come onto the market or are developed by enthusiastic anglers (see Chapter 2, Section 2.4.6).

In conclusion, we believe the results of the long term survival experiments do provide justification for shot lining or venting most species (apart from red emperor) despite the fact that only two species (crimson snapper and redthroat emperor) showed a statistically significant positive effect of such treatment.

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CHAPTER 5. FACTORS INFLUENCING POST-RELEASE SURVIVAL OF LINE-CAUGHT CORAL REEF FISH USING HISTORICAL RECREATIONAL TAG-RECAPTURE DATA.[2]

W. Sumpton, D. Mayer, I. Brown, B. Sawynok, M. McLennan, A. Butcher, and J. Kirkwood

5.1 ABSTRACT

Over 14,000 individuals of six species of line caught coral reef fish (*Plectropomus* spp, *Lethrinus miniatus*, *Lethrinus laticaudis, Lutjanus sebae, Lutjanus malabaricus* and *Lutjanus erythropterus*), were tagged by members of the Australian National Sportsfishing Association in Queensland between 1986 and 2003. The subsequent recaptures were analysed to determine factors likely to impact release survival. All species were classified as residents with few individuals being recaptured more than 20 km from their release point. The survival of *Lutjanus sebae* and *Lutjanus malabaricus* was enhanced by venting swim bladder gases, regardless of whether or not they had appeared to be suffering from barotrauma. None of the fish that were classified as in poor condition on release were subsequently recaptured suggesting a very high capture/tagging mortality of those fish. The recapture rate of *L. sebae* was lower for fish caught in depths exceeding 40 m, although overall this species had a higher recapture rate than the other species studied.

5.2 INTRODUCTION

With changes in fisher attitudes and increases in the regulatory environment in recreational line fisheries there has been greater emphasis in recent years on catch and release fisheries and on the safe return of undersized fish to the water (Mills 2000, Sutton 2001). A review of the survival of line caught fish throughout Australia (McLeay *et al*. 2002) highlighted reef-associated species such as coral trout (*Plectropomus* spp), emperors (*Lethrinus* spp) and snappers (*Lutjanus* spp) as the species likely to have lower survival rates when released.

These species groups are the basis of significant commercial and recreational reef line fisheries in Queensland where the two most important species coral trout (*Plectropomus leopardus*) and redthroat emperor (*Lethrinus miniatus*) have an annual commercial quota of over 2000 tonnes (Anon 2003). A recent review of the regulations governing Queensland reef line fisheries culminated in a range of management measures being introduced in December 2003 (Anon 2003) including increases in minimum legal size (MLS) of many species. The MLS of red emperor (*Lutjanus sebae)* was increased from 45 to 55 cm while the MLS of redthroat emperor (*Lethrinus miniatus*), large-mouth nannygai (*Lutjanus malabaricus*) and small-mouth nannygai (*Lutjanus erythropterus)* have been increased from 35 to 40 cm. These changes have resulted in a dramatic increase in the numbers of each of these species being released by both recreational and commercial line fishers. At present little information is available on the relative survival of each of these species after capture despite the fact that earlier surveys of recreational fishers prior to the management changes in 2003 (Higgs 1998, Higgs 2000) showed that up to 60% of tropical snappers (*Lutjanus* spp) and 45% of coral trout (*Plectropomus* spp) caught by recreational line fishers were returned to the water.

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[2] Material in this Chapter has been published in: Sumpton, W., Mayer, D., Brown, I., Sawynok, B., McLennan, M., Butcher, A., and Kirkwood, J., 2008. Investigation of movement and factors influencing post-release survival of line-caught coral reef fish using recreational tag-recapture data. *Fisheries Research* **92**: 189-195.

In recent years members of the Australian National Sportfishing Association (ANSA) have tagged large numbers of fish in collaborative studies with researchers (Begg *et al.* 1997; McPhee *et al.* 1999, Sumpton *et al*. 2003) and have provided valuable data to assist in the sustainable management of fish stocks. The involvement of recreational anglers is an efficient and cost-effective way to tag large numbers of fish over a wide geographic area (Saul and Holdsworth, 1992) and may also be useful in determining key population parameters, particularly movement (Buxton and Allen, 1989; Van der Elst 1990).

Since 1986 ANSA members in Queensland have tagged over 14,000 individuals of six of the most important line-caught tropical reef species: coral trout (*Plectropomus spp*.), redthroat emperor (*Lethrinus miniatus)*, grass emperor (*Lethrinus laticaudis)* red emperor (*Lutjanus sebae),* large-mouth nannygai (*Lutjanus malabaricus)* and small-mouth nannygai (*Lutjanus erythropterus).* In this paper we analyse this large historical set of tagging data (Suntag database) in an attempt to describe the factors of importance to the post-release survival of these important tropical line caught reef species.

5.3 MATERIALS AND METHODS

Between 1986 and 2003 over 14,000 coral trout (*Plectropomus spp*.), redthroat emperor (*Lethrinus miniatus)*, grass emperor (*Lethrinus laticaudis)* red emperor (*Lutjanus sebae),* large-mouth nannygai (*Lutjanus malabaricus)* and small-mouth nannygai (*Lutjanus erythropterus)* were tagged in Queensland waters by ANSA members and researchers. Fish were tagged and released throughout their distributional range in Queensland waters although tagging intensity was concentrated in tropical waters on the east coast between 16° S and 28° S, and particularly in the Great Barrier Reef Marine Park.

All fish were caught by hook and line, and generally handled using a moist cloth to minimise injury during hook removal and tagging. Participating anglers are assumed to have adhered to handling and release protocols promoted by the ANSA code of practice on releasing fish (as described below). Fish were measured (± 1 cm), tagged and released within 30 seconds of capture. Where fork length was measured this was later converted to total length using morphometric relationships described by McPherson *et al.* (1992) for the lutjanids , Brown and Sumpton (1998) for *Lethrinus miniatus*, and others were taken from unpublished reports and FishBase (Froese and Pauly 2006.). The release location (in some cases recorded from GPS coordinates) and dates of capture and recapture were recorded and on release the fish were assigned a subjective condition rating from 1 to 5 as follows: 1 = excellent , 2 = good , 3 = fair , 4 = poor and 5 = fish apparently dead and sank on release (fish that floated on the surface were retrieved where possible).

Fish were further categorised in terms of their treatment for barotrauma (if symptoms were evident) into those released with or without venting. Fish were classified as suffering from barotrauma if they had a hard and enlarged abdomen or their gut lining was protruding from either the mouth or anus. Venting involved puncturing the swim bladder, usually with a hollow needle, at a point directly below the third dorsal spine and in line with the top of the pectoral fin. Anchor tags (Hallprint ^{TM} ; 75 x 2 mm) and dart tags (Hallprint ^{TM}; 91 x 2 mm) were inserted into the dorsal musculature and locked between the pterygiophores below the dorsal fin rays. Tags were individually numbered and marked with the words 'record date place length' and a 24-hr toll free telephone number.

Distances moved by individual fish were measured by direct route between release point and recapture location (usually specified as GPS co-ordinates). Binomial generalised linear models with a logit link function were used to test the effect of various factors on recapture rate. A range of multi-term models were trialled but for most species tag type, water depth at first capture, barotrauma condition and release condition were the factors of greatest significance included in the final model.

5.4 RESULTS

Lutjanus sebae had the highest recapture rate of all three lutjanid species (19.9%) and there were no significant differences (P > 0.05) in recapture rate between the two closely related nannygai species *L. malabaricus* and *L. erythropterus* (11.7% and 11.2% respectively (Table 5-1)). Recapture rates of both lethrinid species were less than half those of the lutjanids, although low numbers of tagged *Lethrinus miniatus* precluded any statistical conclusions being drawn for that species.

Table 5-1. Numbers of fish tagged by ANSA anglers in Queensland and recaptured between 1988 and 2003.

Species	No. Tagged	No. Recaptured	%
Plectropomus spp	2005	146	7.3
Lethrinus miniatus	376	8	2.1
Lethrinus laticaudis	5415	307	5.7
Lutjanus sebae	4127	823	19.9
Lutjanus malabaricus	1329	155	11.7
Lutjanus erythropterus	1505	168	11.2

Table 5-2. The percentage of fish that were recaptured at various distances from their original tag and release location. Zero distances also included instances where the recapture information supplied by the fisher was insufficient to discriminate distances of less than 2 km. Due to data rounding, totals may not sum exactly to 100%.

Distance (km)	*Plectropomus spp*	*Lethrinus laticaudis*	*Lutjanus sebae*	*Lutjanus malabaricus*	*Lutjanus erythropterus*
0	96.2	81.7	87.2	96.0	93.8
2 to 19	3.1	13.3	11.6	2.6	3.1
20 to 39	0.8	1.0	0.6	0.0	0.0
40 to 59	0.0	0.3	0.3	0.7	0.6
60 to 79	0.0	1.0	0.1	0.0	0.0
80 to 99	0.0	1.3	0.0	0.0	1.2
100 to 119	0.0	0.7	0.0	0.0	0.0
120+	0.0	0.7	0.1	0.7	1.2
n	131	301	792	151	162

There was no evidence of large-scale migration or extensive movement shown by any of the species studied, with over 80% of recaptures for each species being made within 1 km of where the fish had been tagged and released (Table 5-2). No coral trout were recaptured more than 30 km from their release location, and few individuals of any of the other species were recaptured more than 40 km from their release point.

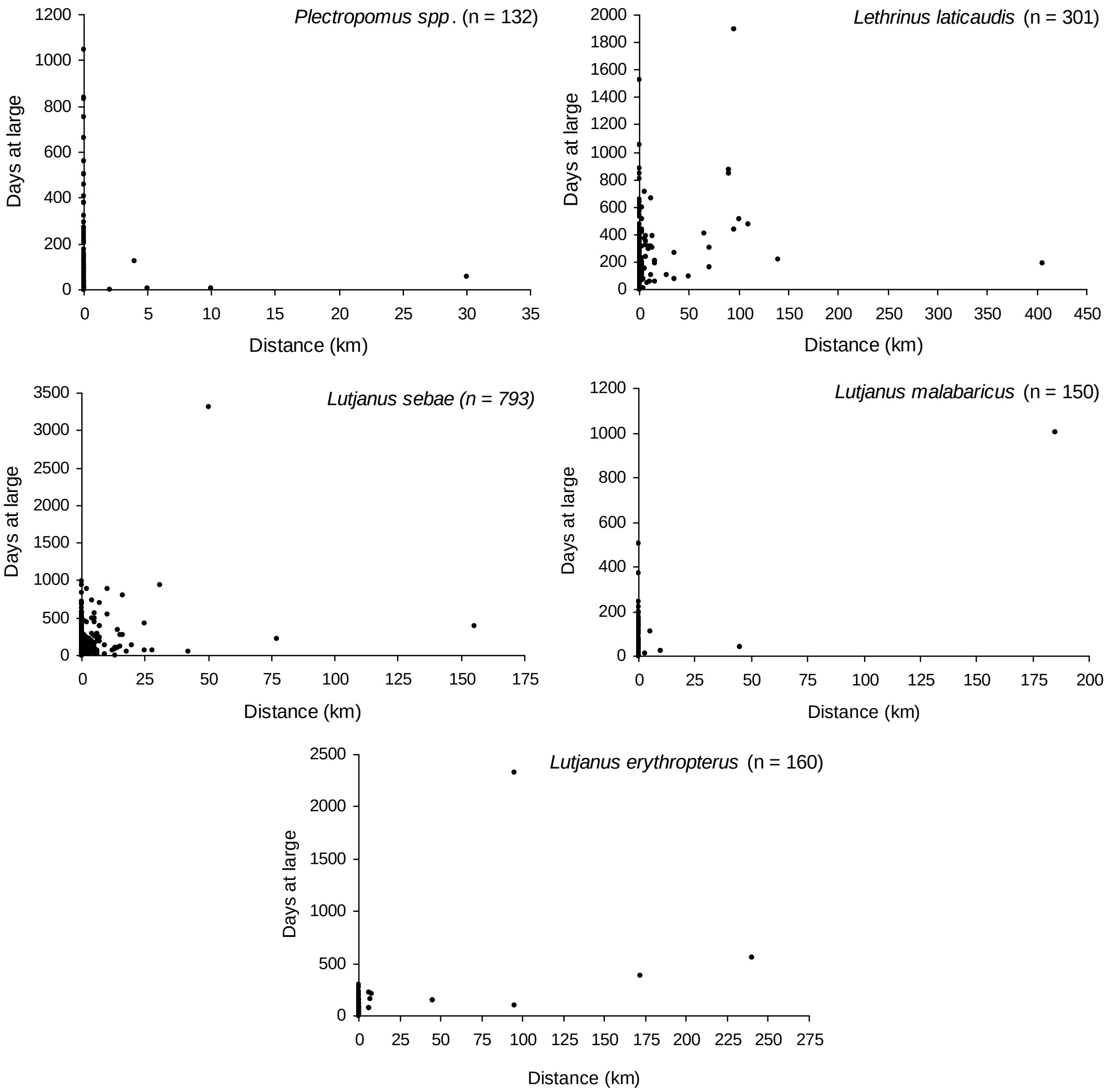

Figure 5-1. Distance between original release locations and recapture locations related to days at large for common tropical reef line species tagged by ANSA fishers in Queensland.

There was no significant relationship between distance moved and time (Figure 5-1) but the tendency for species other than coral trout to be recaptured further from their release location was more evident. The patterns of recaptures over time were similar among the lutjanid species with over 85% of all recaptures being recorded within 3 months of the tagging date (Figure 5-2). *L. malabaricus* tended to be caught within the first month of being released (38%) while fewer than 27% of recaptures of the other two lutjanid species occurred within a month of being tagged. Low recapture rate and insufficient depth, release condition and barotrauma data precluded *Plectropomus* spp and *L. miniatus* being included in the models to analyse factors affecting recapture rate.

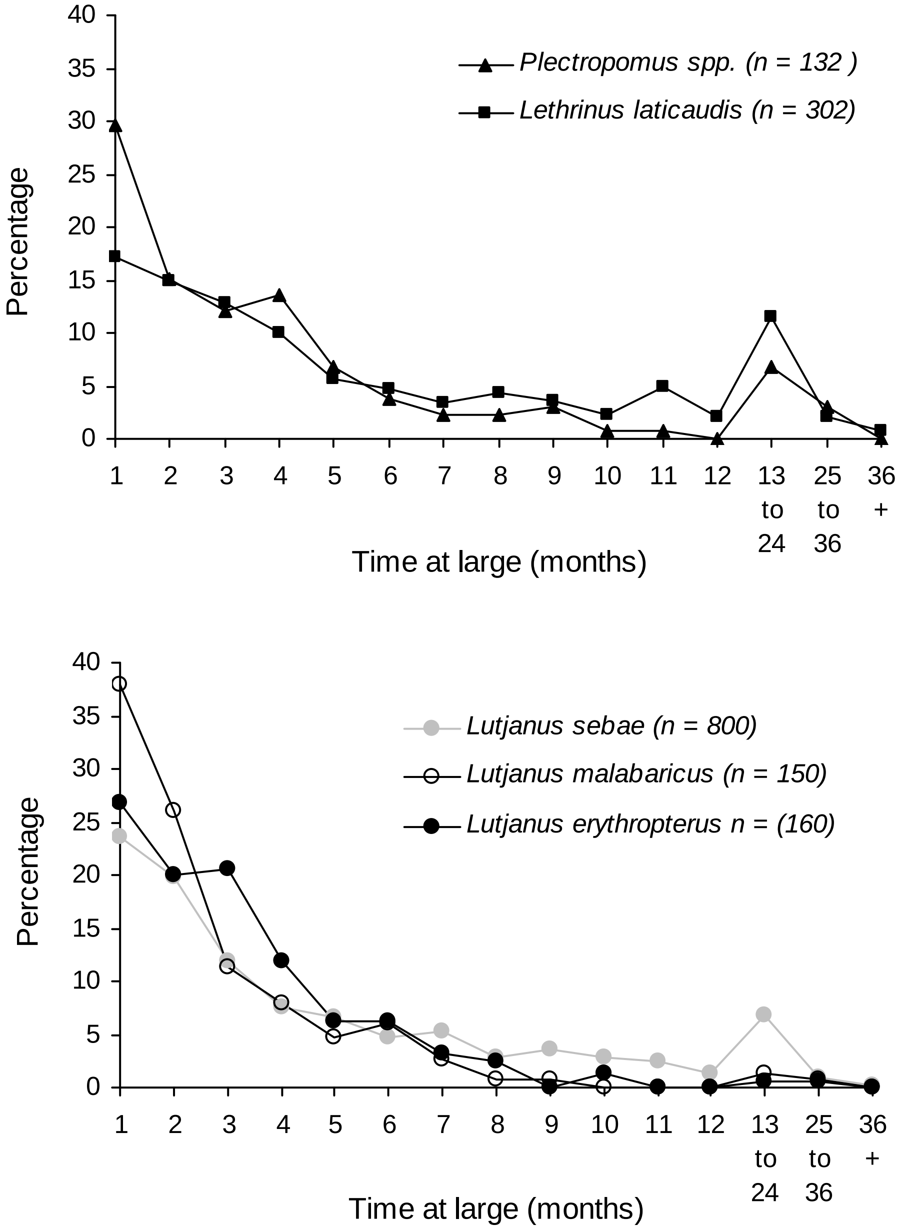

Figure 5-2. Percentage of recaptures made at various time-intervals after release of common reef line species tagged by ANSA fishers in Queensland.

When the effects of release condition on recapture rate were considered, a notable result was the paucity of recaptures of release category 4 fish for all species other than *L. sebae*. Recaptures of category 4 fish were overall too few and these were subsequently excluded from the models. *L. sebae* was also the only species in which the recapture rate of fish classed as category 3 (‘fair’ release condition) was significantly lower than that of fish classed as category 1 or 2 (Figure 5-3).

Lutjanus erythropterus was the only species in which venting individuals that showed signs of barotrauma failed to have a benefit on apparent survival (Figure 5-4). Neither was there a significant difference in recapture rate between those that showed signs of barotrauma and those that did not (after adjusting for the treatment effects). In the other two lutjanid species (particularly *L. sebae)* the recapture rate of vented individuals was significantly higher than that of non-vented fish, (regardless of whether or not there had been signs of barotrauma). Recapture rates of *Lethrinus laticaudis* suffering from barotrauma but not treated were extremely low (0.02%).

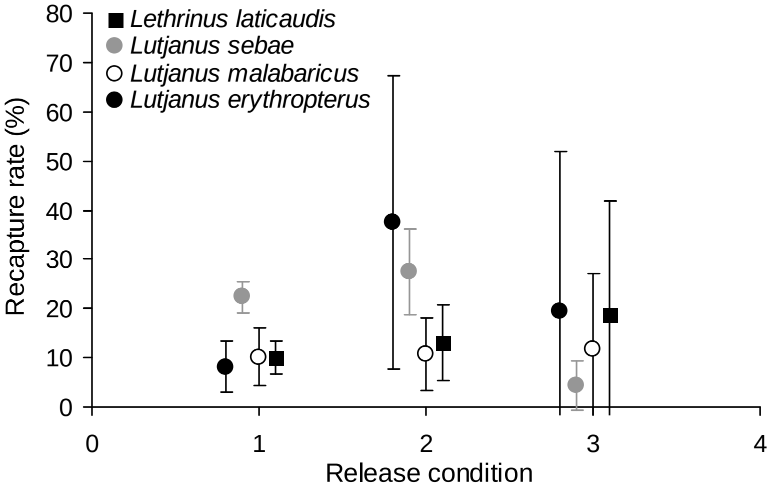

Figure 5-3. Recapture percentage of common coral reef fishes tagged by ANSA fishers based on subjective released condition criteria. Vertical bars represent 95% confidence intervals. See text for descriptions of release conditions.

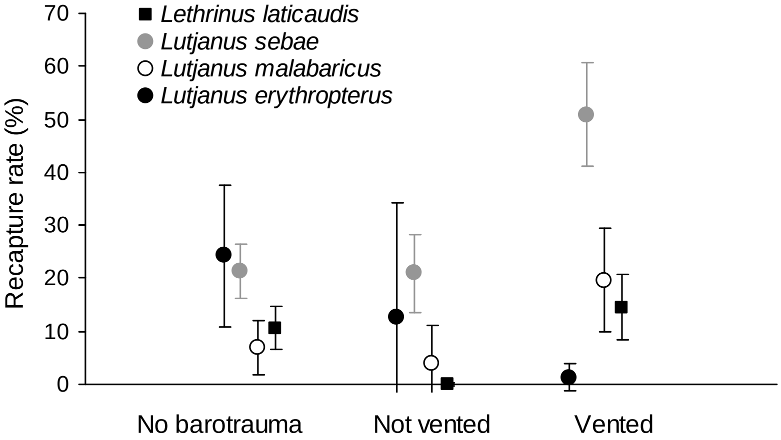

Figure 5-4. Recapture percentage of common coral reef fishes showing no signs of barotrauma (BT) and those with symptoms that were released untreated and those that were "vented". Fish were categorised as suffering from barotrauma (BT) if the gut linings were protruding from the mouth or anus, or if the stomach region was hard and enlarged. Vertical bars represent 95% confidence intervals.

For only three species were there sufficient depth data to enable an analysis of the effect of capture depth on recapture rate (Figure 5-5). Model outputs indicated a generally declining recapture rate for fish that had been in depths exceeding 20 m. There was no statistically significant reduction in recapture rate with depth for *Lutjanus malabaricus*. Recapture rates for *Lethrinus laticaudis* caught in shallow (<10m) and deep (>40 m) water were significantly lower than those of fish caught in intermediate depths. The recapture rate of *Lutjanus sebae* also declined significantly with increasing depth.

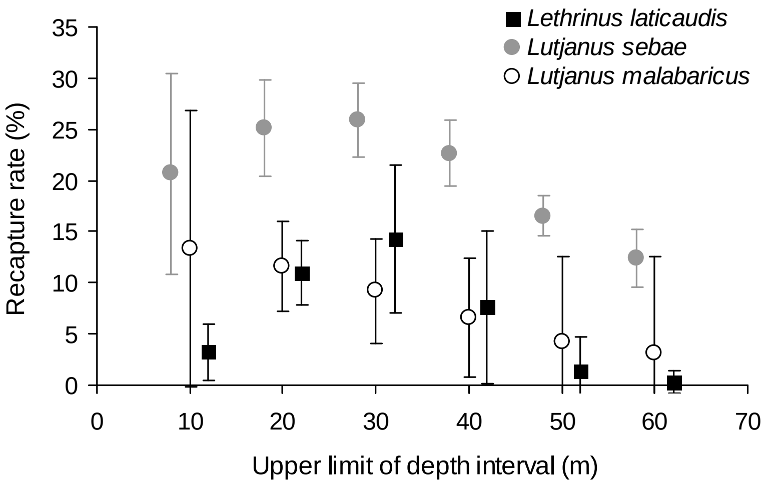

Figure 5-5. Recapture percentage of common coral reef fish species originally caught at different depths and subsequently recaptured. Vertical bars represent 95% confidence intervals.

5.5 DISCUSSION

Based on the pattern of tag returns, none of the species analysed displayed any evidence of large-scale migratory behaviour or extended movement. Of the species studied here, the movement patterns of only the common coral trout (*P. leopardus)* have been reported previously. Samoilys (1997) found that *P. leopardus* moved up to 7.5 km (average 2 km) around Heron Island (23° 26.5′S, 151° 50′E) in the southern Great Barrier Reef. Zeller (1998) estimated the distance between the home ranges and spawning aggregation sites of the same species as being from 0.22 to 5.21 km. Results of the present analysis have confirmed the limited home range of this species with only a very small proportion of recaptures being made further than 1 km from the original tag and release location. The lutjanids and lethrinids investigated also displayed limited movement, but in contrast to coral trout a few individuals were captured more than 40 km from their release location. The limited movement patterns may also be a reflection of the generally small size of fish tagged by recreational anglers and the short time between tagging and recapture of most individuals. Despite this, these findings are consistent with those reported for other demersal reef associated species (Bardach 1958, Springer and McErlean 1962, Kaneshiro 1998, Chapman and Kramer 2000) which tend to be limited in their patterns of movement. Few studies have examined the impact of barotrauma and other traumas on fish behaviour, but we found no evidence that capture and release dramatically influenced fish movements.

The large recreational catch of the species analysed here is one reason why it was not possible to quantify total recapture fishing effort in the present study and link this with tag release and recapture information to provide a more quantitative picture of movement patterns and other population parameters. While recreational surveys (Higgs 1998, Higgs 2000) have estimated recreational catches in Queensland, associated effort data are recorded only on very broad spatial scales and cannot distinguish between demersal and pelagic fishing activities.

It is also recognised that as well as differences in fishing effort, differences among taggers in their handling practises can affect subsequent post release survival and can bias recapture patterns observed in tagging studies. For example, McGlennon and Partington (1997) found that the recapture rate of fish tagged by recreational anglers in South Australia was significantly higher than amongst those tagged by commercial fishers or research staff. However, standardised ANSA handling and release procedures assist in minimising this source of error.

Differences in recapture rates estimated from the ANSA tag-recapture database do not provide a measure of between-species differences in post-release survival. This is because of differences in the fishing behaviour of anglers, varying natural mortality rates between species, and non-random target fishing. However, the fact that these species are caught at similar depths by the same anglers suggest that the survival of *L. sebae* is indeed better than either of the other two lutjanid species analysed.

Fish in poor condition (stage 4) at release were rarely recaptured. Apart from *L. sebae,* in which the lowest recapture rate was for individuals judged to have been in fair condition (stage 3) , none of the species tested showed any trend in recapture rate related to release condition. Because of discussions stemming from the current collaborative research with ANSA on enhancing reef fish survival, member anglers have been using a more objective rating system since 2003 for recording release condition of tagged reef fish. This involves the recording of more objective quantifiable data such as hooking location (lip, mouth, throat etc), and the incidence of bleeding and other less ambiguous damage categories. We anticipate that this more objective categorisation of injury and condition of released fish will in the future provide a better picture of the impact of capture and handling on fish survival.

There is considerable debate about the efficacy of barotrauma relief measures (Rummer and Bennett 2006). Some studies have shown that venting swim bladder gases can enhance the survival of fish. For example, Wilson and Burns (1996) found that venting improved the survival of released groupers (Serranidae) caught in depths > 40 m. On the other hand, Render and Wilson (1996) found that venting swim bladder gases was not effective in enhancing the survival of red snappers (*Lutjanus campechanus*) released after capture by hook and line.

In the present study it is possible that a proportion of fish that were classified by anglers as showing no signs of barotrauma had, in fact, suffered barotrauma. The usual external signs such as exopthalmia (bulging eyes), protruding gut and/or distended and hard abdomen may not have been evident for many of these fish, but barotrauma may still have been severe enough to reduce the probability of survival. In addition, fish are known to self-vent or rupture their swim bladder on ascent from the bottom (Harden Jones 1951, Ross 1979, Harden Jones and Scholes 1985, Parker *et al*. 2006) and these fish may not display immediate overt signs of barotrauma. The observation of higher recapture rates of some species that were vented over those that apparently displayed no sign of barotrauma suggests that even though the fish may not display overt signs of barotrauma there may be benefit in venting gases if fish are caught in water deeper than 10 m. Recapture rates of two species in particular (*Lutjanus malabaricus* and *L. sebae*) were significantly higher when they were vented, regardless of whether or not they showed signs of barotrauma. The current data don't provide a clear answer to this question, and there may be benefit in investigating chronic effects of swim bladder rupturing on damage to internal soft tissues. The results also indicate that inaccurate puncturing that can cause infection or damage internal organs (Parrish and Moffatt 1993) was probably not a significant factor among the many ANSA anglers that contributed to this research. This in turn suggests that anglers can be trained to minimise the potentially adverse effects of fish handling and barotrauma relief procedures on post-release survival.

Capture depth was a significant factor influencing the survival of released *Lethrinus laticaudis* and *Lutjanus sebae,* but the data were insufficient to determine whether the same applied to the other species studied. The low recapture rates of *Lethrinus laticaudis* initially caught in shallow water (<10 m) is counter-intuitive. For the other species, low recapture rates at shallower depths is probably a result of highly variable fishing pressure in nearshore or near-reef areas, as reflected in the large confidence intervals around recapture rate estimates. However estimates for *L. laticaudis* were comparatively precise suggesting that other factors were influencing recapture rates at these shallow depths. Increased mortality of released fish with increasing depth of capture is well documented and our results suggest that for two of the species studied (*Lethrinus laticaudis* and *Lutjanus sebae*) the effect is most noticeable for fish caught in depths exceeding 40 m. St John and Syers (2005) found that the survival of released West Australian dhufish (*Glaucosoma hebraicum*) declined markedly when capture depths were greater than 30 m, and described possible implications to the stock given existing bag limit and minimum legal size regulations. All the species examined in this study are managed by bag limit and minimum size restrictions, and while most fishing effort occurs in areas less than 30 m deep in the Great Barrier Reef

Marine Park, there are nevertheless substantial areas where these particular species are targeted in deeper water and where barotrauma may be a significant factor in post release survival. Walters and Huntsman (1986) showed that in such areas the optimum size and bag limits may be lower than those in shallower locations. As is always the case with fisheries management, the challenge is to develop a regulatory regime which encourages compliance and which may also have a differing spatial impact. The regime must also educate anglers on handling and release practices, and encourage the use of best practise that minimises the impact of barotrauma and enhance post-release survival.

5.6 ACKNOWLEDGEMENTS

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CHAPTER 6. ANALYSIS OF HISTORICAL DATASETS: ESTIMATION OF RECREATIONAL DISCARD RATES

A. Butcher, D. Welch, D. Mayer, J. Kirkwood, and I. Halliday

6.1 ABSTRACT

We examined the RFISH database for evidence of changes in discarding by recreational fishers. The database contains diary based information on catch and release of popular angling species from Queensland waters in the years 1997, 1999, 2002 and 2005. We looked at the discard rate of four individual species; red emperor (*Lutjanus sebae*), grass emperor (*Lethrinus laticaudis*), spangled emperor (*Lethrinus nebulosus*), redthroat emperor (*Lethrinus miniatus*), and two species groups: coral trout (*Plectropomus* spp. and *Variola* spp.), and nannygai (crimson snapper/saddletail snapper, *Lutjanus erythropterus* and *Lutjanus malabaricus*). We used general linear modelling to examine the influence of year, region, season and the two–way interaction of year by region on discard rates for each species. Year, region, season and year by region were significant factors influencing discard rates of red emperor. Year and year by region were significant factors influencing discard rates of coral trout, redthroat emperor and grass emperor. There were no significant factors influencing discard rates of spangled emperor, crimson snapper, or saddletail snapper, although the discard rates of the last two species were significantly different. The dominant reason for discarding was undersize/oversize for all species in all years. The impact of this information on future fishery management requirements is discussed.

6.2 INTRODUCTION

Discarding is a common practice in many fisheries worldwide (Alverson and Hughes 1996). There are many reasons given to justify the practice of discarding. In commercial fisheries these may be size limits, quota and market forces. Discarding in recreational fisheries may be due to similar factors such as size limits and bag limits; however there are also social motivations that may be significant factors influencing the choice to discard by this sector. These include an ethos of ‘catch and release’, targeting based on perceived palatability, and self-imposed catch limits. Recreational fishers also tend to travel shorter distances on fishing trips, potentially targeting different portions of target fish populations. These behavioural factors add complexity in the likely harvest and discard patterns in the recreational sector.

Historically, discard rates have not been quantified, particularly in line fisheries, and it is only in recent years that concerted efforts been made to estimate the level of discarding in Australian fisheries (e.g., Kennelly and Gray, 2000; McLeay *et al*., 2002; Gray *et al*., 2004; Welch *et al*., 2008). Discards represent potential wastage if post–release mortality rates are high. Myers *et al*. (1997) indicated that changes in the rates of discarding, exacerbated by misreporting and high discard mortality, were major driving factors in the collapses of six Canadian stocks of Atlantic cod (*Gadus morhua*). Stock assessments have often neglected to account for discarding (Chopin *et al*., 1996; Borges *et al*., 2005). Myers *et al*. (1997) stated that there was a great need to quantify rates of discarding in order to estimate the total effects of fishing on a stock. In order to achieve this it is important to provide robust estimates of discard rates that can be applied to estimates of total catch and discard mortality rates to derive stock harvest rates. In recent years, data on discards have become more widely available (e.g., ICES, 2006; Punt *et al*., 2006) and several recent studies in Australia investigated the different aspects associated with discarding including discard rates, discard mortality, estimating quantities of fish that are discarded and the effects management changes can have on discarding (Kaimmer and Trumble 1996, Malchoff and Heins, 1997, Ayvazian *et al*. 2002, Millard *et al*. 2003, Butcher *et al*. 2006, Welch *et al*. 2008).

The recreational line fishery on the east coast of Queensland, Australia, is valued at more than \$130 million per annum (BRS, 2003). It is dominated in area by the extensive Great Barrier Reef (GBR) which alone exceeds 360,000 km^2 in area (Mapstone *et al*., 1996; Williams, 2002). It is the largest coral reef fishery in Australia in terms of extent, participation, harvest and value. South of the GBR lies the sub-tropical region of Queensland which is adjacent to the state's capital and the highest density of population.

Across the state, the line fishery is multi-sectoral with commercial, charter and recreational fishers, and multi-species, with over 125 species harvested. Historically the commercial sector harvested between 3000-4000 t and the charter sector land ~300 t (Mapstone *et al*., 1996, 1997, 2004; Begg *et al*., 2005). Common coral trout (*Plectropomus leopardus*) and redthroat emperor (*Lethrinus miniatus*) are the main target species of the fishery for all sectors in most regions, comprising around 50% and 20% of the total catch respectively (Higgs 1999, 2001; Mapstone *et al*. 1996, 1997, 2004). Recent estimates indicate that the recreational fishers in Queensland harvest approximately 2,600 tonnes of coral reef fish per annum (Higgs *et al*. 2007). However, this figure does not include the large numbers of fish that are returned to the sea due to Minimum Legal Size (MLS) restrictions, catch limits and the practice of catch-and-release fishing. Higgs (1999, 2001) estimated the average discard rate of all fish caught by recreational anglers in Queensland in the late 1990s to be of the order of 50%. However in 2003 changes were introduced in the management of line caught reef species, including changes in MLS limits (Anon. 2003). These changes and the increasing popularity of catch-and-release fishing are likely to result in changes in angler behaviour and increase the rate of discarding.

In this study we estimate historical discard rates from the recreational sector of the Queensland east coast line fishery for the major species of the broader study. We define discard rate as the proportion of the total catch (harvest + discards) that is discarded. We estimate variation in discard rates spatially (among regions) and temporally (among years and seasons). We also examine the data among years to see if we can detect changes in discarding that may be attributable to increases in MLS limits as examples of unintended impacts of changed management.

6.3 MATERIALS AND METHODS

The species examined in this study included some of the major coral reef species targeted in recreational fishery on the east coast of Queensland. These species were:

1) Coral trout (CT, *Plectropomus* spp.),
2) Redthroat emperor (RTE, *Lethrinus miniatus*),
3) Spangled emperor (SPE, *Lethrinus nebulosus*),
4) Grass emperor (GRE, *Lethrinus laticaudus*),
5) Red emperor (REM, *Lutjanus sebae*),
6) Saddletail snapper, (STS, *Lutjanus malabaricus*)
7) Crimson snapper (CRS, *Lutjanus erythropterus*).

Discard rate (D) was defined according to Alverson *et al*. (1994):

$$D = \frac{d}{d + k} \qquad (1)$$

where d is the number of fish that are discarded (caught and not kept) and k is the number of fish kept (caught and retained). Discard rate estimates were derived directly from data recorded in recreational fishing diaries and were based on numbers only as weight was not reported. We estimated discard rates for each of the six spatially contiguous regions defined by Mapstone *et al*. (1996), with an additional region to represent the southeast region of Queensland (Fig. 6.1).

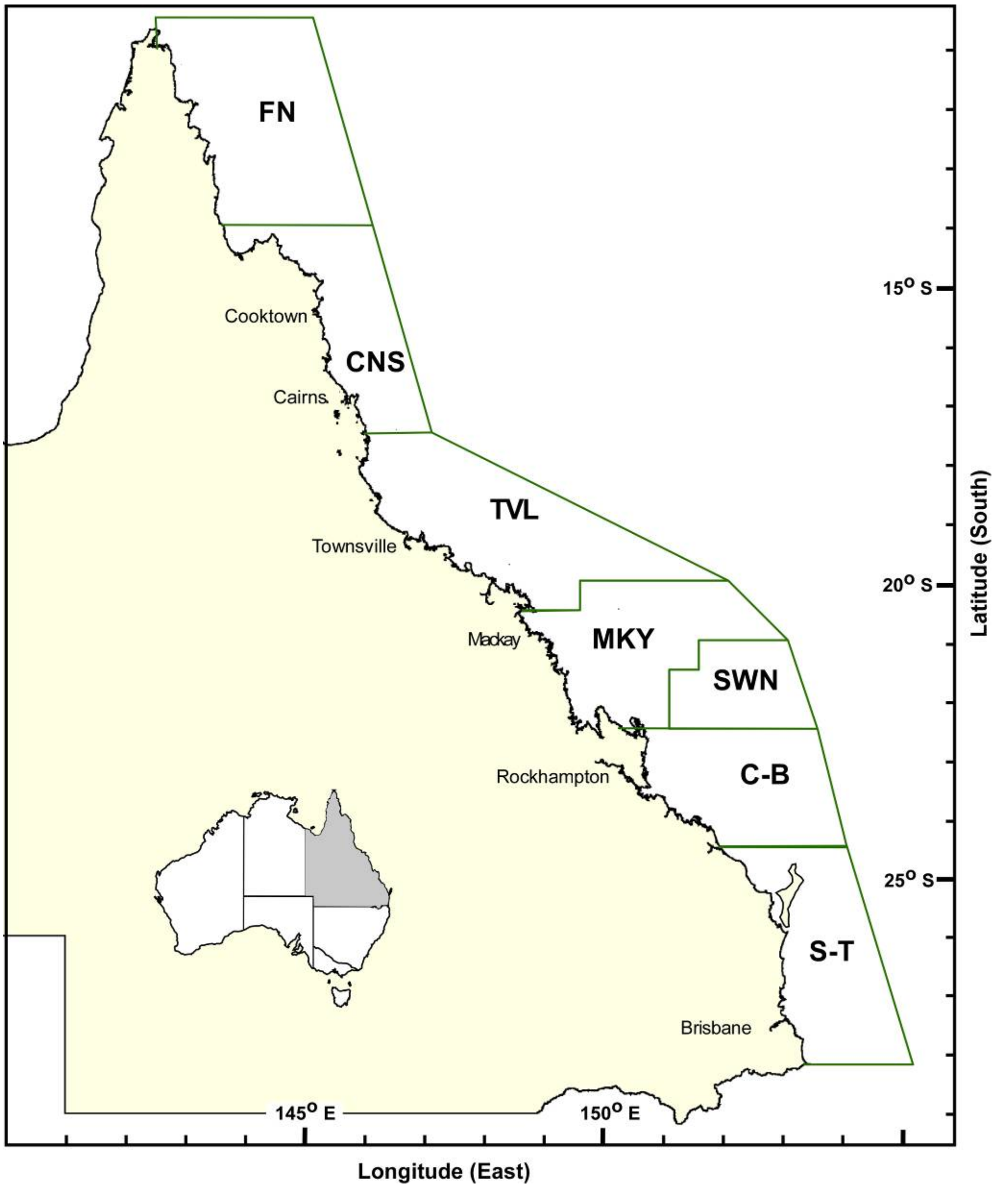

Figure 6-1. Fishery regions used in analysis of discard rates for the recreational line fishery of the Queensland east coast, Australia (derived from Mapstone *et al*. 1996).

6.3.1 Recreational fisheries survey data

Recreational fishing data were available through Queensland's Department of Primary Industries and Fisheries RFISH Program. These data were collected by anglers recording catch details through a voluntary state-wide diary program conducted for the years 1997, 1999, 2002 and 2005 (Table 6-1). The data used in our analyses were inclusive of reef and inshore areas due to the spatial distribution of effort for the recreational sector primarily focused on the more accessible inshore areas. These key species are also caught south of the GBR in variable numbers depending on species ranges.

Table 6-1. Number of diarists participating in the state-wide recreational fisher diary program with recorded catches of any of the six key species.

Year	Number of diarists
1997	348
1999	371
2002	413
2005	469

Diarists were asked to record data on the date and location of fishing, numbers caught and discarded per species, as well as the reason for discarding. Across the four discrete yearly datasets a total of 9109 coral trout, 4648 redthroat emperor, 892 spangled emperor, 6899 grass emperor, 4848 red emperor, 1380 saddletail snapper, and 1041 crimson snapper were recorded as captured (Table 6-2). Due to morphological similarities between saddletail snapper and crimson snapper, particularly amongst small individuals, these species were often identified as a single group (‘reds’). There were a total of 1849 ‘reds’ recorded over the four years (Table 6-2).

6.3.2 Charter vessel fishing data

Charter fishing vessels also target reef line species and report catch and effort through QDPI&F logbooks. These logbooks were voluntary from 1988 and only became compulsory in 1996. Year, season, location, catch and effort data is recorded as well information on discarding. However, it was not possible to discriminate between records in the database where fishers failed to report discards or where fishers simply did not discard any fish from their catch. We therefore decided that the data were not suitable to provide reliable discard rate estimates for the charter sector.

6.3.3 Data analysis

We examined the RFISH discard data using Generalised Linear Models (GLM) assuming a binomial distribution and a using a logit link function (Mayer *et al*. 2004). Discard rate was used as the response variate in all of the analyses. For each species the factors for the models were Region (FN, CNS, TVL, MKY, SWN, C-B, S-T; Figure 6-1), Year (1997, 1999, 2002, and 2005) and Season (summer, autumn, winter, spring). To compensate for regions where data were few and considered unlikely to provide reliable estimates of discard rates, for individual species data were pooled across some regions for the final analyses. The criterion used was that each region would contain a minimum of 20 data points (fish caught). Data were pooled across regions, years or seasons that did not differ significantly to derive the most synoptic estimate of discard rate(s) possible. The conventional significance criterion $P \leq 0.05$ was used for all tests.

Since post-release mortality estimates derived for CRS and STS were found to be very different, (see Chapter 2) we compared estimates of discard rates between these two species. This would determine whether it would be valid to use the category recorded in the diaries as Reds, to derive estimates of discard rates. If estimates for CRS and STS were found to be similar then pooling across the three groups (CRS, STS, and Reds) would give a more robust data set for the main analyses. To test this, the CRS and STS species catch and discard data were combined in the one analysis with the added factor of Species.

6.3.4 Effects of legal size limit changes

In December 2003 changes to the legal size limits (LSL) were implemented for a number of the species in this study (Coral Reef Finfish Fishery Management Plan 2003) (Table 6-3). It was assumed that discard rates would increase with an increase in legal size limits and we were able to assess this by comparing discard rates between 2002 (prior) and 2005 (after). We expected that if there was an effect of this change on discarding then this would be manifest in a significant Year effect in the analyses that would be due to an increase in discard rate in 2005 from all other years. Although changes were made to the MLS for the blue spot coral trout (*P. laevis*) we were unable to discriminate between the various coral trout species from diary entries. This species is however very uncommon in inshore regions of the east coast, and is considered to represent only a very minor proportion of the total recreational coral trout catch.

Table 6-2. Numbers of fish (total catch) used in the estimation of discard rates for statistical analyses of the RFISH data and their respective regions and for each species. Some regions were combined for individual species analysis as indicated in the text.

Region	Year	Species							
		CT	RTE	SPE	GRE	REM	STS	CRS	'Reds'
FN	1997	26	1	9	8	5	0	0	0
	1999	18	0	1	1	4	0	0	0
	2002	3	0	0	0	0	0	0	0
	2005	25	0	1	0	0	0	0	0
CNS	1997	345	145	52	6	38	15	5	57
	1999	365	54	43	37	27	35	25	83
	2002	543	39	19	43	52	62	14	81
	2005	301	62	92	81	86	71	59	14
TVL	1997	1445	729	64	429	140	227	154	206
	1999	1108	389	137	474	206	36	75	564
	2002	1084	193	76	144	152	99	189	270
	2005	803	138	98	565	223	445	374	259
MKY	1997	284	141	12	316	117	1	22	43
	1999	123	67	7	211	61	11	0	56
	2002	464	132	23	134	198	114	10	78
	2005	504	136	14	832	248	36	35	10
SWN	1997	150	30	10	28	41	0	0	0
	1999	164	101	4	40	73	0	0	13
	2002	130	95	2	19	18	2	0	0
	2005	20	17	0	6	0	0	0	0
C-B	1997	82	103	5	87	50	0	0	0
	1999	161	206	26	116	211	1	0	3
	2002	212	826	20	454	411	36	1	3
	2005	316	474	31	393	440	96	16	19
S-T	1997	43	98	13	335	371	0	20	4
	1999	114	196	52	424	376	0	0	10
	2002	44	97	22	481	538	4	12	1
	2005	62	85	37	1014	682	33	13	5

Table 6-3 Changes to the legal size limits introduced in December 2003 for key species examined in this study.

Species	Previous minimum legal size limit (cm)	New legal size limits (cm)
Bluespot/footballer coral trout	38	50 (min), 80 (max)
Red-throat emperor	35	38 (min.)
Spangled emperor	40	45 (min.)
Red emperor	45	55 (min.)

6.4 RESULTS

6.4.1 Patterns in discarding

The summary of GLM results are given in Table 6-4 indicating the factors that were statistically significant for all of the species examined. For the GLM models for individual species, the data from some regions were pooled to ensure adequate numbers of fish for reliable discard rate estimation. These are indicated separately for each species below. Final estimates of discard rates by year for each species are provided in Table 6-5.

Table 6-4. Summary results of analyses of discard rates estimated from the RFISH data set. CT: coral trout all species, RTE: redthroat emperor, SPE: spangled emperor, GRE: grass emperor, REM: red emperor, CRS: crimson snapper, STS: saddletail snapper. Significant at 0.05 level (*); not significant (ns); factor not included in analysis (-).

Factor	Species					
	CT	RTE	SPE	GRE	REM	CRS/STS
Species	–	–	–	–	–	*
Region#	*	*	ns	*	*	–
Year	ns	ns	ns	ns	*	ns
Season	ns	ns	ns	ns	*	ns
Region x Year	*	*	ns	*	*	–

Groupings of individual regions per species as indicated in the text.

Table 6-5. Predicted discard rates (as a proportion of total catch) for each of the six key species by year. Data are predicted from the RFISH data set. CT: coral trout all species, RTE: redthroat emperor, SPE: spangled emperor, GRE: grass emperor, REM: red emperor, CRS: crimson snapper, STS: saddletail snapper.

Species	1997	1999	2002	2005
CT	0.47 ± 0.02	0.44 ± 0.02	0.46 ± 0.01	0.49 ± 0.02
RTE	0.38 ± 0.06	0.32 ± 0.03	0.51 ± 0.03	0.52 ± 0.03
SPE	0.38 ± 0.06	0.32 ± 0.05	0.51 ± 0.07	0.42 ± 0.05
GRE	0.63 ± 0.02	0.57 ± 0.05	0.51 ± 0.07	0.42 ± 0.05
REM	0.66 ± 0.03	0.70 ± 0.02	0.71 ± 0.02	0.83 ± 0.01
CRS	0.46 ± 0.10	0.57 ± 0.12	0.68 ± 0.07	0.69 ± 0.04
STS	0.63 ± 0.06	0.42 ± 0.11	0.33 ± 0.05	0.55 ± 0.04

6.4.2 Coral trout

For coral trout the two northern regions were grouped for the analysis (FN and CNS) giving six separate regions. Neither Year nor Season had a significant effect on coral trout discard rates. However Region (P < 0.001) and the interaction of Region and Year (P < 0.001) were important factors in the model. Discard rates among the different regions ranged from 0.28–0.50 (Figure 6-2) and the significant effect was due to a discard rate in the C–B region that was lower than all other regions (Figure 6-2, pairwise t-test, p<0.05).

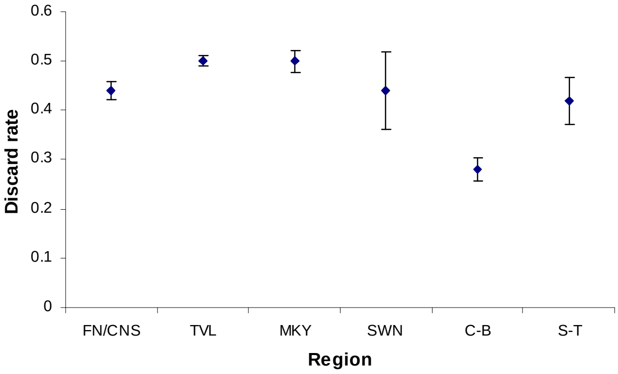

Figure 6-2. Geographic trends in adjusted discard rates (± s.e.) for coral trout across regions. Data for FN and CNS were pooled for due to low numbers.

This was not consistent across years in the C–B region (range: 0.14–0.43), which is likely to explain the significant interaction term. Discard rates were highest in the C–B zone in 1999 (0.43 ± 0.05) than in other years although there was a significant increase from 2002 to 2005 (0.17 ± 0.04 and 0.40 ± 0.04 respectively; pairwise t-test, p < 0.05) (Figure 6-3). Increases between 2002 and 2005 were also observed in FNQ/CNS, and TVL, but these were not significant and discard rates were relatively consistent among years in other regions (Range: 0.32–0.57).

6.4.3 Redthroat emperor

The four regions used for the analysis of redthroat emperor were FN/CNS/TVL, MKY/SWN, C–B and S–T. The significant model terms were Region (P = 0.039) and the interaction Region·Year (P = 0.002). Discard rates were highly variable among years for each region (Ranges: FN/CNS/TVL: 0.38–0.56; MKY/SWN: 0.38–0.68; C-B: 0.50–0.57; S-T: 0.45–0.58), with a significant increase in discard rate from 2002 to 2005 in the combined MKY/SWN region. In all other regions there was no significant difference indicating that any effect on discard rates from the increase in the MLS was negligible outside the MKY/SWN region.

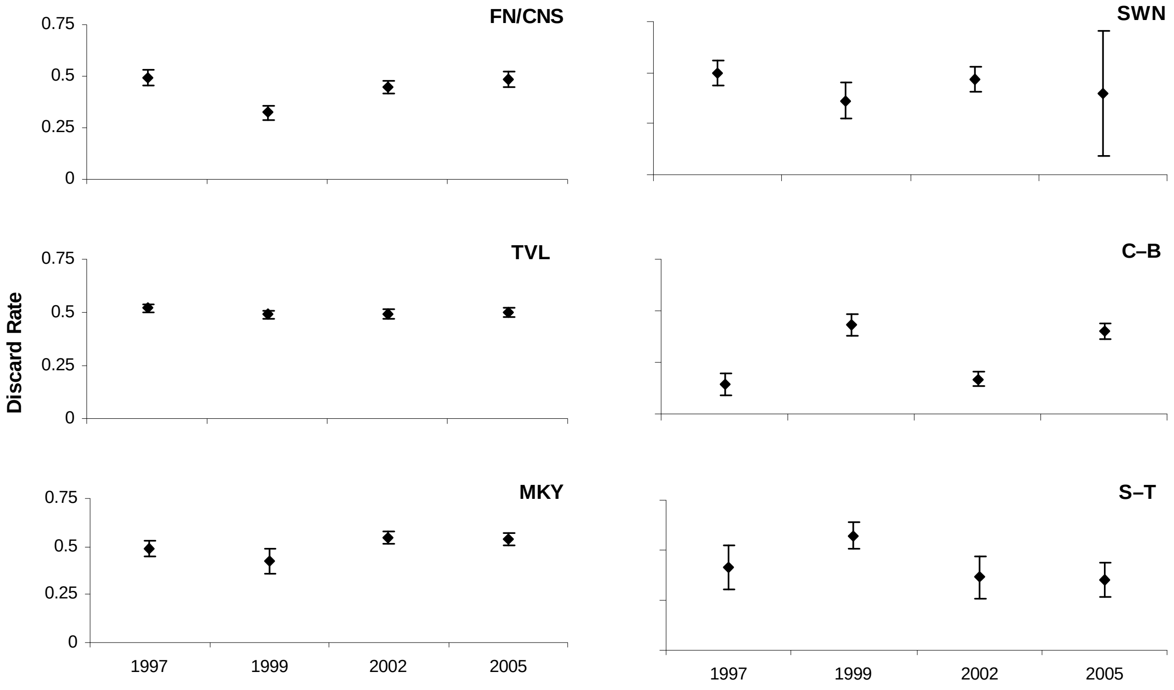

Figure 6-3. Discard rate estimates (± s.e.) for coral trout across regions by year, with FN and CNS pooled for analysis due to low numbers in FN.

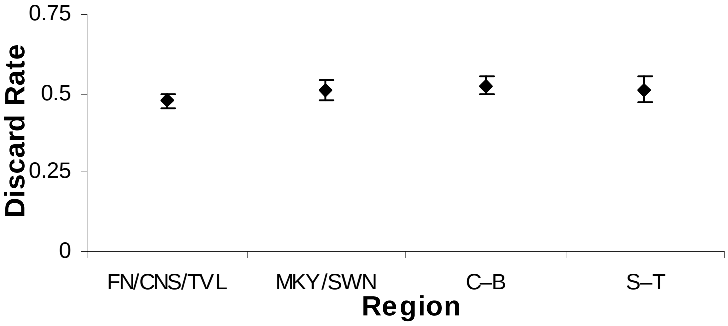

Figure 6-4. Discard rate estimates (± s.e.) for redthroat emperor across regions, with the regions FN/CNS/TVL, MKY/SWN, C-B and S-T.

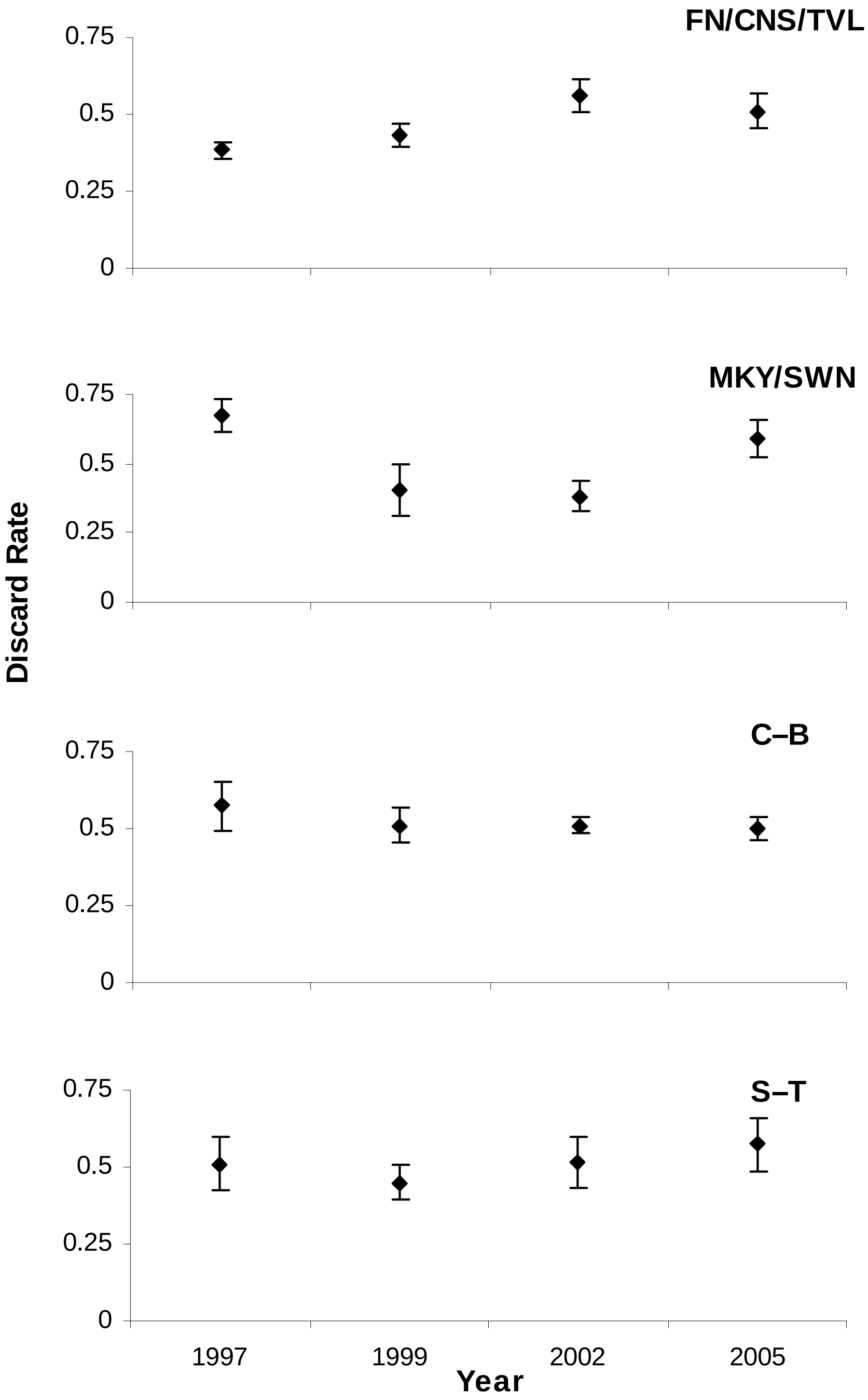

Figure 6-5. Discard rate estimates (± s.e.) for redthroat emperor across regions by year, with the regions FN/CNS/TVL, MKY/SWN, C-B and S-T.

6.4.4 Spangled emperor

Three regional groupings were used in the spangled emperor analyses: FN/CNS, TVL and MKY/SWN/C-B/S-T. No model terms were significant in the analysis, although there was a weak effect of Year (P = 0.073) due to differences between 1999 and 2002. The non–significant result was primarily attributed to the low overall catch reported for this species (n = 870 across all four years). An overall discard rate for SPE (0.39 ± 0.03) was derived by pooling all data across all strata and running the predict function in the GLM. The lack of any Year effect, combined with random changes in discard rates across some years but not others, and a decrease in the TVL zone (2002 to 2005), indicates that the increase in minimum legal size regulations had no major impact on spangled emperor discarding rates.

6.4.5 Grass emperor

Four regions were used in the analysis of grass emperor discarding rates: FN/CNS/TVL, MKY/SWN, C–B and S–T. The significant terms from the GLM were Region (P < 0.001) and the interaction term Region·Year (P = 0.002). Discard rates among the four regions ranged from 0.50 to 0.74 (Figure 6-6), a pairwise t-test indicating that the significant effect was due to higher discard rates in the S-T region than elsewhere (P < 0.001). C–B was also significantly different from the combined northern zones, FN/CNS/TVL (pairwise t-test, P = 0.023). Regional discard rate estimates among years were highly variable, except for the S-T region (ranges: FN/CNS/TVL: 0.45–0.64; MKY/SWN: 0.43–0.62; C-B: 0.35–0.74; S-T: 0.72–0.75). The S-T region had the highest discard rates across all years.

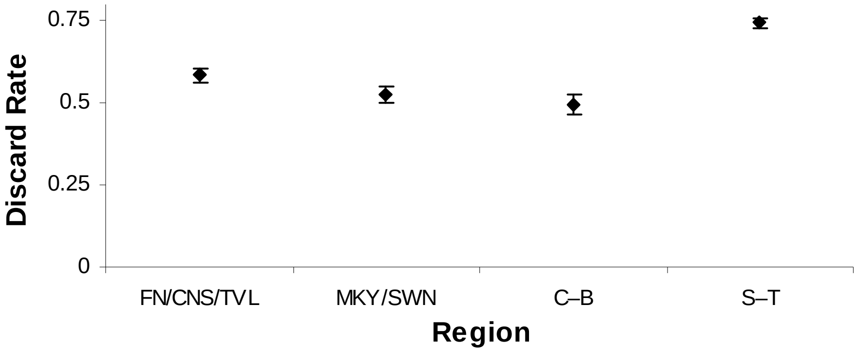

Figure 6-6. Discard rate estimates (± s.e.) for grass emperor across regions FN/CNS/TVL, MKY/SWN, C-B and S-T.

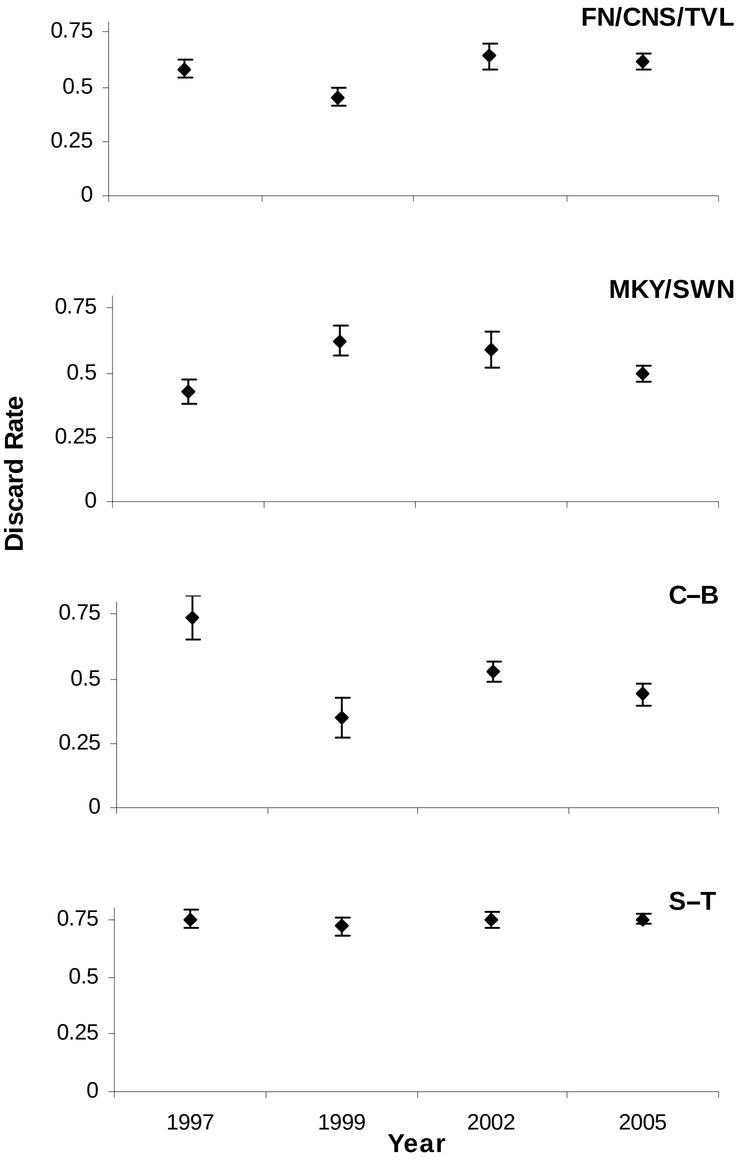

Figure 6-7. Discard rate estimates (± s.e.) for grass emperor by region and year.

6.4.6 Red emperor

Five regions were used in the analysis of red emperor discarding rates: FN/CNS, TVL, MKY/SWN, C-B and S-T. All model terms were significant: Region ($P < 0.001$), Year ($P < 0.001$), Season ($P = 0.027$) and the interaction term Region by Year ($P = 0.016$). Among the five regions examined, discard rate estimates ranged from 0.55–0.84 (Figure 6-8). The pattern was one of increasing discard rates from north to south with the S-T having the highest. The discard rate in the S-T region was higher than all other regions (pairwise t–test, $P < 0.05$).

There was a significantly higher discard rate in summer compared to the preceding seasons, winter and spring (pairwise t test, $P < 0.05$) (Figure 6-9). The significant interaction term was partly influenced by the variable discard rates within regions among the years 1997 – 2002, but mostly by the consistent pattern of an increase in the discard rate estimate between 2002 and 2005 for all regions except TVL (pairwise t-tests, $P < 0.05$ in all regions except TVL where $P > 0.05$).

We consider this to be strong evidence of a direct effect of the increase in the minimum legal size of red emperor. This is also indicated by the significant Year effect in the model which was due to a higher discard rate in 2005 (Figure 6-8). Overall, the discard rates for REM tended to be higher than for other species.

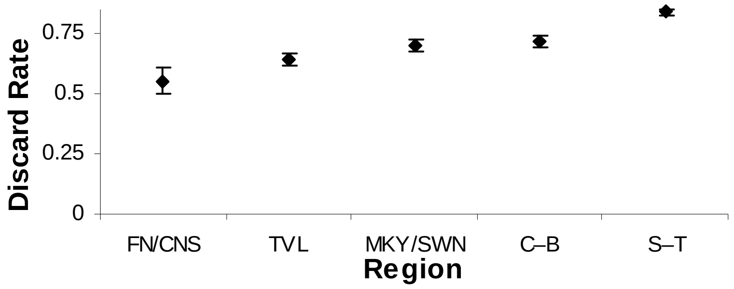

Figure 6-8. Discard rate estimates (± s.e.) for red emperor across regions FN/CNS, TVL, MKY/SWN, C-B and S-T.

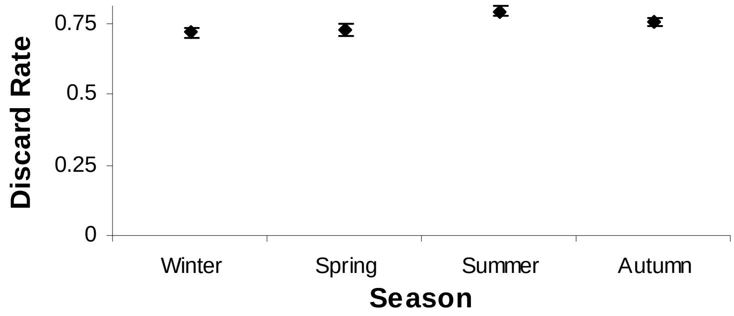

Figure 6-9. Seasonality in adjusted mean discard rates (± s.e.) for red emperor.

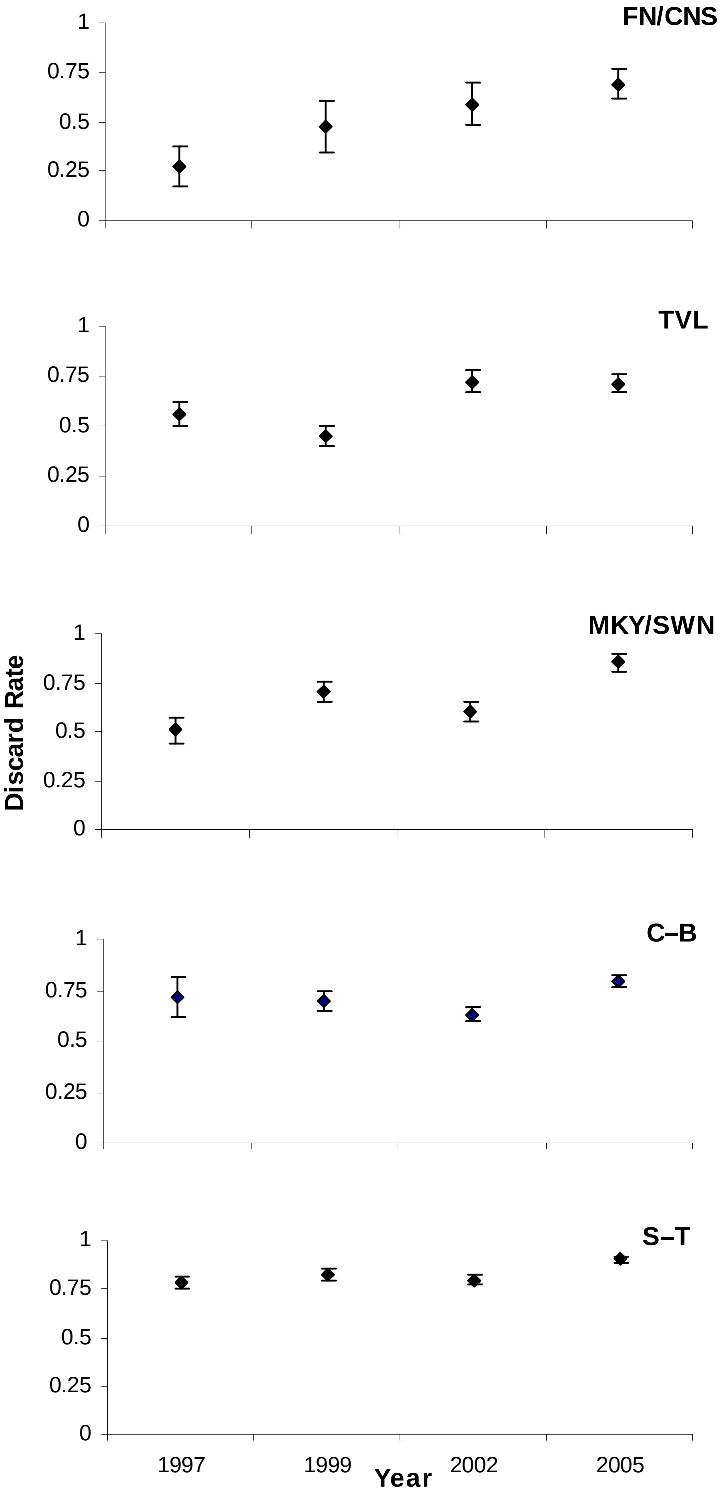

Figure 6-10. Discard rate estimates (± s.e.) for red emperor by region and year.

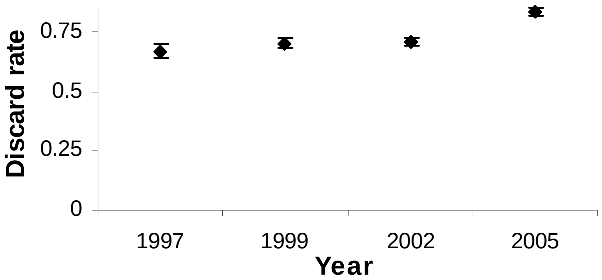

Figure 6-11. Discard rate estimates (± s.e.) for red emperor across years 1997–2005. Note that the MLS was increased in 2003.

6.4.7 Crimson snapper, saddletail snapper and unspecified 'redfish'

A large proportion of the recreational records failed to differentiate between crimson and saddletail snapper, and simply identified them as 'redfish' or 'nannygai'. To explore the statistical validity of pooling all the records (both species with the unspecified), we analysed just the identified species together, excluding 'redfish'. Due to low numbers (Table 6-2) it was necessary to pool the data across regions to compare the discard rates between the two species, which effectively removed Region and the two-way interaction Year·Zone from the model. The GLM was therefore run with the Year, Season and Species as the main effects. Year and Season were both non-significant, but there was a significant difference in discard rates between the two species ($P < 0.001$) with the discard rate estimate for saddletail snapper (0.50 ± 0.029 se) being significantly lower than crimson snapper (0.65 ± 0.033). This meant that we could not combine the two species into one dataset, nor use the category recorded as 'Reds' in the diaries as we have no way of knowing the true species composition.

A follow-up analysis of crimson snapper alone was run, with Year and Season as the main-effect terms. Neither factor was significant, but the overall trend was for a continually increasing discard rate from 1997 to 2005. There was also a trend (albeit non-significant) for higher discarding to occur in spring than winter.

Similarly, the saddletail snapper data were analysed separately, with Region and Region·Year omitted, leaving Year and Season. Only Year was significant ($P = 0.005$), with discard rates falling between 1997 and 2002, followed by a significant increase between 2002 and 2005 (pairwise t test, $P = 0.002$) (Figure 6-12). Contrary to our observations with crimson snapper, the lowest discard rates of saddletail snapper were observed in spring (0.34 ± 0.07; Figure 6-13) and the highest in summer (0.55 ± 0.04).

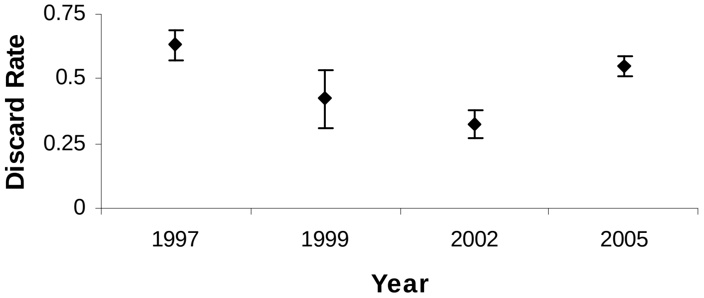

Figure 6-12. Discard rate estimates for saddletail snapper across the years 1997–2005. Standard error bars are given.

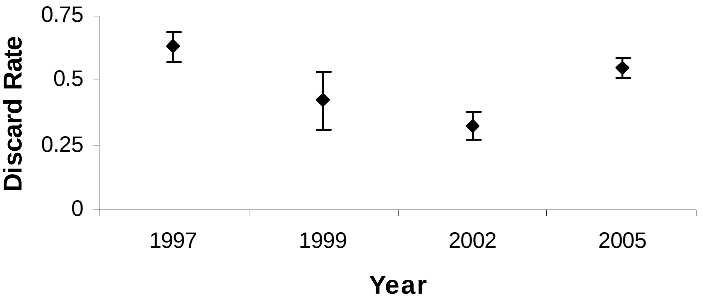

Figure 6-13. Discard rate estimates (± s.e.) for saddletail snapper across the years 1997–2005.

6.4.8 Reasons for discarding

Many reasons were given by diarists as to why they discarded fish. For the species we examined we were able to group these as follows: (i) they had reached their legal bag limit and were required by law to discard (> Bag limit), (ii) the fish were not wanted, perhaps because they had already caught what they thought was enough or they preferred other species (Not wanted), and (iii) the fish was outside of the legal size limits (Under/Over-size). Some of the reasons given were difficult to categorise. For example, we assumed that the response 'Surplus' indicated that the fisher had reached their bag limit. The groupings of reasons into the three categories are given in Appendix 6.1.

The primary reason for discarding for all species was clearly that the fish was under the minimum or over the maximum legal size limit (Table 6-6). Anglers were more likely to discard spangled emperor, saddletail snapper and crimson snapper because they were not wanted, and were more likely to catch their bag limit of redthroat emperor than any of the other species.

Table 6-6. Summary of the reasons for discarding of each species as reported in the RFISH diary program. The percentages shown represent the range among years 1997, 1999, 2002 and 2005.

Species	Over bag limit	Not wanted	Under/over sized	No reason given
Coral trout	1 to 6	0 to 4	91 to 96	0 to 3
Redthroat emperor	0 to 16	0 to 3	79 to 92	0 to 17
Spangled emperor	0 to 7	2 to 21	64 to 96	0 to 10
Grass emperor	0 to 6	1 to 9	88 to 98	0 to 4
Red emperor	1 to 2	0 to 3	93 to 98	0 to 4
Saddletail snapper	0 to 5	0 to 11	88 to 100	0 to 6
Crimson snapper	0 to 2	0 to 14	84 to 100	0 to 1

6.5 DISCUSSION

The RFISH database – resulting from four extensive diary surveys in 1997, 1999, 2002 and 2005 – contains much information on recreational fishing habits. These surveys were discrete, with variable sample sizes. Thus while they provide an excellent resource for temporal analysis of recreational fishing habits, extrapolating the data further to analyse discard rates of individual fish species has proved challenging.

We examined the database for catch and discard information on six individual species and two species groups (trout and redfish). The data required further processing to analyse temporal, seasonal and spatial trends. For example, effort was recorded as a total per trip with no subdivision where a fisher may have caught several different species during the fishing trip. Thus while the interpretation of trends in overall discard rate can be considered as robust, interpreting trends for individual species from this data has required some effort standardization. In particular, some fishers would catch several different species during a single fishing trip. It is unclear whether the total effort assigned by the fisher refers to the time spent catching the individual fish, or the total catch. As there is no way of differentiating this effort, we have assumed that each record relates to one species only. This assumption could lead to an overestimation of discard rates and underestimation of catch rates.

6.5.1 Coral trout

Although the most popular target species, coral trout catch and discard data in the far north and Cairns regions were combined for the analysis. This reflects the comparatively low level of recreational fishing effort and diary participation in these areas, rather than low coral trout population sizes. Coral trout discard rates have remained relatively stable across all four years so it is not surprising that year was not a significant factor on discard rates. The changes in MLS regulations, effected in 2003, relate to footballer and bluespot trout only. These two colour forms of the same species (*Plectropomus laevis*) represent only a small proportion of the total trout catch, thus it was expected that the change in MLS regulations in 2003 would not lead to a significant annual change in discard rates between 2002 and 2005. However, there was a significant increase in discard rate in the Capricorn–Bunker region between 2002 and 2005. We suspect that this relates to the change in social interpretation of the new regulations as common names for *P. laevis* only occur in the RFISH database after 2002 and were not analysed separately from all coral trout.

Region was a significant factor influencing discard rates with the Capricorn–Bunker region having a significantly lower discard rate than all other regions. This is difficult to explain. There is evidence that coral trout from the Capricorn–Bunker region were generally larger than those from the Swains, Innisfail, or Cairns regions (Brown *et al.* 1994). However, the sample size from the Capricorn–Bunker region in this study was significantly larger than all other regions. The largest catches of coral trout in the RFISH database come from the Townsville region, but the discard rates, while high, were similar to the adjacent regions of the Swains, Mackay and Far North/Cairns. Catches in the Swains region were relatively low compared to all other regions, but the discard rate was significantly higher than the adjacent Capricorn–Bunker region. The RFISH data supports the observations of Brown *et al.* (1994) that the Capricorn–Bunker region supports more larger coral trout than other regions of the GBR.

Season did not have a significant effect on discard rate. While coral trout have a relatively short spawning season of late spring to early summer along the GBR (Brown *et al.* 1994), there is evidence of multiple cohorts in some years and single cohorts in others suggesting the potential for decoupling of spawning and recruitment. This would support the concept that inter–annual variability in success of recruitment could have a stronger influence on discard rates than seasonal variability.

While there are a variety of reasons given for discarding coral trout, ‘under MLS’ is the dominant reason across all years, although ‘over bag limit’ accounted for approximately 6% of discards in 2005.

6.5.2 Redthroat emperor

The discard rate of redthroat emperor was the most variable of all species investigated in this study. It declined between 1997 and 1999, but increased in both in 2002 and 2005. However, year was not a significant factor influencing discard rate as individual years did not differ significantly from their adjacent year. However, the interaction of year by region was a significant factor, primarily driven by the differences in the combined northern three regions compared to the other more southerly regions. Although the MLS of redthroat emperor changed from 35 to 38 cm (FL) in 2003, there was no significant increase in discard rate between 2002 and 2005 for any region except the MKY/SWN. This lack of change in discard rate is possibly due to the significant decline in landings of redthroat by diarists between 2002 and 2005 in the Townsville and Capricorn–Bunker region. Declines also occurred in the Swains, and Sub–tropical regions, but these were slight. Historical evidence suggests a much higher fishing mortality from the Capricorn–Bunker region than the Swains (Brown and Sumpton 1998).

Redthroat catches were negligible in the Far North, and low in the Cairns and Swains regions. Some data aggregation was necessary to achieve a robust analysis and has resulted in a significant influence of region on discard rate. The trend was for an increase in discard rate from north to south, with the Subtropical region being slightly lower than the Capricorn–Bunker region. The significance of region is supported by the findings of Brown *et al.* (1994) of a larger proportion of redthroat emperor below MLS in the Capricorn–Bunker region than the Swains, Townsville or Cairns regions.

Below MLS was the dominant reason given for discarding of redthroat emperor by diarists across all years. However, reaching bag limits accounted for 16% of discards in 1997 and 10 % in 2005. Redthroat emperor are known to be a schooling species (Starling 1986). Brown and Sumpton (1998) suggested that some fishers were actively targeting known areas of larger fish, thus it is more likely that fishers would ‘bag out’ on legal sized redthroat emperor than for other more solitary species such as coral trout.

6.5.3 Spangled emperor

Spangled emperor had one of the lowest discard rates across all years of any species investigated in this study, comparable to redthroat emperor. There were no significant factors influencing discard rate. We think this result was affected by the low catch rates across all regions and all years. We did aggregate some regions prior to the analysis, but this did not influence the result. Spangled emperor are patchy in their distribution, often inhabiting shallow lagoon habitats, or spur and groove habitats on the weather side of reefs. These are areas not regularly targeted by recreational fishers. Spangled emperor are not as highly prized as other Lethrinid species (Starling 1986) because of a poor percentage fillet recovery (Grant 1985), and thus not actively targeted by the majority of recreational fishers. There does not appear to be any evidence that the change in MLS in 2003 has had any influence on the discard rates of spangled emperor in any region.

As with most other fish in this study, ‘undersize’ was the primary reason given for discarding spangled emperor, although ‘not wanted’ did account for up to 19 percent of discarding in some years. This was the highest proportion for any species in any year in the ‘not wanted’ category, reinforcing the belief of Starling (1986) that spangled emperor are not as prized as other reef species.

6.5.4 Grass Emperor

Grass emperor are a popular angling species along the entire Queensland coast, particularly in the southern region, but also in the Townsville and Mackay regions. It is a schooling species with smaller fish taken over inshore seagrass habitat while larger adults are commonly taken over reefs (Grant 1985). It is very similar in appearance to several other lethrinids such as *L. fraenatus* and *L. fletus* (Carpenter and Allen 1989) and there is some taxonomic confusion amongst recreational anglers between these and other species such as lancer fish (*L. genivittatus*) and the variegated emperor (*L. variegatus*). While there was no significant change in the annual discard rate between 1997 and 2005, there was a significant interaction between year and region. Discard rates differed markedly in the subtropical region, remaining relatively consistent across all years, compared to the variable discard rate in all other regions. Catches were highest in the Townsville and Subtropical regions and the aggregation of data into four regions strengthened the model's predictive capability. From a regional perspective, discard rates declined from north to south with the exception of a significantly higher discard rate in the subtropical region which also had the highest catch rate. We suspect this was due to a larger proportion of the subtropical catch being smaller fish from the inshore sea grass beds around Hervey and Tin Can Bay regions as these are known hotspots for grass emperor amongst the recreational sector (Grant 1985).

The primary reason given for discarding of grass emperor, consistently across all years and all regions, was that they were below the current MLS of 25 cm. Carpenter and Allen (1989) report a higher proportion of smaller female fish in landings from the eastern Australian coast, which would support the hypothesis that grass emperor are primarily taken by the recreational sector from inshore habitats where the smaller fish are more prevalent.

6.5.5 Red emperor

Although not the most popular by catch, red emperor are probably the most widely distributed recreational target fish along the east coast of Queensland, being especially prevalent in the southern regions, close to the largest areas of human population. Consequently, it is not surprising that the discard rates were significantly different between year, region, season and region by year. Generally, they had the highest annual discard rate across all regions of any fish investigated in this study.

The increase in discarding rates from north to south reflects the geographical importance of this species to anglers. They are much more esteemed as a target species in the south where there are fewer coral reef species to target. Annual discard rates have increased steadily between 1997 and 2005 with a significant increase between 2003 and 2005. This reflects the social impacts of the changes in MLS regulations from 45 to 55 cm. Discard rates increased in all regions between 2003 and 2005 with the exception of the Townsville region where it remained static. It is difficult to understand why the Townsville region is different from the other regions, as catches indicate it to be an area of intermediate catch rates. Grant (1985) reports red emperor to be a schooling species, aggregating in similar size shoals. He attributed this behaviour to the reason some reefs are known haunts of small fish, while other reefs were favoured by larger fish. An alternative hypothesis is that there is a greater abundance of juveniles in the southern waters (Sumpton, *pers. com.*).

Discard rates were higher in summer than all other seasons. Red emperor are known to have an extended spawning season (McPherson and Squire 1992a) with a peak in late spring and early summer in the Cairns region. This would be expected to be marginally later in lower latitudes. Red emperor are reported to be sexually mature as small as 48.5 cm (FL), or three to four years of age (McPherson and Squire 1992a, 1992b). Given the time lag between spawning and attaining MLS (three years pre 2003 and 4 years post 2003), it is highly likely that the significant seasonal influence on discard rates may reflect anthropogenic impacts of seasonal changes in effort by the recreational sector rather than a time-lag in recruitment patterns into the fishery.

The dominant reason for discarding red emperor across all years was because they were below the MLS. In 2003 the MLS was increased from 45 to 55 cm and there has been a significant increase in discarding between 2003 and 2005, associated with the change in regulations.

6.5.6 Crimson snapper/saddletail snapper

Amongst the recreational sector, the nannygai represent a taxonomic anomaly. Crimson snapper and saddletail snapper are both schooling species and are known to aggregate in the same schools (Allen 1985). The taxonomy, especially of juveniles, is quite challenging and they are commonly identified in the RFISH database as ‘nannygai–unspecified’. There are several known hotspot reefs near Townsville where large mixed schools aggregate and catches in excess of 100 fish per fishing session are common (A. Mapleston, *pers. comm.*). In the RFISH database, these two species and their collective category are common in the Townsville region only and all discard analysis was based on the complete data set as one region. Reported catches and discards of these two species are confounded by the large proportion of fish that were unspecified in 1999 and 2002, thus it has been difficult to determine if changes in discard rates are related fishing mortality or taxonomy.

Crimson snapper discard rates increased from 1997 to 2005, but the increase between 2002 and 2005 was negligible. In comparison, saddletail discard rates declined from a high in 1997 to a low in 2002 before increasing significantly in 2005. There is no clear reason for these changes in discard rates, other than perhaps that some fishers frequenting the inshore Townsville reefs are becoming better able to distinguish the two species. However, there is a significant difference in the discard rates between the two species, with crimson snapper being discarded more frequently than saddletail snapper. This is an important point as there is a significant difference in post-release survival between the two species (refer to Ch. 2, Section 2.4 for further discussion on this topic).

The primary reason given for discarding these two species has consistently been that they were undersized. Both species are subject to the same minimum legal size (40 cm), with a combined bag limit of 9 for both species since 1995. In 1997 ‘reaching the bag limit’ accounted for 5% of saddletail snapper discard reports, while in 2005 14% of crimson snapper discards were attributed to the fish ‘not being wanted’. Given their aggregating behaviour, it is clear that the favoured fishing locations in the vicinity of Townsville must support a very high proportion of small fish.

6.5.7 Conclusions

The RFISH database presents a very broad picture of recreational fishing behaviour in Queensland. The survey was never designed for more detailed analysis of recreational fishing behaviour pertaining to individual fish species and any results must be closely scrutinised. The database does, however, give some indication of discarding behaviour over the four discrete annual sampling events.

It would appear that for most of the species investigated, recreational fishing effort is predominantly focused in areas where smaller fish dominate the catch, leading to discard rates in excess of 50%. This has occurred in 16 out of 28 annual estimates of discarding. We conclude that recreational fishers are more likely to be fishing in shallower waters, and probably more likely to be fishing in inshore waters than other sectors of the line fishery.

Changes in MLS regulations introduced in 2003 directly affected four of the species investigated in this study. However, only red emperor data have shown any significant effect with a significant increase in discarding between 2002 and 2005. A significant increase in discarding was also observed in the saddletail snapper data, but this was probably due to improvements in catch identification, rather than changes in recreational sector fishing behaviour.

Season was a non-significant factor on discarding for all species except red emperor. However, it was interesting to note that for crimson snapper, saddletail snapper, spangled emperor and redthroat emperor, summer was the season where discarding appeared to be higher. This needs further investigation as we are not sure if this is an artefact of social fishing effort (summer holidays), or corresponds to the period where a cohort becomes selected for by the gear, yet is still below the MLS.

Humans operate as very effective and highly selective predators in marine systems, and can influence stock resilience by shifting fishing pressure. It is important to understand how this fishing pressure is applied and what its impact on the total stock might be. To determine the effects of fishing on target species, we need to know the total mortality that results from that fishery, and how selective that mortality is on discarded fish. This study has provided four individual snapshots of discard rates for several key species along the east coast of Queensland. The information can be applied to future stock assessments and provide fishery mangers with better information on the impacts of regulatory changes on popular fish stocks.

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6.8 APPENDIX

Bag limit	Not Wanted	Undersize/Oversize
Over Bag Limit	All Good	Undersize
Too Many	Catch & Release	Too Small
	Didn't Need Them	Too Big
	Didn't Want	Too Long
	Don't Like to Eat	
	N/A	
	Not Edible	
	Not Wanted	
	Protected	
	Tagged and Released	
	Unwanted	

CHAPTER 7. SPATIAL AND TEMPORAL VARIATION AND EFFECTS OF CHANGES IN MANAGEMENT IN DISCARD RATES FROM THE COMMERCIAL GBR LINE FISHERY.[3]

D.J. Welch, B.D. Mapstone and G.Begg.

7.1 ABSTRACT

Discarding in commercially exploited fisheries has received considerable attention in the last decade, though only more recently in Australia. The Reef Line fishery (RLF) of the Great Barrier Reef (GBR) in Australia is a large-scale multi-sector, multi-species, highly regulated hook and line fishery with the potential for high levels of discarding. We used a range of data sources to estimate discard rates and discard quantities for the two main target groups of the RLF, the coral trout, *Plectropomus spp*, and the redthroat emperor, *Lethrinus miniatus*, and investigated possible effects on discarding of recent changes in management of the fishery. Fleet-wide estimates of total annual quantities discarded from 1989-2003 were 292–622 t and 33–95 t for coral trout and redthroat emperor, respectively. Hypothetical scenarios of high-grading after the introduction of a total allowable commercial catch for coral trout resulted in increases in discard quantities up to 3895 t, while no high-grading still meant 421 t were discarded. Increasing the minimum size limit of redthroat emperor from 35 to 38 cm also increased discards to an estimated 103 t. We provide spatially and temporally explicit estimates of discarding for the two most important species in the GBR RLF of Australia to demonstrate the importance of accounting for regional variation in quantification of discarding. Effects of management changes on discarding are also highlighted. This study provides a template for exploring discarding levels for other species in the RLF and elsewhere.

7.2 INTRODUCTION

Discards are defined as the portion of a total fishery catch that is returned to the water (Kelleher, 2005). Discarding in commercially exploited fisheries has received considerable attention in the last decade because of the poor state of global fisheries resources and the failure of fisheries management to stem their overexploitation (Kaimer and Trumble, 1998). Only in more recent years, however, have concerted efforts been made to estimate the level of discarding in Australian fisheries (e.g. Kennelly and Gray, 2000; McLeay *et al*., 2002; Gray *et al*., 2004). Stock assessments have often neglected to account for discarding (Chopin *et al*., 1996; Borges *et al*., 2005), though this situation has improved in recent years as data on discards have become more available (e.g. ICES, 2006; Punt *et al*., 2006).

There is an increasing literature on discarding practices and survival of discarded fish (e.g. Kaimer and Trumble, 1998; Machias *et al*., 2001; Gurshin *et al*., 2004; Vander Haegen *et al*., 2004; Revill *et al*., 2005; Sumpton and Jackson, 2005). Most work is based on trawl fisheries, resulting in a common assumption that discarded fish generally suffer high rates of mortality (Chen and Gordon, 1997; Allen *et al*., 2001; Machias *et al*., 2001). There are relatively few reports, however, on discarding or fates of discarded fish in commercial line fisheries (e.g. Trumble *et al*., 2000; Willis and Millar, 2001; Rudershausen *et al*., 2007). Handlining is the dominant fishing method in coral reef finfish fisheries in most tropical countries. Coral reef fisheries are typically multi-species and, where they are regulated by

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size limits, species exclusions or catch quotas, discard rates may be substantially higher than the global average of 2% reported by Kelleher (2005).

The Reef Line fishery (RLF) of the Great Barrier Reef (GBR) in Australia operates over 14° of latitude and an area exceeding 360,000 km^2 (Mapstone *et al*., 1996; Williams, 2002) (Figure 7-1). It is the largest coral reef fishery in Australia in terms of extent, participation, harvest and value, and generates about AU$50–80M of commercial sales each year. The fishery is multi-sector, with commercial, charter and recreational fishers, and multi-species, with over 125 species harvested. Historically the commercial sector harvested between 3000–4000 t, with the recreational and charter sectors landing ~2000 t and ~300 t, respectively (Mapstone *et al*., 1996, 1997, 2004; Begg *et al*., 2005). Common coral trout (*Plectropomus leopardus*) and redthroat emperor (*Lethrinus miniatus*) are the main target species of the fishery for all sectors in most regions, comprising around 50% and 20% of the total catch, respectively (Higgs, 1996; Mapstone *et al*. 1996, 1997, 2004). Commercial operators typically use handlines, fishing from small 'dories' (< 7 m) tendered to larger primary vessels (up to 20 m). Fishing occurs on individual coral reefs usually in less than 20 m depth. Since the mid-1990s, there has been a rapid growth of an export market for live fish, particularly coral trout (*Plectropomus spp*.), to southeast Asia (Mapstone *et al*., 2001; Sadovy *et al*., 2003), although a small number of vessels still kill their catch, particularly redthroat emperor, for local frozen markets (Williams, 2002) (Figure 7-2).

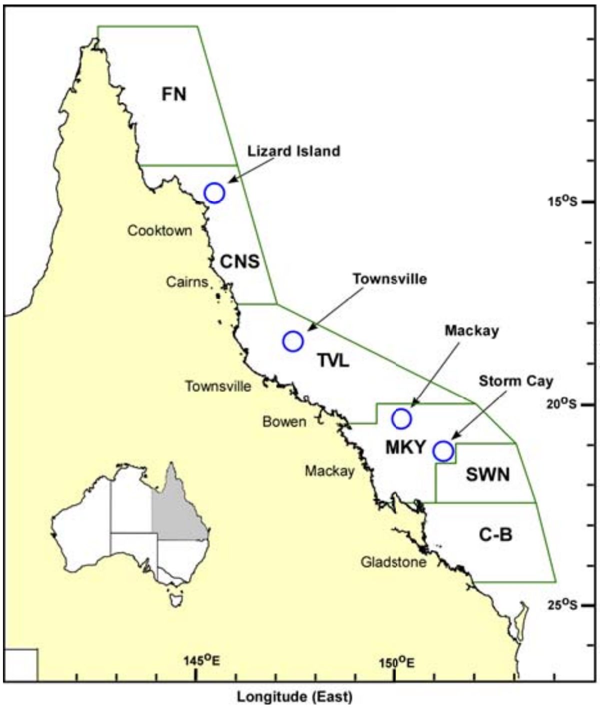

Figure 7-1. Fishery regions used in analysis of discard rates for the commercial sector of the reef line fishery of the GBR (Mapstone *et al*. 1996). Circles show the reef clusters from the Effects of Line Fishing Experiment catch surveys.

Prior to 2004 the commercial sector was regulated mainly by effort controls and the recreational and charter sectors by daily or trip bag limits. Gear regulations and minimum size limits (MSL) for harvest applied to some species for all sectors. Management of the fishery changed substantially in 2003–2004 in several ways, including introduction of a total allowable commercial catch (TACC) allocated as individual transferable quotas (ITQs), new or increased MSLs for many species, and reductions in bag limits for recreational and charter fishers (Coral Reef Fin Fish Fishery Management Plan 2003). These changes are likely to result in changes in discard rates from the commercial sector because of the increased MSL for many species and the requirement to adhere to individual quotas. Different prices for live or frozen product and different sizes or species, also represent incentives for high-grading, with lesser valued fish discarded in preference for higher valued fish within catch quotas. For example, smaller coral trout (< 1.5 kg) are priced at the same rate (e.g., $40–$60) per kg as larger fish (> 1.5 kg) fetch per fish, establishing clear incentive for high-grading (Copes, 1986; Turner, 1997; Dewees, 1998). Similarly, an increase in the MSL for redthroat emperor from 35 to 38 cm will increase the levels of discarding, though high-grading is less likely for redthroat emperor because separate and independent quotas apply for the two species and currently there is no size-related price differential for redthroat emperor. The extent and level of discarding in the RLF have never been estimated and nor has the likelihood of increased discarding under the revised management measures.

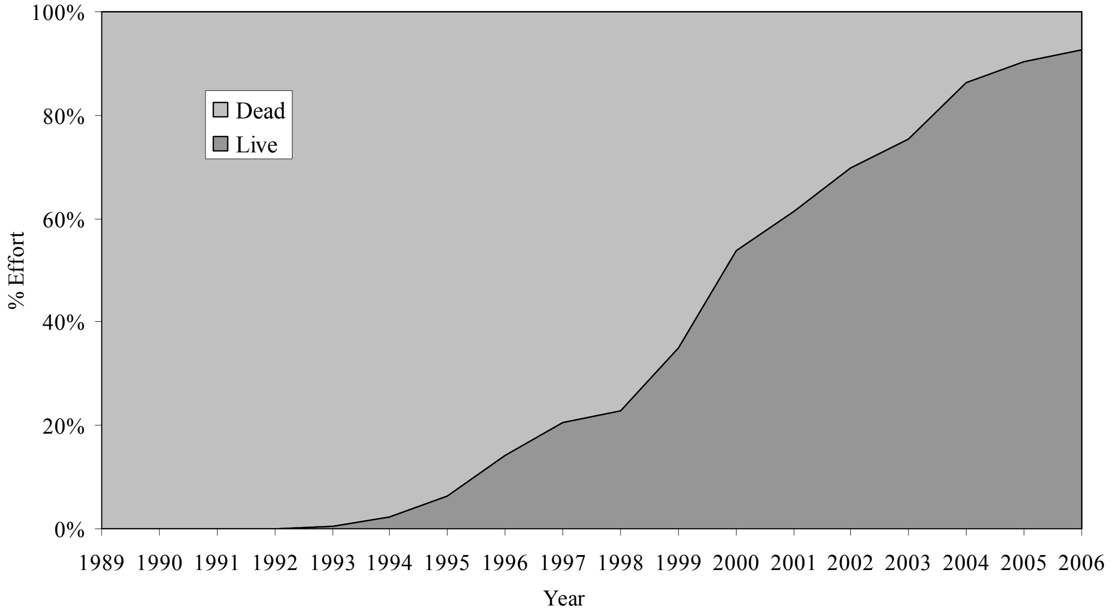

Figure 7-2. Commercial line fishing effort of the Great Barrier Reef line fishery directed predominantly to supplying the frozen product and live fish markets 1989-2003.

We estimate historical discard rates from the commercial sector of the GBR RLF for the two main target groups, coral trout and redthroat emperor. We define discard rate as the proportion of the total catch (harvest + discards) that is discarded, calculated either by number or gross mass of fish caught. We estimate variation in discard rates spatially (among regions) and temporally (among years and spawning/non-spawning seasons) and in relation to intended market (live or frozen product) and use these to estimate gross levels of discarding over the whole fishery, taking into account variation across these strata. We then model possible changes in these estimates due to increase in the MSL for redthroat emperor and using scenarios of high-grading for coral trout under the new TACC and ITQs as a case study of unintended impacts of changed management.

7.3 MATERIALS AND METHODS

7.3.1 Estimation of discard rates

Discard rate (*D*) was defined according to Alverson *et al.* (1994):

$$D = \frac{d}{d+k} \qquad (1)$$

where, *d* is the number (or weight) of fish that are discarded (caught and not kept) and *k* is the number (or weight) of fish harvested (caught and retained). Discard rates of coral trout and redthroat emperor from the commercial sector were calculated from three sources: 1) structured catch surveys by the CRC Reef Research Centre as part of the Effects of Line Fishing (ELF) Experiment (Mapstone *et al*., 2001, 2004); 2) an observer program on routine commercial fishing operations (Mapstone *et al*., 2001); and, 3) historical data from another research program (Capricorn-Bunker region, southern GBR, I. Brown, unpublished data). All ELF data were collected by researchers on board individual dories, with one fisher per dory (the normal practice in the RLF).

Catch surveys

The catch surveys were part of a large-scale manipulative experiment to examine the impacts of line fishing on the GBR (Mapstone *et al*., 1996, 2004; Campbell *et al*., 2001). Six reefs were surveyed in each of four 'clusters' over 7 degrees of latitude: Lizard Island (LI, 15° S; CNS region); Townsville (18.5° S; TVL region); Mackay (20.5° S; MKY region); and Storm Cay (SC, 21.5° S; MKY region) (Figure 7-1). The four clusters of reefs fall into 3 of the operational regions [Cairns(CNS), Townsville (TVL) and Mackay (MKY)] defined for the commercial sector by Mapstone *et al.* (1996) (Figure 7-1), with two of the clusters in the MKY region. The most southern cluster (SC), however, is very close to the northern boundary of the Swains (SWN) region defined by Mapstone *et al.* (1996) and hence, was assumed to represent the SWN region in the following analyses. This assumption allows us to use a common set of regions, rather than discriminating between 'research regions' and 'fishery regions'. Fishery 'no-take' and fished reefs were sampled, but we used data only from reefs open to fishing to estimate discard rates as these most likely reflected discard rates in the fishery.

Data from a total of 20 trips to 8 open reefs (2 in each cluster) between 1995 and 1999 were included in analyses. Data after 1999 were excluded because previously open reefs were then closed to fishing for the remainder of the ELF experiment and so catch survey data from them may not have reflected normal fishery data. All fish caught during catch surveys were retained and observers recorded time, session (AM or PM), depth, length and weight of individual captures by species. Fishing was done by commercial fishers using their usual fishing gear and 'structured' by depth, location and fishing time to comply with the sampling design of the ELF Experiment. Fishing occurred in depths from 5-35 m, although most was at 10-20 m. Discard rates were inferred from the size information recorded for each species during the catch surveys based on the assumption that only fish below the MSLs would have been discarded in normal fishing practice. As length was recorded for all fish and individual weight for a large proportion of them, estimates of discard rate were derived by numbers and weight (Table 7-1). Estimates of discard rate by number were calculated for each day on each reef in each year when five or more individuals were caught. Discard rates by weight were calculated only when over 80% of the catch from a fishing session was weighed, with daily discard rates derived from either one or both sessions that satisfied this criterion on each day.

Table 7-1. Numbers of fish used in the estimation of discard rates for statistical analyses for each the catch survey and Capricorn-Bunker data sources, their respective regions, each species, and whether the estimate was numbers- or weight-based.

Data Source	Region	Year	Coral trout			Redthroat emperor		
			Reefs	No.	Wt	Reefs	No.	Wt
Catch Surveys	LI	1995	2	287	-	-	-	-
		1996	2	149	-[4]	-	-	-
		1997	2	230	222	-	-	-
		1998	2	202	198	-	-	-
		1999	2	244	243	-	-	-
	TVL	1995	2	111	-	2	7	5
		1996	2	118	118	2	19	16
		1997	2	97	77	2	53	52
		1998	2	159	157	2	35	35
		1999	2	170	168	2	48	48
	MKY	1995	2	332	-	2	80	78
		1996	2	216	201	2	76	70
		1997	2	109	110	2	53	54
		1998	2	243	262	2	75	63
		1999	2	338	336	2	98	94
	SC	1995	2	337	-	2	44	43
		1996	2	271	261	2	39	33
		1997	2	245	152	2	52	44
		1998	2	283	252	2	51	51
		1999	2	404	391	2	71	70
Brown (unpub.)	C-B	1991	-	413	413	-	729	729
		1992	-	308	308	-	1180	1180
		1993	-	-	-	-	87	87

Observer program

The observer program involved placing observers on 29 commercial line fishing trips between September 1996 and July 1998 (Mapstone *et al*., 2001; live product – 16 trips, dead, frozen product – 13 trips). Average trip length varied with the intended market of the catch (live: 7 days; frozen: 9.5 days; Mapstone *et al*., 2001). Trips were observed between 12° and 22° S latitude covering the Far Northern (FN), Cairns (CNS), Townsville (TVL), Mackay (MKY) and Swains (SWN) regions of the GBR (Mapstone *et al*., 1996, 2001; Figure 7-1), but few trips were observed in the FN and CNS regions and so data from those trips were pooled with TVL data for analyses. Observers recorded the species and fate (harvested or discarded) of each fish captured. Discard rates for coral trout and redthroat emperor were estimated directly from these observations, based only on numbers as weights of individual fish were not recorded (Table 7-2). Discard rates were calculated for each reef on each day that reef was fished provided that at least five individuals were caught.

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[4] The discard rate estimate for one of the LI reefs in 1996 was taken as the average for that reef across the years 1997-99 as insufficient fish were weighed in each session for that year.

Table 7-2. Numbers of fish used in the estimation of discard rates for statistical analyses from the observer data source, for each region and for each species.

Data Source	Region	Year	Season	Coral trout		Redthroat emperor	
				Reefs	No.	Reefs	No.
Live	TVL	1	Spawning	24	518	14	100
		1	Non-Spawning	6	62	6	36
		2	Spawning	5	136	5	37
		2	Non-Spawning	-	-	-	-
	MKY	1	Spawning	-	-	-	-
		1	Non-Spawning	13	228	10	91
		2	Spawning	-	-	-	-
		2	Non-Spawning	11	332	9	20
	SWN	1	Spawning	-	-	-	-
		1	Non-Spawning	2	9	1	1
		2	Spawning	24	372	16	72
		2	Non-Spawning	28	659	17	95
Dead	TVL	1	Spawning	-	-	-	-
		1	Non-Spawning	8	145	8	279
		2	Spawning	17	228	13	317
		2	Non-Spawning	-	-	-	-
	MKY	1	Spawning	11	385	11	232
		1	Non-Spawning	7	121	7	51
		2	Spawning	6	64	5	133
		2	Non-Spawning	18	432	18	145
	SWN	1	Spawning	-	-	-	-
		1	Non-Spawning	-	-	-	-
		2	Spawning	-	-	-	-
		2	Non-Spawning	7	175	7	81

Capricorn-Bunker Region

The Capricorn-Bunker (C-B) region (Figure 7-1) is relatively isolated from the other GBR regions by the wide, deep Capricorn Channel. Fishers report high numbers of large coral trout and small redthroat emperor from the C-B region relative to other regions, but it was not sampled by catch surveys or the observer program. Discard rates for the C-B region, therefore, were estimated using research catch size-frequency data from 1991¯1993 collected by I. Brown as part of another research program (unpublished data). These data were collected from fishing by researchers rather than commercial fishers, but otherwise were sampled in a similar manner to other regions. Numbers and fork lengths (FL) of the catch were recorded by species, but fish were not weighed. Length data were converted to weight using the length-weight relationship, $Weight(kg) = aFL(mm)^b$, where the parameters a and b were estimated for common coral trout and redthroat emperor from the catch survey weight-length data (Table 7-3). FL was converted to total length (TL) using, $TL = l \times FL(mm) + l_0$, where l and l_0 were estimated from catch survey data (Table 7-3).

Table 7-3. Parameters of weight-length (*a*, *b*) and FL–TL (l, l_0) relationships for common coral trout (CCT) and redthroat emperor (RTE) as estimated from ELF catch survey data. Numbers of individuals (n) from which relationships estimated and r^2 also shown.

Species	$Weight(kg) = aFL(mm)^b$				$TL = l \times FL(mm) + l_0$			
	a	*b*	*n*	r^2	l	l_0	*n*	r^2
CCT	3×10^{-9}	3.2657	9185	0.950	1.0641	-1.0205	2029	0.998
RTE	7×10^{-9}	3.1488	1838	0.955	1.0691	6.1017	282	0.998

7.3.2 Statistical analyses

No one data set included data across all regions, seasons (spawning and non-spawning), intended markets (live or frozen) or years. The catch survey data, having consistent cover across several years (1995–1999) and regions (LI, TVL, MKY, SWN) in the spawning season for coral trout were used to test for annual and regional differences in discard rates within the context of structured fishing surveys (Table 7-4) and provided the only direct estimates of discard rates by weight. The observer program data were used to test for differences in discard rates between spawning and non-spawning seasons and the intended market for the catch over three regions (TVL, MKY, SWN) (Table 7-4). Finally, catch survey data and observer data were compared to assess the implications, if any, of using discard rates estimated from catch surveys to estimate fleet-wide discard quantities from commercial catches.

Table 7-4. Summary of sources of data used to test for the influence of different factors potentially influencing discard rates. Interaction terms in analysis are not listed.

Factor	Catch Surveys	Observer Data	Brown (unpub. data)
Region	Yes	Yes	Yes
Year	Yes	Yes	No
Season	No	Yes	No
Market	No	Yes	No
Survey Method	Yes	No	No
Data Source	No	Yes	No
Fishing Trip	Yes	Yes	No

Catch surveys

In the first year (1995) of the catch surveys, one day per reef was fished by the structured sampling design (hereafter structured fishing) and a second day was fished by 'normal, at will' fishing that would occur when commercial fishers operated without research restrictions (hereafter normal fishing). As only structured fishing occurred in all subsequent years, we compared discard rates of structured and normal fishing operations in 1995 only to assess whether discard rates inferred from structured catch survey data were likely to reflect those in the operational fishery. This was done by repeated measures analysis of variance (RMANOVA; Winer *et al.*, 1992) with between-subjects (reefs) factors, Region (LI, TVL, MKY, SWN) and Reef (1, 2) and the within-subjects repeated measures effect Method (structured, normal) estimated from each reef. This was only tested for discard rates by number because of gaps in the weight data pairs (normal vs. structured) in some regions.

Discard rates from structured catch surveys were compared among regions and years by RMANOVA with between-subjects factors Region (LI, TVL, MKY, SWN) and Reef (1, 2) and the repeated measures (within reefs) effect Year (1995-1999). Data were pooled across regions or years that did not differ significantly to derive the most synoptic estimate of discard rate(s) possible. One of the open reefs in each region was closed to fishing in 1998 and 1999 as part of the ELF Experiment (Mapstone *et al*., 1996, 2004; Campbell *et al*., 2001), but data from those reefs and years were included in the analysis on the assumption that the first two years of closures would not have changed population structure enough to substantially affect discard rates. Common coral trout and redthroat emperor do not recruit to the fishery until 3 years or older and so any impacts of the closures on, for example, recruitment would not have been manifest in catches in 1998 or 1999, as shown by Mapstone *et al*. (2004). The LI region was excluded from the analyses for redthroat emperor because that species rarely occurs that far north on the GBR (Mapstone *et al*., 2004; Williams *et al*., 2003). Mauchly's test of sphericity was used prior to each RMANOVA to test the assumption of homogeneity of the error variance-covariance matrices of the dependent variable and so choose the most appropriate test statistic (Huynh and Mandeville, 1979). The conventional significance criterion $P \leq 0.05$ was used for all tests.

Observer data

Observer data were analysed using ANOVA with the factors Market (live, frozen), Region (TVL, MKY, SWN), Year and Season (Spawning = Sept–Dec, spawning period for coral trout; Samoilys 1997; and Non-Spawning = rest of the year). 'Year' was defined to include a full complement of Spawning and Non-Spawning season data rather than as calendar years, resulting in each season being represented in two different years (Years 1 *and* 2), but not the same two calendar years (Spawning in 1996 and 1997, Non-Spawning in 1997 and 1998). Thus, the factors, Market, Season and Region were crossed, but Year was nested within Season and crossed with Market and Region. Year was considered a random factor and all others fixed effects. Different reefs were sampled in each combination of Season, Year, Market and Region and so RMANOVA was not appropriate. Discard rates per reef were potentially related to the operational characteristics of a trip (e.g., gear used, fishing crew, choice of fishing depths, etc), however, and so the additional factor 'Trip' was included in the ANOVAs to assess trip (operation) related effects on discard rate and test whether reef-specific discard estimates could be considered independent replicates for more powerful analyses. Trip was considered a random variable and nested within the combination of Season, Year, Market and Region. Insufficient trips were observed to allow a full-rank ANOVA, however, and so the analyses excluded the three-way interactions Market*Region*Season and Market*Region*Year(Season). These analyses were refined progressively in a step-down fashion with removal of interaction effects for which $P > 0.25$ (Winer *et al*., 1992) and reanalysis of the simplified model until no further terms could be excluded, to increase the power of tests of the primary factors of interests (Season, Year, Market and Region).

Comparison of survey and observer estimates

We compared discard rates based on numbers from the catch surveys in all years in the TVL, MKY and SWN regions with observer data from the same regions using ANOVA (Zar, 1984). LI region was excluded because of insufficient observer data from that region. The ANOVAs comprised the crossed fixed factors Region and Source of data (catch survey, live operations, frozen operations) and the random factor Trip nested within the combination of Region and Source, with reefs providing replicate estimates of discard rates within trips. This structure meant that there was only one trip (to two reefs) per region per year for catch surveys, but multiple trips (to varying reefs) per region and year for observer data. Effects of Year and Season were omitted because both proved to be inconsequential in most prior analyses.

Estimates of discard rates from the C-B region were compared with the simplest set of spatially homogeneous estimates from other regions resolved after the above analyses using a *t*-test or ANOVA depending on the results of the above regional analyses.

We also report here estimates of the statistical power of non-significant results. Specifically, we report the range of differences among means or groups of means[5] (a measure of Effect Size, ES, Mapstone, 1995; Keough *and* Mapstone 1997) of discard rate that would have been expected to be detected if present with a statistical power of 0.8 given a significance criterion of p=0.05. We denote this effect size as $ES_{0.8}$.

Discard quantities

The commercial RLF has been in operation on the GBR since the 1950s, although compulsory logbooks have been kept only since 1988[6] (Mapstone *et al*., 1996, Williams, 2002). The logbook data provide only effort and gross harvested catch information and so do not allow direct estimation of discarding. Further, commercial harvest data (catch retained and sold) from the logbooks preceding 2004 are recorded in weight only and not numbers. We used the estimates of discard rates by weight estimated from research catch survey data together with the fleet-wide logbook data on harvest to estimate the total weight discarded from the commercial sector for each of the main target species as:

$$d'_r = \frac{D_r k_r}{1 - D_r} \qquad (2)$$

Where d'_r is the estimated discard biomass for region *r*; D_r is the discard rate estimated from (1) for region *r*; and k_r is the harvested biomass reported for region *r* in the compulsory logbooks.

We used estimates of D_r and corresponding commercial catches for each year from 1989-2003 to estimate discard amounts for each of the six spatially contiguous regions defined by Mapstone *et al.* (1996) (Figure 7-1). Estimates of discard rates by weight were available only from the four clusters of reefs at which catch surveys were done, which we have inferred represented the CNS, TVL, MKY and SWN regions (Figure 7-1). Estimated discard rates for coral trout from the LI region were assigned to the Far North (FN) region and TVL estimates for redthroat emperor were assigned to the CNS and FN regions[7], as the spatially closest estimates for regions from which we had no discard data. Weight based discard rates for the C-B region were derived from Brown's unpublished data after deriving fish weights from recorded lengths. Historical (1989-2003) estimates of the total amount of coral trout[8] and redthroat emperor discarded annually were estimated by summing estimated discard quantities across regions in each year.

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[5] When more than 2 means are compared, the detectable effect size depends on the pattern of differences among the means. In these cases, we report the minimum (best case) and maximum (worst case) difference between alternative groupings that would have been detectable.

[6] Logbook data from 1988 were not included in our analyses as it was the first year of compulsory reporting and data were considered to be incomplete.

[7] *L. miniatus* are not caught north of Cairns in large quantities, but as annual catches can be variable, estimates of discard quantities for CNS and FN regions were included for completeness.

[8] Coral trout harvest comprises three or more similar species of which *P. leopardus* comprises approximately 95% of the total (Source: Effects of Line Fishing catch survey database). The different species of coral trout were not routinely distinguished historically in catch logs. We assume that metrics for *P. leopardus* that influence discard estimates adequately represented the coral trout catch across all species.

7.3.3 Management scenarios

The recent introduction of a TACC and changes to MSLs means that commercial discarding practices are likely to change. We examined hypothetical scenarios of high-grading to demonstrate potential effects on discarding of coral trout. We used the estimates of discard rate and discard quantities derived for 2003 as the base case of no high-grading where only fish smaller than the MSL of 38 cm TL (~0.56 kg) were discarded. We then re-estimated regional discard rates from research data and annual discard quantities from fleet data assuming high-grading occurred under the TACC. We chose different scenarios of high-grading at different fish weights, since price structuring is weight-based. For example, if 2.0 kg was the high-grading cut-off, then all fish above that size and all fish below the MSL were assumed to be discarded. We applied high-grading cut-off values of 1.0 kg, 1.5 kg, 2.0 kg, and 2.5 kg. Projected discard quantities were derived assuming the newly introduced TACC for coral trout (1350 t) would be harvested annually and catch would be distributed regionally as it was historically (1989-2003), and were summed across the regions to give a fishery-wide estimate for each scenario. We did not attempt to simulate potential dynamic changes in discard practices, such as change in the discard cut-off as either the TACC was approached or the end of a year was approached without realising the TACC.

The effect of the increase in the MSL for redthroat emperor also was assessed by re-estimating the discard rates for the new MSL regionally using the catch survey size data, summing revised discard quantities across regions for a fishery-wide estimate and comparing these with the 2003 estimates as the base case. The TACC for redthroat emperor is 700 t and was assumed to be realised annually for projections.

7.4 RESULTS

7.4.1 Patterns of discarding

Catch surveys

There was no difference between structured and normal fishing in discard rates by number for coral trout either regionally (Method*Region interaction, $F_{3,4} = 1.747$, $P = 0.296$, $ES_{0.8} = 0.16^{-}0.25$) or overall (Method main effect, $F_{1,4} = 0.348$, $p = 0.587$, $ES_{0.8} = 0.11$) or for redthroat emperor (Method*Region, $F_{2,3} = 1.210$, $P = 0.412$, $ES_{0.8} = 0.14\text{-}0.22$; Method, $F_{1,3} = 0.592$, $P = 0.498$, $ES_{0.8} = 0.13$).

Discard rates of coral trout by number were not significantly different among years or regions (Year, $F_{4,16} = 2.23$, $P = 0.112$, $ES_{0.8} = 0.09\text{-}0.15$; Region, $F_{3,4} = 4.94$, $P = 0.078$, $ES_{0.8} = 0.18\text{-}0.29$; Year*Region, $F_{12,16} = 0.73$, $P = 0.707$, $ES_{0.8} = 0.16\text{-}0.37$). Analyses of coral trout discard rates by weight excluded 1995 because insufficient fish were weighed in that year and also excluded data from one session on each of two reefs in 1997 for the same reason. Further, the discard rate for one of the LI reefs in 1996 was estimated as the average for that reef across 1997-1999 because insufficient fish were weighed in both sessions at that reef in 1996. The degrees of freedom for reef effects in the analyses were reduced by one accordingly. As for discard rates by number, discard rates by weight did not vary significantly over years or regions (Year, $F_{3,9} = 1.208$, $P = 0.361$, $ES_{0.8} = 0.09\text{-}0.16$; Region, $F_{3,3} = 4.159$, $P = 0.136$, $ES_{0.8} = 0.13\text{-}0.21$; Year*Region, $F_{9,9} = 0.277$, $P = 0.965$, $ES_{0.8} = 0.19\text{-}0.38$).

Discard rates of redthroat emperor by number were not influenced by the interaction of year and region (Year*Region, $F_{8,12} = 1.80$, $P = 0.172$, $ES_{0.8} = 0.11–0.23$), but differed among years and regions (Year, $F_{4,12} = 3.47$, $P = 0.042$; Region, $F_{2,3} = 36.05$, $p = 0.008$) (Figure 7-4). The year effect was clearly influenced by 1997 data. Re-analysis without these data removed the significant year effect (Year, $F_{3,9} = 0.67$, $P = 0.590$) but did not qualitatively change the Region or Region*Year results. The year 1997 was subsequently considered an outlier in the data and overall discard rates were estimated for each region based on all data from the other years. The region effect was due to the discard rates differing significantly among all three regions ($D_{TVL} = 0.01 < D_{\mathrm{SWN}} = 0.14 < D_{MKY} = 0.24$, $p < 0.05$).

Discard rates of redthroat emperor by weight were also analysed after excluding 1997 data and the result was similar to that for discard rate by number (Year, $F_{3,9} = 0.934$, $p = 0.463$, $ES_{0.8} = 0.05–0.08$; Region, $F_{2,3} = 9.535$, $P = 0.050$; Year*Region, $F_{6,9} = 0.494$, $P = 0.798$, $ES_{0.8} = 0.08–0.15$). Regional patterns in discard rate by weight ($D_{TVL} = 0.004$, $D_{SWN} = 0.03$, $D_{MKY} = 0.11$) appeared qualitatively similar to those for discard rate by number, but the post-hoc tests were not sufficiently powerful to detect the significant difference(s) indicated by the ANOVA: TVL (0.008) v MKY (0.134), $p = 0.072$; TVL v SWN (0.041), $P = 0.92$; MKY v SWN, $p = 0.17$). We therefore inferred conservatively that discard rates for redthroat emperor should be estimated separately for the three regions for subsequent analyses.

Observer data

Model simplification for analyses of observer derived discard rates (by numbers) for coral trout resulted in a final model comprising just the main effects of Market (Live, Frozen), Region (TVL, MKY, SWN) and Trip (Market*Region); all other effects (Year, Season and interactions) having been excluded as trivial ($p > 0.25$). Discard rate by number did not vary significantly with the intended market of the catch (Market, $F_{1,27} = 0.54$, $P = 0.471$, $ES_{0.8} = 0.13$) but varied significantly among the three regions (Region, $F_{2,27} = 5.55$, $P = 0.010$; Means: TVL = 0.27, SWN = 0.40, MKY = 0.45, common SE = 0.035).

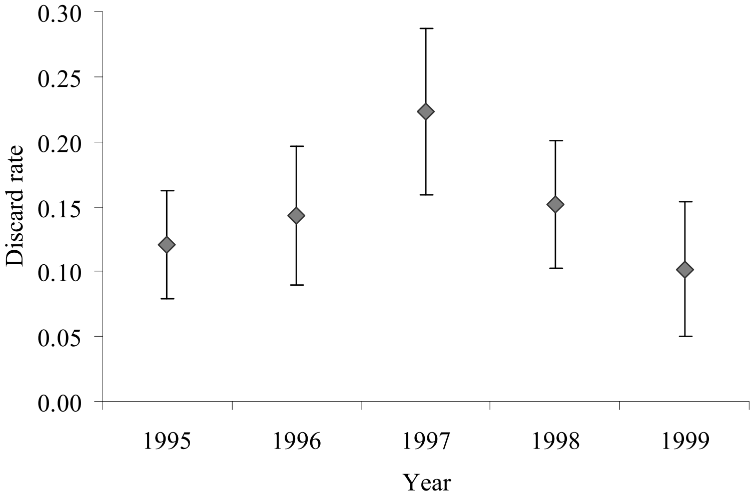

Figure 7-3. Discard rates based on numbers of fish for redthroat emperor derived from the ELF catch survey data set and pooled across regions per year. Re-analysis with 1997 excluded resulted in no significant differences among years. Error bars are standard errors.

Model simplification for redthroat emperor data resulted in a final analysis comprising just the main effects of Market, Season and Region, of which none was significant (Market, $F_{1,74} = 2.70$, $P = 0.104$, $ES_{0.8} = 0.07$; Season, $F_{1,74} = 1.74$, $P = 0.191$, $ES_{0.8} = 0.07$; Region, $F_{2,74} = 2.10$, $P = 0.130$, $ES_{0.8} = 0.05$-0.09).

Survey versus observer data

Discard rates by numbers of common coral trout varied significantly among regions (TVL, MKY, SWN: $F_{2,37} = 9.92$, $P = 0.001$) but not with data Sources (Survey, Live, Frozen: $F_{2,37} = 1.34$, $P = 0.276$, $ES_{0.8} = 0.09$-0.14) when catch survey and observer data were analysed together. The interaction between Source and Region was not significant ($F_{4,37} = 0.53$, $P = 0.713$, $ES_{0.8} = 0.07$-0.12). Post-hoc tests indicated that overall average discard rate from the TVL region ($D_{TVL} = 0.27$) was significantly less than those from the MKY ($D_{MKY} = 0.45$) or SWN ($D_{SWN} = 0.42$) regions, which did not differ.

Analysis of the combined catch survey and observer data for redthroat emperor indicated a significant interaction between Region and data Source ($F_{4,99} = 4.88$, $P = 0.001$). Post-hoc tests indicated that the interaction arose because discard rates differed among all regions when estimated from catch surveys, between SWN and the other two regions for frozen operations, and did not differ among regions when fishers were targeting the live market (Figure 7-5). There were no differences in discard rates of redthroat emperor among the different data sources for either the TVL or SWN regions, but in the MKY region discard rate estimated from the catch surveys was higher than those from both live and frozen trips, which did not differ (Figure 7-5).

Our results indicated relatively consistent regional variation in discard rates, no effects of Season or intended Market for the catch and infrequent or non-consistent effects of Year or data Source (Table 7-5). Accordingly, we derived year-averaged discard rates from combined observer and catch survey data (for numbers) or catch survey data alone (weights) for each of the LI, TVL, MKY and SWN regions for comparison with the discard rates from the C-B region. The inclusion of the catch survey estimates for redthroat emperor from the TVL region, the only estimates that differed from observer-based estimates, would amplify the regional variation and potentially over-estimate fleet discard rates of redthroat emperor for the TVL region. We did so, however, because a) regional variation was important already, and b) this was the only case where catch survey estimates differed from observer estimates and we opted to apply a consistent method across all regions rather than use differently derived estimates in different regions.

Table 7-5. Summary results of analyses of discard rates estimated from different data sets. All main effects in analyses are listed but only interaction terms that were significant in at least one analysis are included. CCT: common coral trout; RTE: redthroat emperor; *: $P \leq 0.05$; ns: $P > 0.05$; -: Factor not included in analysis; na: test not applicable because of higher order interaction.

Factor	Data Set and Species							
	Catch Surveys		Observer Data		Combined catch		All data	
	CCT	RTE	CCT	RTE	CCT	RTE	CCT	RTE
Region	ns	*	*	ns	*	na	*	*
Year	ns	*	ns	ns	-	-	-	-
Season	-	-	ns	ns	-	-	-	-
Market	-	-	ns	ns	-	-	-	-
Survey method	ns	ns	-	-	-	-	-	-
Data source	ns	na	ns	na	ns	na	-	-
Fishing trip	-	-	*	ns	-	-	-	-
Data source x Region	-	-	-	-	ns	*	-	-

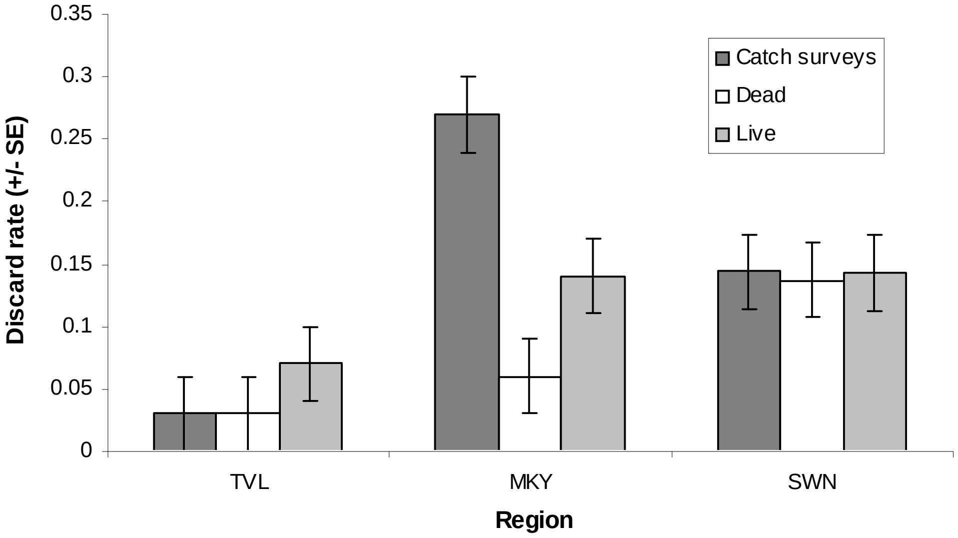

Figure 7-4. Discard rates based on numbers of fish for redthroat emperor for each data source in each region: Townsville (TVL), Mackay (MKY) and Swains (SWN). Error bars are standard errors.

Capricorn-Bunker Region

Year-averaged estimates of discard rates were compared among all regions, including the C-B fishery region, by one-way ANOVA. Discard rates of common coral trout by both number and weight varied among the five fishery regions in the same pattern: SWN ≈ MKY > TVL ≈ LI > C-B (Table 7-6). Discard rates of redthroat emperor also varied regionally averaged over years and the patterns were ordered similarly though not statistically consistently between discard rates by numbers and weight: Discards by numbers - C-B > MKY ≈ SWN > TVL; Discards by weight - C-B ≈ MKY > SWN ≈ TVL.

Table 7-6. Estimated discard rates based on numbers and weight for coral trout and redthroat emperor for each of the regions of Mapstone *et al.* (1996). The estimates are derived from the analyses of the catch survey and observer data. Discard rates of common coral trout and redthroat emperor from the Lizard Island (LI) and Townsville (TVL) regions respectively are applied to the CNS and FN regions as described in the text. The common standard error (SE) from the analyses for discard rate estimates are indicated.

	Coral trout		Redthroat emperor	
Region	DR - Number	DR - Wt	DR - Number	DR - Wt
CNS	0.324	0.175		
TVL	0.262	0.177	0.024	0.008
MKY	0.437	0.311	0.149	0.134
SWN	0.466	0.322	0.134	0.041
C-B	0.123	0.036	0.405	0.200
Common SE	*0.027*	*0.022*	*0.027*	*0.021*

7.4.2 Discard quantities

We concluded from the above analyses that discard rates should be estimated separately for each region on the GBR (Table 7-6). Estimates of the quantities of both coral trout and redthroat emperor discarded from the commercial sector were calculated for 1989-2003 using the region-specific weight-based estimates of discard rate applied to the reported commercial harvest of each group in each year (Figure 7-5; Figure 7-6). Discard quantities for redthroat emperor in most regions in 1997 were estimated using discard rate estimates from that year alone as we concluded 1997 to be an outlier based on earlier analyses, but we used the same discard rate in 1997 as in other years for the C-B region.

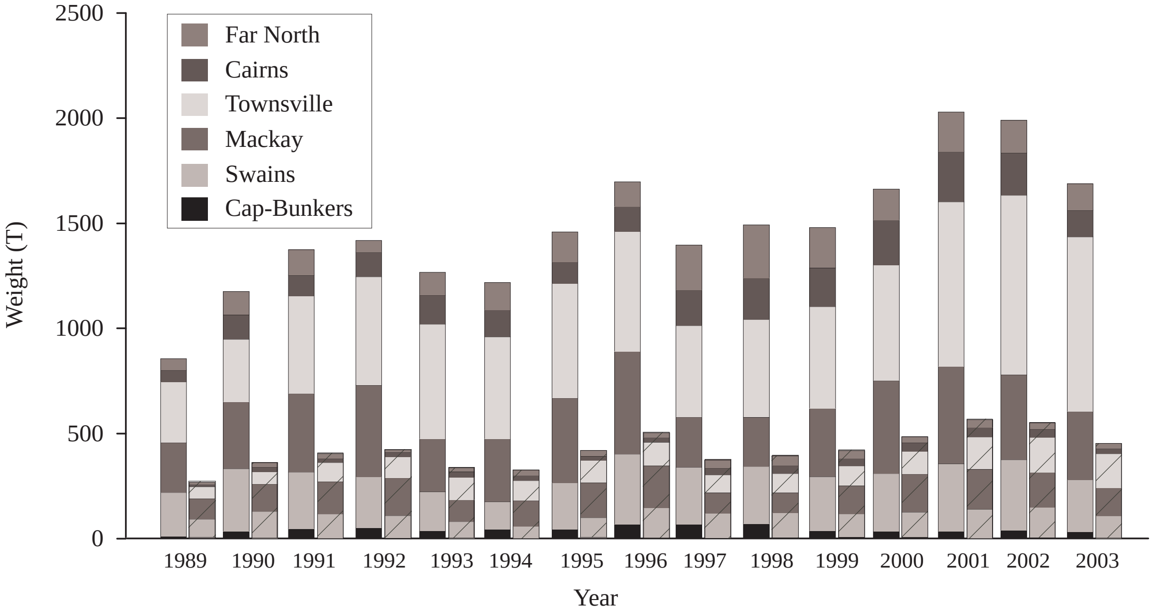

Figure 7-5 Commercial harvest and estimated amounts discarded (hatched bars) of coral trout (all species) 1989-2003. Shading in the bars indicates catches from the different fishery regions.

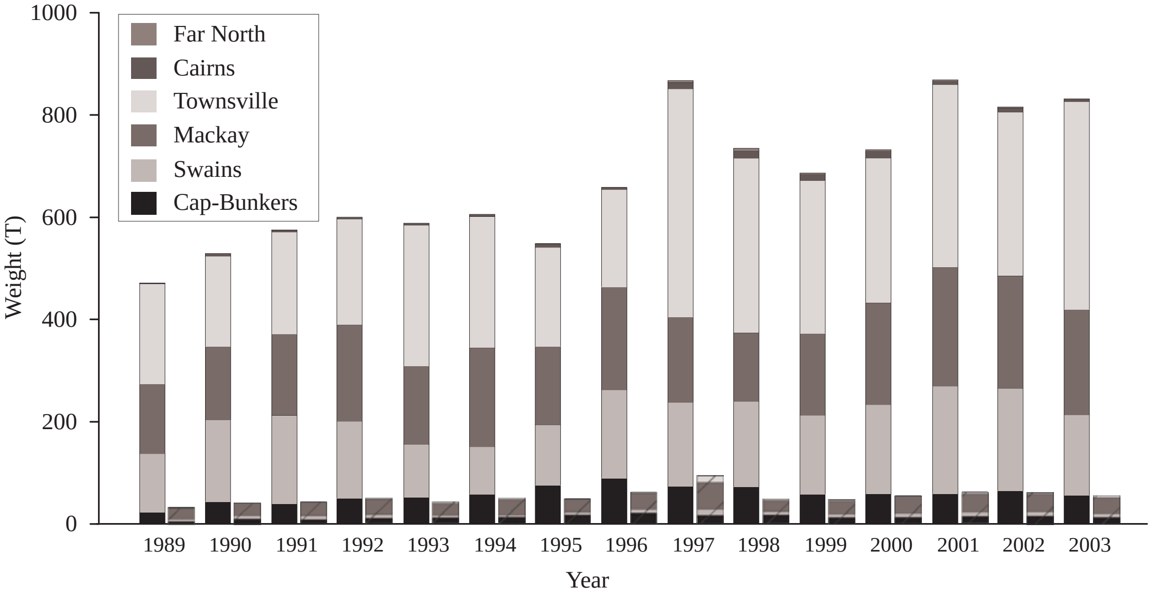

Figure 7-6 Commercial harvest and estimated amounts discarded (hatched bars) of redthroat emperor, 1989-2003. Shading in the bars indicates catches from the different fishery regions.

In general, the discarded quantities did not reflect the patterns of regional harvest. This was most likely a reflection of the regional variability in the size distribution of coral trout and redthroat emperor on the GBR (Mapstone *et al*., 2004; Williams *et al*., 2003). For example, the regions MKY and SWN on average contributed 42% of the harvest of coral trout but produced 61% of the discards, while the regions north of MKY collectively comprised 55% of the harvest but only 38% of the discards. Discarded quantities of redthroat emperor were estimated to be lower than those of coral trout but tended to be greater at higher latitudes (Figure 7-6). For example, the C-B region had the highest discard rates and provided over a quarter of the total discarded quantity of redthroat emperor, despite a relatively low harvest. Conversely the most productive region in terms of harvest, TVL, had a very low quantity discarded due to low discard rates.

7.4.3 Management effects on discarding

Changes to discard rates for coral trout under the hypothetical scenarios of high-grading are shown in Table 7-7. The changes in discard rates were different for each of the different regions, again most likely because of regional variation in size distributions of the species (Mapstone *et al.*, 2004; Williams *et al.*, 2003). Discard rates based on number showed relatively moderate increases for the northern regions (CNS) with high-grading of >1.0 kg or >2.5 kg fish, respectively, resulting in discard rates of 0.66 (104% increase on the base case) and 0.34 (5% increase) (Table 7-7). The MKY and SWN regions were similar, with relatively high base case discard rates and relatively modest increases under the various high-grading scenarios. In contrast, the TVL and the C-B regions showed far greater impacts of high-grading scenarios with high-grading fish >1.0 kg or >2.5 kg resulting, respectively, in discard rates of 0.72 (TVL, 175% increase) and 0.81 (C-B, 557% increase) and 0.31 (TVL, 20% increase) and 0.29 (C-B, 137% increase) (Table 7-7).

Changes in discard rates based on weight were more dramatic. In the CNS regions, high-grading fish >1.0 kg or >2.5 kg increased discard rates to 0.71 (306% increase) and 0.24 (36% increase), respectively. High-grading fish >1.0 kg in the TVL, MKY and SWN regions changed discard rates to 0.77 (337% increase), 0.67 (115% increase) and 0.71 (120% increase), respectively, while high-grading fish >2.5 kg caused less dramatic changes (Table 7-7). The discard rate in the C-B region with high-grading fish >1.0 kg or >2.5 kg increased to 0.90 (2394% increase) and 0.37 (919% increase), respectively (Table 7-7).

Table 7-7. Discard rate estimates of common coral trout for the regions CNS, TVL, MKY, SWN and C-B under different hypothetical scenarios of high-grading if it occurred in the reef line fishery as a result of the introduction of a Total Allowable Commercial Catch (TACC) quota in 2004. The 2003 "no high-grading" refers to prior to TACC, while the post-2003 refers to periods after the TACC was introduced.

		2003	Post-2003				
	Region	No high-grading	No high-grading	>1.0 kg	>1.5 kg	>2.0 kg	>2.5 kg
Discard rate (no.)	CNS	0.324	0.324	0.660	0.431	0.362	0.341
	TVL	0.262	0.262	0.720	0.459	0.350	0.314
	MKY	0.437	0.437	0.660	0.544	0.498	0.486
	SWN	0.466	0.466	0.699	0.602	0.561	0.538
	C-B	0.123	0.123	0.808	0.562	0.399	0.291
Discard rate (wt)	CNS	0.175	0.175	0.710	0.409	0.284	0.238
	TVL	0.177	0.177	0.774	0.452	0.271	0.192
	MKY	0.311	0.311	0.670	0.484	0.380	0.345
	SWN	0.322	0.322	0.708	0.558	0.467	0.407
	C-B	0.036	0.036	0.898	0.699	0.519	0.367

The changes in discard rates by weight were reflected in the changes in discard quantities estimated for each region, with the C-B and TVL regions in particular showing disproportionably higher discarded amounts under scenarios of high-grading (Table 7-8). Under the most conservative high-grading scenario, the fishery wide estimate of discard quantity was 555 t, while under the severest scenario examined the estimate was 3895 t, compared with a harvest quota of 1350 t. This was compared to a base case (no high-grading) of 421 t under the new TACC.

Table 7-8. Estimated discard quantities (tonnes) of common coral trout for each fishery region under different hypothetical scenarios of high-grading if it occurred in the reef line fishery as a result of the introduction of a Total Allowable Commercial Catch (TACC) quota in 2004 (TACC = 1350 t). The 2003 "no high-grading" refers to prior to TACC, while the post-2003 refers to periods after the TACC was introduced. The 95% confidence limits for total discard estimates, derived from applying the confidence limits on discard rates to regional catches and summing over regions, are given in parentheses.

		2003		Post-2003				
	Region	Harvest (t)	No high-grading	No high-grading	>1.0 kg	>1.5 kg	>2.0 kg	>2.5 kg
Discard quantity (t)	FN	127	26.98	26.58	306.77	86.71	49.70	39.14
	CNS	125	26.58	27.59	318.46	90.02	51.59	40.63
	TVL	832	178.80	106.13	1689.99	407.02	183.44	117.26
	MKY	324	146.38	144.07	648.04	299.39	195.63	168.12
	SWN	249	118.14	115.59	590.14	307.27	213.25	167.05
	C-B	31	1.17	1.44	341.21	89.66	41.56	22.41
TOTAL:		1688	498 (76)	421 (61)	3895 (58)	1280 (103)	735 (83)	555 (72)

The change in the MSL for redthroat emperor resulted in increases in discard rates by number in the MKY, SWN and C-B regions of between 42% and 71%, with nearly 60% of fish caught in the C-B region having to be released. In contrast, the TVL regions showed a much greater increase in discard rates due to the already low rates at the old MSL (Table 7-9). The increases in discard rates by weight showed a similar pattern among the regions. The reef-wide estimate of the discarded quantity in 2003 was 56 t and was estimated to increase to 103 t (84% increase) with the change in the MSL when the new TACC was realised, with most of the increased quantity coming from the TVL region.

Table 7-9. Predicted changes in discard rates and quantities for redthroat emperor based on the number and weight of fish with the increase in the minimum legal size (MSL) limit from 35 cm to 38 cm TL for each of the regions: FN (Far North); CNS (Cairns); TVL (Townsville); MKY (Mackay); SWN (Swains); and C-B (Capricorn-Bunkers). The discard quantities based on the 35 cm discard rate use the 2003 catch estimates while the change in estimated annual quantities discarded (tonnes) are given with the 'new' estimate taking into account the increase in the MSL and the annual TACC of 700 t. 95% confidence limits are given in parentheses for the total discard quantities. Discard rates estimated from the TVL region are applied to the CNS and FN regions because insufficient data were available from the latter regions to estimate local discard rates.

Region	Discarding (no.)		Discarding (wt)			
	Discard rate 35cm TL	Discard rate 38cm TL	Discard rate 35cm TL	Discard quantity 35cm TL	Discard rate 38cm TL	Discard quantity 38cm TL
FN	0.009	0.151	0.008	0.01	0.086	0.12
CNS	0.009	0.151	0.008	0.03	0.086	0.59
TVL	0.009	0.151	0.008	3.27	0.086	24.54
MKY	0.237	0.405	0.134	31.73	0.248	45.35
SWN	0.142	0.222	0.041	6.74	0.074	12.25
C-B	0.405	0.575	0.200	14.02	0.336	19.88
Total				56 (36)		103 (52)

7.5 DISCUSSION

These analyses provide the first comprehensive estimates of commercial discard rates and quantities for the GBR RLF. Discard rates in reef line fisheries may be much higher than the worldwide estimate of 0.02[9] attributed to handline fisheries by Kelleher (2005), particularly where fisheries are highly regulated. Estimated discard rates for coral trout in some regions on the GBR were higher than for most other non-trawl fisheries and comparable to many trawl fisheries (Kelleher, 2005). Discard rates from line fisheries might be expected to vary widely among species, as shown by the results presented here but our results compare well with a recent report of discard rates by recreational hook and line anglers on the GBR (e.g. red emperor, *Lutjanus sebae*; 68%) (Henry and Lyle, 2003). We have demonstrated that changes in management regulations and fisher responses to them may have substantial effects on discard rates and quantities.

7.5.1 Patterns of discarding

We were able to use three independent data sources to estimate discard rates and test for consistency in estimates, as well as examining spatial, temporal and operational (live vs frozen markets) patterns in discarding. These factors are particularly important given the large area in which the RLF operates and the market and operational diversity that is likely to trigger changes in discarding practices. For example, live boats primarily target coral trout while frozen boats may target several species, meaning that live operations might be more inclined to discard because of rejection of non-target species or high-grading to maximise profit within a single species quota. Such behaviour might explain the higher discard rate of redthroat emperor we observed from live operations than from frozen in some regions. Mapstone *et al.* (2001) also found higher discard rates of coral trout from live operations than those marketing frozen fish and also noted that live operations discarded many species that could not be sold alive but were retained by frozen operations.

Estimates of discard rates for both coral trout and redthroat emperor consistently differed among regions. The regional groupings for each species, however, tended to show commonality (TVL/CNS, MKY/SWN, C-B), though the ranking of the regional groups differed with species. The regional patterns are likely to reflect regional differences in the population structure of each species on the GBR (Mapstone *et al.*, 2004; Williams *et al.*, 2003) and perhaps regional variation in the impacts of past fishing which has been characterised by strong regional difference in effort (Mapstone *et al.* 1996). The higher discard rates for common coral trout in the MKY and SWN regions are consistent with underwater visual survey data which show undersize common coral trout to be significantly more abundant in those regions than elsewhere (Mapstone *et al.*, 2004). Welch (unpublished Masters Thesis, James Cook University) also demonstrated higher numbers of smaller common coral trout in the southern regions of the GBR, particularly in the MKY region, as well as regional differences in growth.

The MKY (Williams *et al.*, 2003) and C-B (A. Williams, unpublished data) regions are regions with high proportions of small redthroat emperor, TVL having the lowest proportion of small fish and the SWN region intermediate between MKY and TVL (Williams *et al.*, 2003). Knowledge of the regional variation in discard rates, as well as population structure, is important to accurately estimate fleet-wide discard quantities and corresponding post-release fishing related mortality.

Mapstone *et al.* (2001) reported significant inter-annual variation in discarded catches of common coral trout, though the variation was primarily a feature of vessels supplying the live fish markets and possibly a result of the rapid growth in the live fish trade from the GBR over the years of their study (1996-1998; Mapstone *et al.*, 2001; Figure 7-2). Variation in discard rate among years might be expected due to natural inter-annual variability in population structure because of variable recruitment that is common in

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[9] Kelleher (2005) estimated discard rates based on weight only.

coral reef fish (Doherty and Fowler, 1994; Russ *et al*., 1996). The upward-trending discard rates we recorded for redthroat emperor from 1995 to 1997 followed by declining rates subsequently would be consistent with the progressive recruitment to the fishery of a strong cohort. The regional patterns in estimated discards we report did not vary over time, however, indicating that those regional patterns might be robust to normal variation in recruitment and historical fishing impacts. The low temporal variation we observed also reassures us that the temporally confounded comparison between estimates from the C-B region (1991-93) with those from the other regions (1995-2003) are likely to reflect regional rather than temporal variation.

7.5.2 Discard quantities and effects of management

Although the discard quantities we estimated were, or would be, discarded over a very large area, those quantities could represent significant wastage if post-release mortality was non-trivial. Broadhurst *et al.* (2005) showed that post-release mortality can be as high as 37% for species caught and released by recreational anglers, although they also demonstrated considerable variation among species. In general, commercial reef line fishers release undersize fish relatively quickly and apparently in good condition, but the long term fate of released coral trout or redthroat emperor is unknown. Increased depth of capture was found to significantly increase mortality of line caught released West Australian dhufish (*Glaucosoma hebraicum*) (St John and Syers, 2005) and the RLF operates in depths down to at least 30 m. The significance of the estimated discard quantities will be further realised with estimates of post-release survival currently being investigated by the authors and others.

The introduction of a TACC based on ITQs for the RLF introduces the economic incentive for fishers to high-grade fish, particularly given the live fish market preference for ‘plate-size’ (~1 kg) coral trout. Although we have examined different scenarios of this occurring, there are several trade-offs which must be considered in this evaluation. The largest estimated quantity of discarded coral trout was 3895 t (DR = 0.743), nearly three times the TACC. Operationally this equates to over 8 in every 10 coral trout captured being discarded. The cost per harvested fish of such high discard rates is likely to be unacceptable to fishers because of wasted fishing and handling time and the costs of ‘wasted’ bait. Anecdotal reports from fishers in the months immediately following introduction of the TACC suggested that the size beyond which high-grading would become important was around 2 kg. This would equate to 735 t of discarded common coral trout, or over half of the TACC. The scenarios we examined, although hypothetical, highlight the potentially large quantum of discards and suggest a need to monitor discarding behaviour since the introduction of the TACC. Recent changes to the compulsory logbooks for the RLF require fishers to record discards, but targeted observations will be necessary to validate the reported data.

In contrast, estimates of discard rate and quantity of redthroat emperor were relatively low compared to discards of common coral trout. Despite having the highest historical levels of catch, the TVL region has had very low levels of discarded redthroat emperor than other regions, probably due to the predominance of larger fish in that region (Williams *et al*., 2003), again emphasising the importance of documenting spatial patterns in discard rates where populations structure is believed to vary. Even the very small change in MSL for redthroat emperor (3 cm) is likely to have precipitated significant changes in the quantity of discards.

7.5.3 Conclusions

Discard rates for coral trout and redthroat emperor on the GBR are highly variable among regions, as are harvests and underlying population size structures. Thus, neither discard rate nor harvest on their own are likely to be useful indicators of the consequences of discarding, even if post-release survival of discards were known. Estimates of both are required regionally to provide realistic estimates of likely impacts of discarding. Such estimates also will improve the robustness of stock assessments where discarding is included as a source of fishing-related mortality. Punt *et al*. (2006) included discards in stock assessments of blue grenadier (*Macruronus novaezelandiae*) and blue warehou (*Seriolella brama*), two high-value species from south-eastern Australia, and demonstrated greater certainty in the model outputs, while ignoring discards led to biased outcomes. Regional differences in discard rates may also inform other management decisions. For example, regions of high discarding may indicate locations of nursery or ‘grow-out’ areas for migratory stocks or be favoured for area closures, particularly if post-release survival is low. Recent increases in MSL for many of the species harvested in the RLF means that discard rates almost certainly will have increased. Our study provides a template for exploring discarding for these other species in the RLF and elsewhere.

7.6 ACKNOWLEDGEMENTS

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CHAPTER 8. GENERAL DISCUSSION AND SUMMARY

Compiled and edited by I.W. Brown and W.D. Sumpton

8.1 OVERVIEW OF RESULTS

8.1.1 Discarding or release rates

Analyses of 'historical' data sets (i.e. representing data collected by various agencies prior to the initiation of this Project) have provided particular insights into the factors affecting the rates of discarding in the recreational and commercial fisheries. The primary reason given for discarding in the recreational fishery was due to legal size limits. Discard rates vary considerably between the key species examined, and also vary significantly spatially and temporally. In most species discarding rates increased during the period from 1997 to 2005, to a large extent as a result of increases in legislated minimum legal size limits. In December 2003 the minimum legal size limit for red emperor had been raised significantly, from 45 cm (TL) to 55 cm. Concurrent increases in MLS of bluespot coral trout, redthroat emperor and spangled emperor did not result in an observable change in discard rate. By 2005 the reported recreational discarding rates for coral trout, redthroat emperor, spangled emperor and saddletail snapper ranged between 42% and 55%, but for crimson snapper the rate was 69%, and for red emperor it was 83%.

In the commercial reef line fishery on the GBR discard rates for the two main target species, coral trout and redthroat emperor, varied spatially though were more stable temporally. Due to the nature of the data available the impact of increased size limit on discard rates for redthroat emperor was only possible by modelling. We estimate that during the period 1989–2003, about 300–620 t of coral trout and 33–95 t of redthroat emperor were discarded annually by the commercial reef line fishery on the GBR. Modelling of potential high-grading after the introduction of a (competitive) total allowable commercial catch for coral trout indicated that, in an admittedly extreme case, discard rates for this species could increase to as much as 3,900 t yr^{-1}. The potential for large increases in discarding and subsequent cryptic mortality as a result of further increases in minimum legal sizes is highlighted.

8.1.2 Hooking damage

In comparisons of the injuries resulting from capture by three hook patterns (offset circle hooks, non-offset circle hooks and conventional J-hooks) in two sizes (4/0 or 5/0 and 8/0), we found considerable variation between species, and no significant overall patterns. There was, however, a consistent trend across all species and groups (coral trout, redthroat emperor, crimson snapper, saddletail snapper, red emperor, bluespot rockcod, blackblotch emperor and trevally) for hooks to lodge in the lip or mouth rather than the throat or gut. Overall, 88% of fish were shallow-hooked, and fewer than 4% deep-hooked.

Rates of observed external injury varied significantly with hook pattern in the two snapper species. While crimson snapper were less prone to damage from non-offset circle hooks than from either of the other patterns, the opposite trend occurred with saddletail snapper. There was no consistent trend across species in the influence of hook pattern on injuries sustained, nor on (presumably) injury-related bleeding.

For some species small hooks were more likely to result in shallow-hooking than large hooks, although the effect was weak, and only significant in crimson snapper and blackblotch emperor. In both of these species the reduction in 'shallow' hooking resulting from the use of larger hooks was balanced by an increase in hook lodgment in 'other' locations, rather than deep-hooking. The anatomical hook location category 'other' includes 'eye' as well as 'foul', the latter referring to hook lodgement locations outside the mouth. The prevalence of foul hooking is almost certainly a function of hook size *relative to* the size of the fish and its gape. Most of the fish caught during the hooking trials were small (particularly in the case of crimson snapper and blackblotch emperor) and we postulate that a small fish is more prone to be foul-hooked by a large baited hook – which it may not be able to take into its mouth – than by a small one. In addition, the head morphology of crimson snapper and blackblotch emperor is evidently such that fish of a particular size are prone to having the points of large mouth-lodged hooks emerge at the eye socket, although not necessarily causing observable damage to the eye itself. For the purposes of this discussion we refer to the 'other' hook location category as 'foul-hooked', recognising that it may contain some instances that would otherwise be attributed to the 'shallow-hooked' category.

Large hooks were associated with more frequent injury (possibly due to increased foul-hooking referred to above) than small hooks in all species. While this effect was statistically significant only in coral trout and blackblotch emperor, there was a generally similar trend across most of the other species tested.

If particular gear types or characteristics are to be promoted for conservation benefit it is essential to demonstrate whether or not the recommended gear is effective at catching the fish. Catch rates appeared to be little influenced by hook pattern, except for blackblotch emperor which were more susceptible to capture by circle hooks than J-hooks. A weak opposite effect was observed with coral trout, whose catch rates were marginally higher with J-hooks than circles. Small hooks out-performed large ones in capturing only crimson snapper and blackblotch emperor, possibly because of the generally small individual body size of these species at our study locations. As almost all the crimson snapper were below their minimum legal size, it could be argued that avoiding the use of small hooks may potentially reduce the 'by-catch' of undersize fish. However in the absence of a significant sample of legal-sized fish of these species it impossible to determine from our data if large fish are more likely to be caught on large than small hooks.

On re-examination of the results of (the now published) Chapter 3, it is necessary to qualify one of the recommendations in light of additional information from other components of the study. The published paper recommends the use of smaller-sized, non-offset circle hooks (rather than J-hooks or offset circle hooks) as an 'obvious conservation benefit for both target and non-target species'. This recommendation arose from the findings: (i) that non-offset circle hooks resulted in a lower incidence of injury to crimson snapper than J- or offset circles (although the reverse was the case for saddletail snapper), (ii) that large hooks caused more bleeding than small hooks among saddletail snapper, and (iii) that significantly more crimson snapper and blackblotch emperor were foul-hooked by large hooks than by small hooks, leading to a highly significant 'hooking location' effect in these species. In evaluating these results, two issues must be addressed: (i) the relationship between hook size and the size of the fish, and (ii) whether 'bleeding' and/or 'injury' can be demonstrated to have adverse survival consequences. Inshore fishing sites where some of the hooking trials were carried out were characterised by large populations of relatively small fish (possibly resulting from sustained heavy fishing pressure). All the red emperor and blue-spotted rock cod, and most of the crimson and saddletail snapper caught were below their respective MLS, with mean fork lengths less than 33 cm. Although most of the blackblotch emperor were above their MLS, they were still small fish (mean 24.5 cm FL). Only among coral trout and redthroat emperor could significant numbers of individuals be considered 'large' (mean > 40 cm FL). It is likely that the probability of a fish being foul-hooked is a direct function of hook size and an inverse function of body size. This is partly a 'gape size' effect, in that the smaller the gape, the less likely a fish is to be able to ingest a large baited hook. It is not surprising, then, that there was a high incidence of foul-hooking recorded among the smaller individuals (particularly crimson snapper and blackblotch emperor) when large hooks were being used. The relationship between gape size and hook size appears to be important when considering the performance of hook patterns.

In addressing the second of the above issues, we refer to the results of our field experiments, which revealed hook location as being a major determinant of short-term survival in coral trout, crimson snapper and saddletail snapper, with survival rates among deep-hooked fish being much lower than among those hooked in the mouth or lip. This was the case even (as was required exclusively in our experiments) when deep-set hooks were left in place by cutting the line according to best practice procedures. On the other hand, these short-term experiments revealed that the effects of injury and bleeding, even when testable, were very much less clear. Seven percent of the crimson snapper exhibited signs of bleeding, but there was no significant effect of bleeding on short-term survival, and while hooking location was significant, there was no difference in survival rate between shallow-hooked and foul-hooked individuals. In saddletail snapper there was some statistical evidence of reduced survival among foul-hooked fish (compared to shallow-hooked individuals), but the ‘bleeding’ effect was not significant and there were insufficient data to test the effect of injury. There is therefore very little empirical evidence from our experimental work to link the increase in foul-hooking (resulting from the use of large hooks) to a reduced probablilty of survival in any species except perhaps for saddletail snapper. This means that it is unwise to generally promote the use of small hooks for all of the species studied here.

While the observed rates of deep hooking were quite low (typically < 5%), we believe it advisable to recommend any procedure or gear that minimises deep-hooking in these species given the significant effect of deep-hooking on short-term survival in our field experiments. Technological advances in fishing gear manufacture have produced braided lines that have very little stretch and are therefore more sensitive to the bites of fish. This, in combination with a more active approach to angling (*viz*. keeping the line taut to improve bite detection), may be a positive way to reduce the incidence of deep hooking.

8.1.3 Barotrauma relief

We examined historical ANSA c&r data from the reef line fishery, as well as carrying out short term experiments and long-term tag release-recapture experiments to determine whether there is any conservation value in treating fish for barotrauma relief, and if so, whether either of the currently-recommended procedures is superior to the other.

Assuming that recapture rate represents some index of long-term survival, the historical ANSA data indicate that one of the best predictors of survival, across all species, is the simple subjective ‘release condition’ index. This finding was consistently supported in both the short- and long-term experiments carried out during this project. However release condition is really a visual appraisal of the combined effects of many possible factors contributiong to the physical and physiological condition of the fish resulting from capture and on-board handling, and does little to identify which factors are the most influential. Identifying which of these factors or covariates were significant predictors of survival, and whether treatment had any effect on survival, was confounded by the variable quality, reliability and consistency in the data. As with many fisheries-related investigations, there were many sources of variation (covariates) over which the experimenter has little or no control. This was certainly the case with this investigation, and the problem was exacerbated by the number of covariates that were not amenable to objective quantification. As a result much data culling or pooling was needed in order to obtain interpretable output from the various statistical models used.

At the outset, it was clear that the species investigated were not equally susceptible to the effects of capture, handling and treatment. The most resilient species is red emperor (*Lutjanus sebae*), which, although generally caught in deeper water than the other species, evidently has a high capacity to recover from the effects of barotrauma regardless of the treatment applied. The historical data indicated that venting red emperor increased recapture rates by a factor of 2.5 (from 20% for untreated fish, whether or not exhibiting signs of barotrauma) to 50%. In our three-day short-term (enclosure) experiments the survival rate was over 98%, with all but 2 of the fish surviving. These two had both been shotline-released but statistically it is unreasonable to make any inferences about the short-term effect of treatment on the basis of this small sample. The longer term c&r experimental data suggest that treatment by either method may actually be detrimental to the survival of red emperor, with recapture rates of treated fish about 30% below those of untreated (control) fish. This is contrary to the findings of the historical data, but more in line with the short- and long-term experimental results. Subsequent to the analysis and presentation of the historical data, it was noted that one highly experienced angler was responsible for a large percentage of the releases of vented red emperor and also recaptured a disproportionally large number of his released fish. When the biasing effects of this individual's fishing practises were removed from the long term experimental data there was no longer a statistically significant benefit to treating red emperor. On balance we would recommend not treating this species either by venting or shotlining.

Redthroat, grass and spangled emperor (all lethrinids) were moderately susceptible to post-release mortality. There were insufficient data relating to redthroat emperor in the historical c&r data set to enable any analysis of the recapture rate of this species, and grass emperor were not addressed in the short-term experiments. From the historical data it seems that grass emperor respond positively to venting, with long-term recapture rates around 15% compared to 10% for vented fish showing no signs of barotrauma, and 0% for non-vented fish showing signs of barotrauma. The long-term c&r data support this trend, with a (statistically non-significant) improvement of an order of magnitude in the recapture rate of vented fish over untreated controls. The virtual absence of any shotline-released grass emperor precludes any meaningful conclusions on the effectiveness of this treatment.

The 3-day survival rate comparisons for redthroat emperor indicated that treatment could be detrimental, but the effect was not significant. The overall short-term survival rate of this species was about 85%, irrespective of treatment. In the longer term, both venting and shot-line releasing appeared to have a beneficial effect on survival, with recapture rates for shotline-released fish three times higher than those of controls, and for vented fish twice those of the controls. However the difference between these estimates was not statistically significant, presumably because the low recapture numbers (in the order of 5-6 per treatment) restricted the model's power to discriminate between the main effects.

Too few spangled emperor were represented in the historical data set to analyse, and although there were some treated releases in the long-term tagging experiment (38 shotline and 47 vented) the recapture rates were too low to allow any conclusions to be drawn. Most of the treated spangled emperors were released by research staff at the conclusion of the short-term experiments at Gould Reef towards the end of the Project period. Two factors contributed to the low recapture rate: (i) the relatively brief 'time at large' for those fish compared to the other species, and (ii) the remote location of the release area, resulting in minimal 'recapture' effort. Short-term adjusted survival rates for both treatments and controls averaged about 80%, but again, because of the small sample sizes resulting from shark damage to the experimental enclosures, the differences between treatments was non-significant.

Coral trout (serranids) that had been vented were poorly represented in the historical data, so that this source provided no useful information on the effects of treatment. In our short-term experiments venting appeared to confer a slight survival advantage (81%) over shotline-releasing (77%) or controls (78%). However the results of the community-based long-term c&r experiment were at variance with this finding, suggesting that venting actually has a detrimental effect on survival (7% recapture rate compared to 9% [shotline] and 10% [controls]). These differences were not statistically significant and may well have occurred by chance, but they are consistent with the short-term results in that the magnitude of the changes in survival resulting from barotrauma treatment are quite small.

The species that stands out as being the most susceptible to the effects of barotrauma is the saddletail snapper (a lutjanid, and until recently known generally as largemouth nannygai). The historical c&r tagging data indicated that venting improved survival chances by a factor of 4 (recapture rate of 20% compared to about 5% for untreated 'controls'). The long-term experimental data indicated that venting was the preferable treatment, but only for fish showing no signs of barotrauma. In cases where there was some external evidence of barotrauma (e.g. bloating or exophthalmia) venting appeared counter-productive, while shotline releasing resulted in (slightly) superior survival rates than the controls. In the short-term experiments both treatments resulted in increased survival rates, with venting (73%) performing better than shotlining (67%) which in turn was an improvement on no treatment (59%). Although in most cases the observed differences in survival between treatments were not statistically significant, the general trends in the results appear to favour some sort of treatment.

An unexpected finding from this Project was the difference in response to c&r effects between two very closely-related and morphologically similar lutjanid species – saddletail snapper and crimson snapper

(*Lutjanus malabaricus* and *L. erythropterus* respectively). Not only are these species difficult to tell apart when young, they are found in the same habitat and even form mixed schools. Unlike saddletail snapper, crimson snapper appeared from the historical data not to respond well to barotrauma treatment, with very few recaptures of vented fish being reported in the tagging database. However the long-term tagging study indicated that (like the congeneric saddletail snapper) this species responded positively to treatment (particularly venting) although the magnitude of the changes in recapture rate were small. Curiously though, when the effects of barotrauma signs, hooking location and body size on recapture rate were factored into the model, the effects of treatment were reversed, with control recaptures outnumbering those from either treatment. Similarly, the short-term experimental data estimated very similar adjusted survival rates, with controls showing higher survival (89%) than either shotlining or venting (83%).

While some of the results of this work are paradoxical in terms of identifying which of the currently-promoted barotrauma relief procedures is more effective, other evidence indicates that at least some form of treatment is advisable. This evidence comes from analyses of the status of fish (in the short-term experiments) immediately after their introduction into the experimental enclosures. Apart from red emperor (where few if any of the fish floated) and redthroat emperor (which were tested before the recording process was changed to include information on floating status), in all species the survival rate among floaters was significantly lower than among non-floaters. This disparity was particularly evident in saddletail snapper, where a mere 7% of the floaters survived, compared with 62% of non-floaters. Some fish floated because they were suffering from barotrauma and had not been treated, and others floated because the treatment may not have been entirely effective. The latter occurred on a number of occasions, in instances where a fish being released with a shotline detached itself from the (barbless) hook before it reached equilibrium depth, and in others where a fish was released after only partially-successful venting. Given the magnitude of these differences in short-term survival rates, it makes sense to recommend some form of barotrauma-relief treatment, even though the statistical models frequently failed to show a significant effect when a number of other factors and covariates had been adjusted for. Some evidence of delayed bloating was observed, but because of the nature of the experiment we were not able to test for the effect. Delayed bloating may be the result of progressive relaxation of body-wall musculature around the abdomen within a minute or so, but not immediately, after the fish is brought to the surface. This relatively brief period immediately after capture could be critical to the development of external signs of Stage 1 barotrauma. Fish immediately disengaged from the hook and released may have a greater chance of being able to submerge effectively that those that have been taken on board, measured, tagged and perhaps photographed (as may occur in tag-and-release fisheries).

In conclusion, we recommend that apart from red emperor, which seems to be particularly tolerant of the effects of barotrauma and does not benefit from treatment, all the key reef species examined in this project should be treated, particularly if caught in depths greater than about 15–20 m. Whether venting or shotlining should be used is problematical, and may well be a choice best left to the indiviual angler. Both techniques have their advantages and disadvantages in terms of ease of application and personal safety, and our results show that while they have different effects in different species, in practical terms the differences are not great. In other words there is no general rule-of-thumb which favours one method over the other for all reef species. Many anglers familiar with venting were reluctant to continue to use the shotline release weight during the long-term tag-release experiment, suggesting that they found the former method to be generally easier to manage.

There exists, however, an alternative method – the release capsule – which we briefly examined under operational conditions in the field and found to be most promising. The capsule is easy to operate, relatively inexpensive, non-invasive to the fish, and less prone to failure or incomplete effectiveness than venting and shotline-releasing. Field staff who evaluated the method towards the conclusion of the Project were impressed by its potential, having observed a series of successful releases of coral trout and redthroat emperor using SCUBA and underwater video recordings. We strongly recommend that further evaluation of this method be undertaken, particularly in the context of species like small reef cod that don’t respond well to venting, and because of their high minimum legal size are very frequently released by anglers.

8.2 BENEFITS

The results of these investigations will benefit the recreational fishing industry in particular, but also those responsible for the management of the line-fishery in general. For some years the recreational fishery has been advised to use certain procedures to maximise the survival of fish that are released after capture, but there has been little empirical evidence to justify these ‘best practice’ arrangements. In many cases they are self-evident, but in the case of whether to promote the use of shotline-releasing or venting as a means of ameliorating the adverse effects of barotrauma, or whether to use circle hooks instead of J-hooks, the evidence was conflicting. For fishery managers the project results will assist in evaluating the likely outcomes of potential changes to the minimum (and maximum) legal size legislation. Although it was never suggested that absolute long-term survival rates would be able to be estimated from this work, the insights gained from our short-term experiments and discarding rate analyses will go a considerable way toward providing guidelines for the inclusion of cryptic fishing mortality in assessmentss of tropical reef line-fisheries in northern Australia.

8.3 FURTHER DEVELOPMENT

The involvement of recreational anglers in a long-term scientific experiment did not work as well as was originally expected, despite the great initial enthusiasm of the participating anglers. Using broad-based tag release-recapture in this context is problematical for these sorts of experiments because of a lack of experimental control over a number of very important factors, such as the distribution of catch and effort across temporal and spatial dimensions. We would recommend that further work on the effects (for example) of barotrauma should be done in a much more tightly-controlled experimental framework. This may be achieved using barochambers to directly simulate the effects of pressure reduction, or with controlled tag-release-recapture experiments at clearly circumscribed locations where catch-and-take fishing is prohibited and effectively enforced.

The physical changes involved in the latter stages of barotrauma are not well documented, and may represent the most critical part of the process for species such as saddletail snapper. Focussed research into soft-tissue damage resulting from barotrauma should be undertaken to better identfy the risks to long-term survival. This could be done in a way that extends the results of preliminary work by Bittar *et al.* on the physical characteristics of swim-bladders in key reef species.

While venting and shotline releasing have been shown to increase post-release survival in some species, both methods have their disadvantages. If not done correctly, venting may result in damage to visceral organs, and may not be completely effective in serranids such as coral trout. Shotline-releasing can also be ineffective in cases where an active fish releases itself from the apparatus before reaching its equilibrium depth. An alternative releasing device which was briefly evaluated during the project definitely deserves further attention. This is a weighted bell-shaped capsule covered with mesh that is lowered to an appropriate depth with the fish inside, effectively forcing it down to its equilibrium depth where the fish can easily swim out of the apparatus. Project staff have observed and filmed this in action, and believe it could effectively replace the other release methods. It is a less physically-invasive technique than either venting or shotline releasing, and is less likely to result in injury to the operator such as might occur when using a hypodermic syringe to vent an active fish in a small boat. However more research needs to be done to determine whether there is a significant level of pre-release escapement, and to accurately determine the appropriate equilibrium depths for the various species, including small reef cods which are widely known not to respond well to venting.

8.4 PLANNED OUTCOMES

The main planned outcome of the research (identified as Objective c in the Non Technical Summary) was to inform the recreational fishing community of appropriate best-practice arrangements for handling and releasing line-caught fish. This has been done through publicity material developed as part of the National Strategy's Extension project, various DPI&F publications, industry magazines and radio/press media releases.

An indication of the range of information products and communication opportunities used to generate these outcomes is shown in Table 8-1. Note that the table is not entirely comprehensive, nor does it refer to the many regional visits made by project staff to fishing clubs and angling groups during the course of the project. These visits were essential during the initial phase of the project, to identify anglers who would be prepared to collaborate with the project team in the long-term (tag release-recapture) experiment, to provide them with the necessary equipment, and ensure that they understood the experimental protocols.

Examples of some of the promotional material referred to in Table 8-1 are included in Appendix 3 (Section 8.7.3).

Table 8-1. Project publicity dossier, illustrating the methods used to communicate project objectives and results to the angling community and general public.

Date	Name	Type of communication	Contact name	Contact Organisation
Aug 03	McLennan		Roger Bowden	ANSA
Sept 03	Brown	Press release	Mark Dawson	DPI
Sept 03	Brown	Press release	Mark Dawson Ross McIntyre	DPI
Sept 03	Brown	Radio interview	Michael Semmler	The Travelling Fisherman (local FM radio)
Sept 03	Brown	Newspaper article		The Courier Mail (published Fri 26 Sept.- Weekend Extra)
Oct 03	Sumpton	Radio Interview	Ingrid Wilson	ABC Radio Rockhampton
Oct 03	Brown	Potential radio interview	Murray Cornish	ABC Radio Townsville
Oct 03	Brown	Radio interview	Diana Slater	ABC Radio Geraldton, WA
Nov 03	McLennan	Presentation	Tony Devine	Gold Coast Sportsfishing club
Nov 03	Mapleston	Article		CRC Fish & Fisheries Newsletter. Qld Fisherman. Sunfish
Dec 03	McLennan	Presentation		Gladstone Angling Club
Feb 04	Mapleston	Rec magazine article		Queensland Fishing Monthly
Apr 04	Brown	Article for 'Fish'	Liz Smith	QFS, DPI&F Vol 3, Issue 2.
Apr 04	Welch	Seminar		CRC Reef Research Centre
Apr 04	Brown	Presentation		Salvation Army (Redcliffe) social group
Apr 04	Brown	Article	Brendan O'Malley	Courier Mail (p.3, 22/4/04)
Apr 04	Brown	Radio interview	Frederice	QUT Radio
Apr 04	Brown	Radio interview	Peter Scott	ABC Coast FM Radio (Gold Coast & Sunshine Coast)
Apr 04	Brown	Radio interview	John Walden	ABC Radio Mackay
Apr 04	Brown	Radio interview	Warren Boland	ABC Radio Statewide
Jul 04	McLennan	PPT presentation		Yooralla Sports Fihing Club
Aug 04	McLennan/Sumpton	Progress seminar	Bill Sawynok	ANSA State Conference, Yeppoon

Date	Name	Type of communication	Contact name	Contact Organisation
Oct 04	Mapleston	Article in 'Fishing and Fisheries' newsletter	Annabel Jones	CRC Reef Research Centre, JCU. Issue #25
Nov 04	Mapleston	Poster presentation		ASFB 2004
Nov 04	Welch	Presentation/paper		ASFB 2004
Jan 05	Mapleston	Part article in rec fishing magazine		The Queensland Fishing Monthly, January 2005.
Jun 05	Brown	Seminar		SFR Seminar Ser. DPI&F
Jun 05	Project team	Conference Paper		4th World Rec Fishing Conference
Jul 05	Brown	Conference Paper		AMSA National Conference. 2005
Jul 05	Brown	Conference Paper		ASFB National Conference. 2005
Jul 05	Brown	Radio interview		ABC Radio Townsville/ABC Online
Sep 05	Sumpton	Radio Interview	Teresa Phillips	ABC Radio Townsville
Sep 05	Sumpton	Radio interview	Michael Matin	ABC Radio Townsville
Sep 05	Project team	Press release	Mark Dawson	DPI&F (for Townsville release)
Sep 05	Sumpton	Newspaper article	Jessica	Townsville Bulletin
Jan 06	Welch	Radio interview	David Cusson	Science Show, ABC Radio NQ
Feb 06	Brown	Seminar presentation	Bill Sawynok	Recfishing Research Steering Committee meeting (Brisbane)
Mar 06	Welch	Progress seminar		Northern Fisheries Centre (DPI&F)
June 06	Kirkwood	Seminar		SFC Seminar Ser. (DPI&F)
Aug 06	Kirkwood	Conference paper		ASFB National Conference, Hobart.
Aug 06	Mapleston	PPT presentation	Bill Sawynok	ANSA State Conference, Yeppoon
Jan 07	Brown	Comprehensive progress report	To ~30 participating anglers	
Feb 07	Brown	Contribution to best practice release brochure	Bill Sawynok	Infofish Services (Released Fish Survival programme)`
June 07	Brown	Newspaper article	Geoff Orr	Courier Mail, Fri. June 8.
June 07	Brown	Progress article for rec fishing magazine.	Steve Morgan	Queensland Fishing Monthly
July 07	Brown/Sumpton	Material for 'Gently Does It' Releasing Tropical Reef Fish brochure	Bill Sawynok	Infofish Services (Released Fish Survival programme)`
Nov 07	Brown	Progress article for rec fishing magazine.	Jim Harnwell	Fishing World
Nov 07	Brown	Article in 'Hooked on Fish'	Katherine Boczynski	DPI&F on-line and hard copy magazine
Feb 08	Brown	Advice on venting for GBRMPA extension	Phil Laycock, Regional Liaison Officer	Great Barrier Reef Marine Park Authority, Far Northern regional office
Feb 08	Brown	Abstract for invited conference paper	Chuck Adams	American Fisheries Society Annual conference – Fish Barotrauma Symposium. Ottawa, Aug 08
Feb 08	Brown/Sumpton	Contrib. to promotional DVD	Bill Sawynok	Infofish Services (Released Fish Survival programme)`

8.5 CONCLUSIONS AND RECOMMENDATIONS

The main conclusions from this project are

- Non-offset circle hooks generally cause less injury (but not bleeding) than J-hooks.
- Offset circle hooks do not cause less injury or bleeding than conventional J-hooks, nor do they reduce the incidence of deep-hooking.
- Small and large hooks are equally implicated in deep-hooking.
- Large hooks cause more injury and bleeding than small hooks to small-sized fish, probably because they are associated with an increased incidence of foul-hooking.
- Catch rates from J-hooks and circle hooks are similar across species.
- The conservation value of applying a barotrauma-relief treatment varies from species to species, but in general there is an advantage in treating a fish showing signs of barotrauma.
- Red emperor do not appear to benefit from barotrauma treatment.
- Barotrauma treatment, provided it is carried out with due care, does not have an adverse effect on the survival prospects of the fish.
- The relative effectiveness of venting vs. shotline releasing differs slightly between species, but overall there is no clear evidence that either method is superior to the other.

On the basis of the above, we recommend that anglers be encouraged:

- to use non-offset circle hooks rather than J-hooks.
- to take whatever steps may be available to minimize the incidence of deep-hooking.
- to treat barotrauma-affected fish (except for red emperor) with one or other of the release procedures depending on their own preferences and experience. Treating fish that are apparently unaffected is not likely to be detrimental to their survival, and is a good option in cases where the barotrauma status of a fish is not immediately obvious.
- to explore the use of alternative release methods (such as the release capsule) to overcome positive buoyancy in fish suffering from barotrauma.

8.6 REFERENCES

Relevant references are included at the end of each chapter, so are not repeated here.

8.7 APPENDICES

8.7.1 Appendix 1: Intellectual Property.

This is not applicable to this project.

8.7.2 Appendix 2: Staff engaged on Project

Dr Ian Brown[1] (Principal Investigator)
Dr David Mayer[2] (Consulting Biometrician)
Dr Wayne Sumpton[1] (Co-investigator)
Dr David Welch[1,3] (Co-investigator)
Mr Amos Mapleston[3] (Co-investigator)
Dr John Kirkwood[1] (Co-investigator)
Dr Gavin Begg[3] (Co-investigator)
Mr Mark McLennan[1] (Senior Fisheries Technician)
Mr Matthew Campbell[1] (Senior Fisheries Technician)
Dr Ian Halliday[1] (Collaborating Scientist)
Mr Adam Butcher[1] (Collaborating Scientist)
Dr Bruce Mapstone[3] (Collaborating Scientist)
Mr Bill Sawynok[4] (Principal, Infofish Services Inc.)
Mr B Davidson[1] (Skipper, *RV Tom Marshall)*
Mr S Kondylas[1] (Skipper, *RV Tom Marshall)*
Mr S Maberley[1] (Skipper, *RV Tom Marshall)*

[1] Southern Fisheries Centre, Department of Primary Industries and Fisheries, Queensland.

[2] Animal Research Institute, Department of Primary Industries and Fisheries, Queensland.

[3] Fish and Fisheries Research Centre, James Cook University, Townsville, Queensland.

[4] Australian National Sportfishing Association (ANSA); Infofish Services, Rockhampton.

8.7.3 Appendix 3: Print media extension products

The following pages contain a selection of newspaper reports, magazine articles and project update newsletters used to communicate project information to the general public, and to the recreational fishing sector in particular:

Ones that get away have a story to tell

Brendan O'Malley

FISHERMEN like to tell tall tales about the one that got away, but now scientists are trying to help their "escapees" survive to tell their own tale.

Recent surveys showed recreational anglers tossed back half of all the fish they caught, usually because they were too small or not a tasty species.

While most people thought they were doing the right thing, it was not known how many released fish survived.

Researchers at Queensland's Agency for Food and Fibre Science are trying to answer the question as part of a national study into which species bounce back best from near-death encounters with fishermen.

"We're looking at a number of things including the species, whether the type of hook makes a difference and where the fish gets hooked," AFFS scientist Ian Brown said.

"We also want to look at the effect of barotrauma (damage to swim bladders), which tends more to be a problem with fish pulled up from water 10m or more deep.

"Fishermen have different techniques to reduce barotrauma, and we want to see if the type of technique has an effect on survival."

Fish from deep waters tend to float like balloons if tossed back in the water, making them a target for predators.

Environmentally aware anglers deal with the problem by piercing swim bladders with a small hypodermic-like needle or by sinking fish on a weighted line.

Although AFFS and the Reef Co-operative Research Centre in Townsville were concentrating on tropical reef species like red emperor and coral trout, other states were also looking at common coastal species.

"We have two different experiments. One will look at short-term survival, which we are going to measure by putting fish we catch into cages for three or four days," Dr Brown said.

Survival of the fittest

Recent surveys have shown that around half the fish recreationally caught in Queensland are returned to the water. However, there is little information about how many of these fish survive. A new research program is helping to answer this question.

The Department of Primary Industries and Fisheries and CRC Reef Research Centre have joined forces to investigate the fate of fish released in Australia's tropical reef line fisheries.

The Fisheries Research and Development Corporation is funding the project, one of several studies coordinated under a national strategy aimed at maximising the survival of released line-caught fish.

The project will investigate how different capture and release methods such as hook type and the swim-bladder deflation technique affect fish survival.

Short-term survival will be estimated using fish contained in enclosures.

Calculating survival over a longer period is more complex and will require a carefully designed tag-recapture program.

The work will focus on key tropical reef species including coral trout, red throat emperor, small- and large-mouth nannygais, red emperor and grassy sweetlip.

A small group of specialist tag and release anglers fishing at strategic locations along the tropical Queensland coast will assist with the tagging research.

Another of the project's goals is to identify methods of handling fish that will maximise their chance of surviving when released.

Results of the research will be promoted through the national Gently Does It campaign.

Knowing how many fish survive after being released is important information, assisting fisheries resource managers to develop strategies that will help ensure the long-term sustainability of Queensland's recreational and commercial line fisheries.

For more information contact Dr Ian Brown on (07) 3817 9580 or email ian.brown@dpi.qld.gov.au

Juvenile red emperor

'Fish' Vol 3 issue 2
Autumn '04.

4 **Smart State** smart fishing

CRC Reef Research Centre

FISHING & FISHERIES

NEWSLETTER

October 2004
issue no. 25

ARRIVE ALIVE

survival of released fish

By Amos Mapleston

In an earlier edition of the Fishing and Fisheries newsletter an article appeared outlining the new post release survival project. This project is part of a National Strategy focused on determining the survival of released line caught fish. Funded by the Fisheries Research and Development Corporation (FRDC), the project is a partnership between CRC Reef, the Department of Primary Industries and Fisheries and Infofish Services. The aims of the project are to determine the survival rates of released line caught fish for a number of important tropical reef fish species including red emperor, red throat emperor, coral trout, small and large mouth nannygai and spangled emperor.

The project is now well underway with researchers undertaking a number of field trials of cages which will be used to determine the short term survival of the reef fish. The cage used in the recent trial was a large 15m deep, cylindrical 'sock' like enclosure, and while a number of teething problems need to be ironed out, the cage appears ideally suited for use in the experiment.

The long term survival of released reef fish is being studied in a large scale tagging program run through the existing SUNTAG network. Recreational fishers already involved in tagging through the Australian National Sport Fishing Association (ANSA), some charter skippers and commercial fishers have been busy over the last 12 months tagging released fish. As well as tagging fish, volunteers have been using one of three release techniques (venting using a hollow needle, shot release using heavy weight to take fish to the bottom and no treatment) and recording important information about depth of water, the types of hooks used, where the hooks lodged in the mouth of the fish, and what condition the fish was in when caught and released.

With all this work undertaken to tag and collect data it is vitally important that when tagged fish are recaptured this information is received by researchers. If you capture a tagged fish while out fishing you are requested to record the tag number from the tag and the location (GPS position or reef name if possible), a measurement of the fish's length and whether the fish was released or kept. To report this information, call the 1800 phone number recorded on the tag (Ph: 1800 077 001) when you return home. This will ensure we can all get the maximum benefit from this important research.

Photo courtesy of QDPI&F

Red emperor kept in large cylindrical 'sock' like enclosures for several days during recent caging experiments are providing data on the short term rates of survival of released reef fish using a variety of release techniques.

Photo courtesy of QDPI&F

If you catch a fish with a tag (see left) it may be part of this research project. You are requested to record the tag number from the tag (see above) as well as a location of capture (GPS position or reef if possible), a measurement of the fish's length and whether the fish was released or kept. To report this information, call the 1800 phone number recorded on the tag when you return home (1800 077 001).

Continued
Page 2

editor:
annabel jones

phone: 07-47816365
fax: 07-47814099
email:
annabel.jones@jcu.edu.au

Published by
CRC Reef Research Centre
Fishing & Fisheries Project
based at
James Cook University
Townsville 4811

www.reef.crc.org.au

PROJECT UPDATE

a word from the project leader

Gavin Begg

With all the major changes that have recently been implemented in the reef line fishery, we have been actively catching up with many of you over the past couple of months. It has been good to hear your views on these changes and where you think the fishery is heading in the long-term.

A recent stakeholder workshop held by the F&F team in Townsville, involving commercial, recreational and charter fishers, and QDPI&F and GBRMPA managers provided us with a great opportunity to discuss the reef line fishery, with a particular emphasis on red throat emperor. At this workshop stakeholders discussed how they operated, what they caught, and what was important to them for the future of the fishery. From these discussions, we are now examining the things we were told in helping us understand the dynamics of the fishery.

On a similar note, our students will shortly be holding a second Student-Stakeholder Workshop to present their research and discuss its implications. The first of these was extremely well received by the stakeholders that attended. A range of topics will be covered at this second workshop from the population dynamics of coral trout to traditional fishing in Torres Strait. Once again this will be a great opportunity for our students to interact with a wide range of stakeholders and to hear their views.

Finally, I would like to congratulate one of our team members, Ashley Williams, for receiving the Graeme Kelleher Prize for his recent findings on the dynamics of red throat emperor. This prize is awarded annually in recognition of an outstanding PhD thesis relevant to the ecologically sustainable development of the Great Barrier Reef World Heritage Area. The prize was established in 2003 by the CRC Reef Research Centre to acknowledge the contribution of Graeme G. Kelleher to the wise use of the Great Barrier Reef.

Award winning research

The F&F team is very pleased to congratulate one of our younger scientists on winning a prestigious award for research carried out towards his PhD. Ashley Williams has been awarded the Graham Kelleher Prize for his discoveries about the movements and biology of red throat emperor and impacts for management of this important reef fish species. The prize is awarded by the CRC Reef Research Centre annually in recognition of an outstanding PhD thesis relevant to the ecologically sustainable development of the Great Barrier Reef World Heritage Area. This prize winning research formed part of the Effects of Line Fishing Project, and the F&F team has been fortunate to retain Ashley as a research scientist now that his PhD study is complete.

Ashley Williams receives the Graham Kelleher Prize from CRC Reef Chairman, Sir Sydney Schubert. Ashley's research into red throat emperor is critical for management of this important reef fish species.

From Page 1

The number of fish tagged has steadily increased over the past year. However, while some species are well represented such as red emperor, others are not as prominent, particularly the offshore reef species such as coral trout, red-throat emperor and spangled emperor. Over the next few months we hope to be able to address this and increase the numbers of these under represented species.

To date, 276 tagged fish have been recaptured, with at least one recapture for each of the fish species included in the study. This is a great start and we hope numbers will increase in the months to come as more fish are tagged.

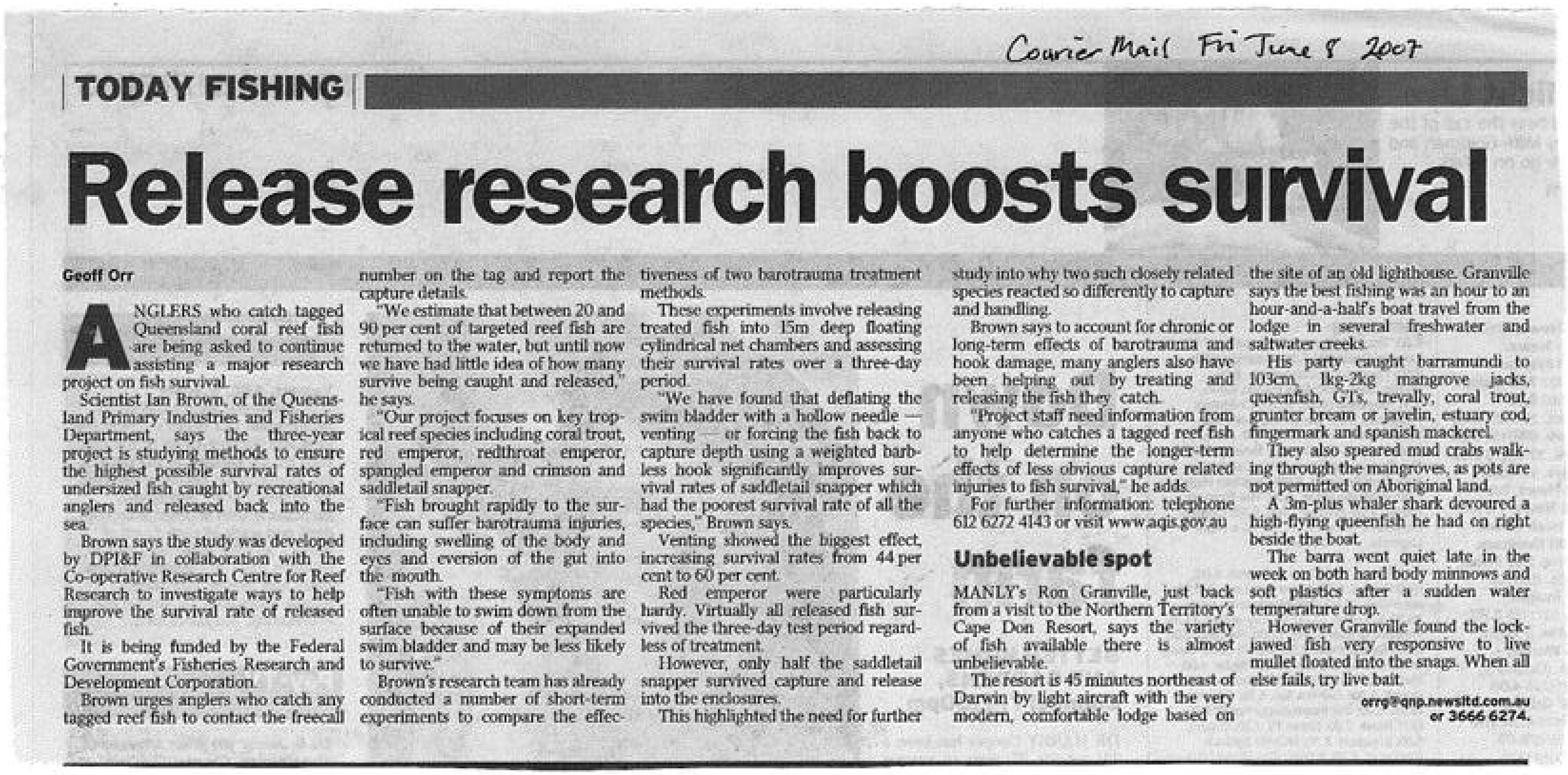
The information from this research project will provide essential information about the survival of released fish and the best practices for handling and releasing line caught reef fish. This is important information for fisheries managers and all recreational, commercial and charter fishers to improve the survival of the fish which they release.

The researchers would like to thank all the taggers who have taken the time to tag fish and record information for the project, or who have recorded recaptures of fish.

If you would like more information on this research project please contact either: Amos Mapleston at the CRC Reef Research Centre, James Cook University, Townsville, Qld 4811, phone 07 47815247, e-mail amos.mapleston@jcu.edu.au or Mark McLennan at the Southern Fisheries Centre, Deception Bay, Qld 4508, phone 07 3817 9596, e-mail Mark.McLennan@dpi.qld.gov.au.

Good numbers of fish have been tagged and released for the post release survival project. Some species, such as red throat emperor and spangled emperor are in fairly small numbers, but we hope to have more of these species tagged and recaptured in the coming months.

Species	Tagged	Recaptured	% recaptured
Coral trout	113	11	9.73
Grass emperor	331	12	3.63
Large mouth nannygai	108	19	17.59
Red emperor	463	200	43.20
Red throat emperor	87	3	3.45
Small mouth nannygai	37	30	8.90
Spangled emperor	44	1	2.27
Total	**1483**	**276**	**18.61**



Courier Mail Fri June 8 2007

TODAY FISHING

Release research boosts survival

Geoff Orr

ANGLERS who catch tagged Queensland coral reef fish are being asked to continue assisting a major research project on fish survival.

Scientist Ian Brown, of the Queensland Primary Industries and Fisheries Department, says the three-year project is studying methods to ensure the highest possible survival rates of undersized fish caught by recreational anglers and released back into the sea.

Brown says the study was developed by DPI&F in collaboration with the Co-operative Research Centre for Reef Research to investigate ways to help improve the survival rate of released fish.

It is being funded by the Federal Government's Fisheries Research and Development Corporation.

Brown urges anglers who catch any tagged reef fish to contact the freecall number on the tag and report the capture details.

"We estimate that between 20 and 90 per cent of targeted reef fish are returned to the water, but until now we have had little idea of how many survive being caught and released," he says.

"Our project focuses on key tropical reef species including coral trout, red emperor, redthroat emperor, spangled emperor and crimson and saddletail snapper.

"Fish brought rapidly to the surface can suffer barotrauma injuries, including swelling of the body and eyes and eversion of the gut into the mouth.

"Fish with these symptoms are often unable to swim down from the surface because of their expanded swim bladder and may be less likely to survive."

Brown's research team has already conducted a number of short-term experiments to compare the effectiveness of two barotrauma treatment methods.

These experiments involve releasing treated fish into 15m deep floating cylindrical net chambers and assessing their survival rates over a three-day period.

"We have found that deflating the swim bladder with a hollow needle — venting — or forcing the fish back to capture depth using a weighted barbless hook significantly improves survival rates of saddletail snapper which had the poorest survival rate of all the species," Brown says.

Venting showed the biggest effect, increasing survival rates from 44 per cent to 60 per cent.

Red emperor were particularly hardy. Virtually all released fish survived the three-day test period regardless of treatment.

However, only half the saddletail snapper survived capture and release into the enclosures.

This highlighted the need for further study into why two such closely related species reacted so differently to capture and handling.

Brown says to account for chronic or long-term effects of barotrauma and hook damage, many anglers also have been helping out by treating and releasing the fish they catch.

"Project staff need information from anyone who catches a tagged reef fish to help determine the longer-term effects of less obvious capture related injuries to fish survival," he adds.

For further information: telephone 612 6272 4143 or visit www.aqis.gov.au

Unbelievable spot

MANLY's Ron Granville, just back from a visit to the Northern Territory's Cape Don Resort, says the variety of fish available there is almost unbelievable.

The resort is 45 minutes northeast of Darwin by light aircraft with the very modern, comfortable lodge based on the site of an old lighthouse. Granville says the best fishing was an hour to an hour-and-a-half's boat travel from the lodge in several freshwater and saltwater creeks.

His party caught barramundi to 103cm, 1kg-2kg mangrove jacks, queenfish, GTs, trevally, coral trout, grunter bream or javelin, estuary cod, fingermark and spanish mackerel.

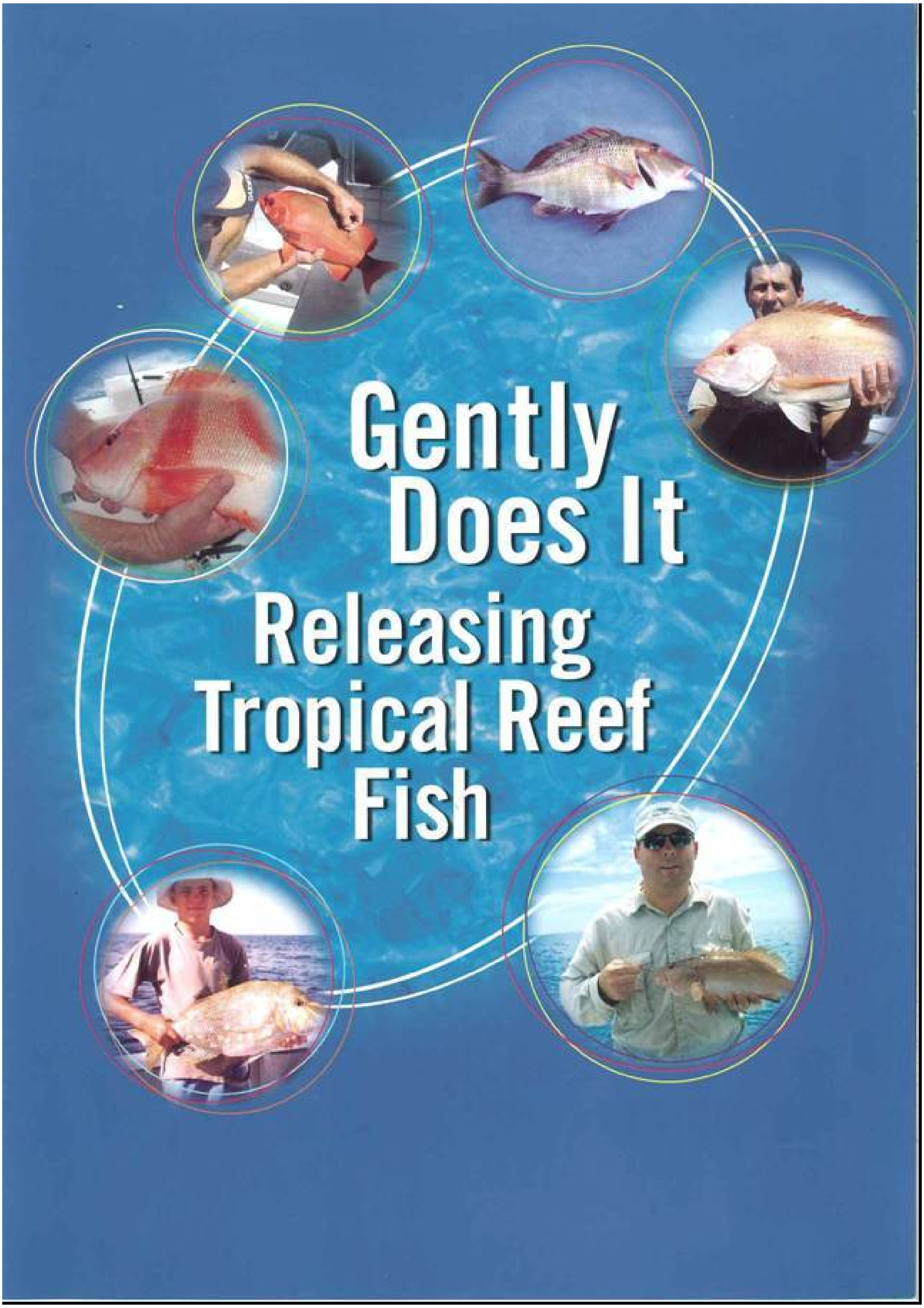
They also speared mud crabs walking through the mangroves, as pots are not permitted on Aboriginal land.

A 3m-plus whaler shark devoured a high-flying queenfish he had on right beside the boat.

The barra went quiet late in the week on both hard body minnows and soft plastics after a sudden water temperature drop.

However Granville found the lockjawed fish very responsive to live mullet floated into the snags. When all else fails, try live bait.

orrg@qnp.newsltd.com.au
or 3666 6274.



Gently
Does It
Releasing
Tropical Reef
Fish

Bag and size limits now result in an increased number of reef fish being released with between 20% and 90% of targeted reef fish released in Queensland, depending on species. Research has been undertaken on six key reef species to determine short and long-term survival, testing of different release techniques and the effects of using different hook types.

The key causes of mortality of reef fish that are released are the effects of barotrauma (over expanded swim bladder), deep hooking, handling and predation on release.

Barotrauma

Barotrauma results from the expansion of gases in the swim bladder and its effects are related to the depth from which the fish is brought to the surface. For many species the symptoms begin to appear in fish caught in about 10m of water. Mild symptoms are a hardening of the fish's stomach. More severe symptoms include bulging eyes and the stomach pushed out of the mouth. Fish from very deep water may show no signs of barotrauma because the swim bladder has burst, releasing all the gas.

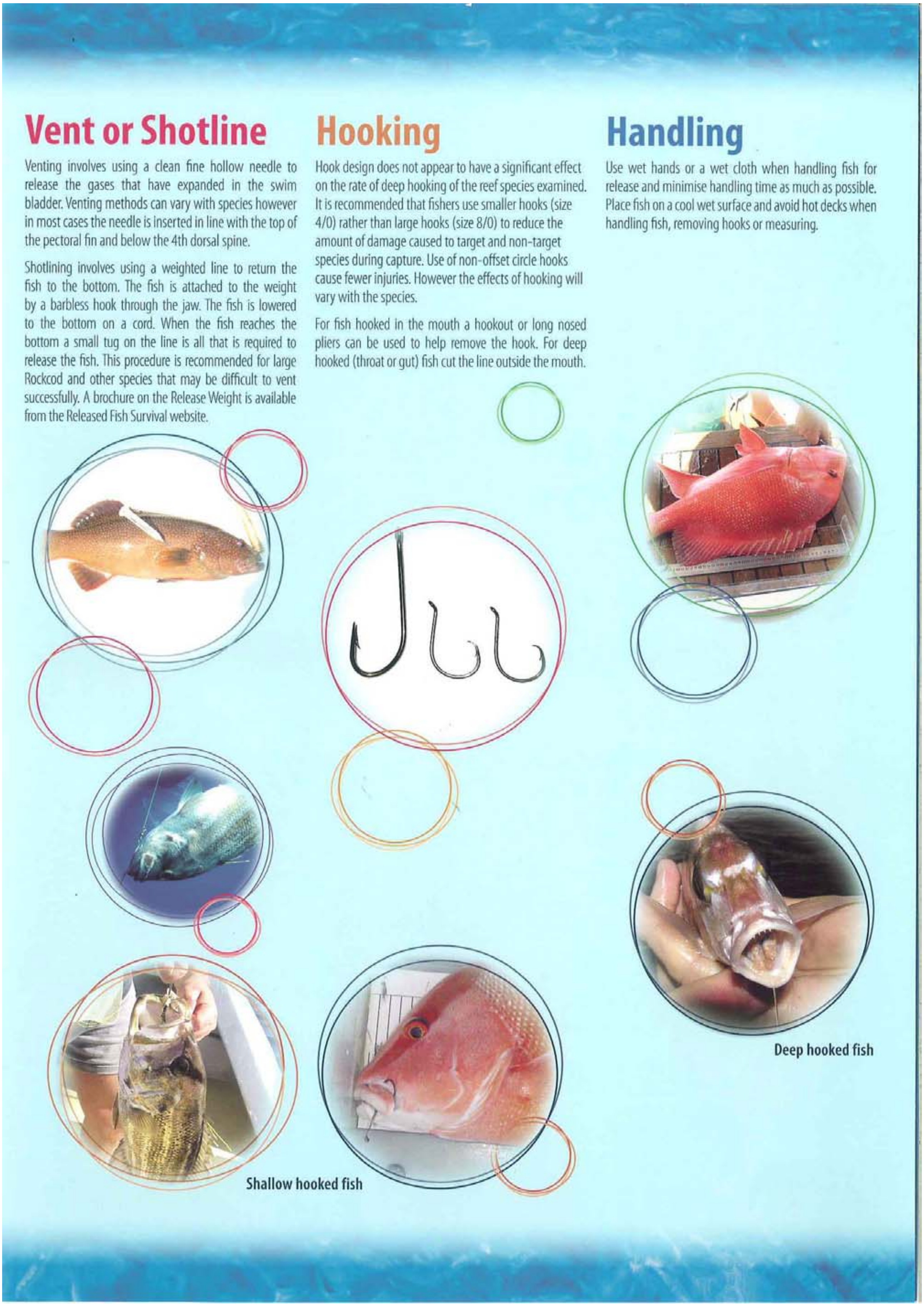
The research tested three methods of release to see if they could affect the survival rates of released fish. The methods were no treatment (releasing the fish as caught), venting the fish with a clean fine hollow needle to release the expanded gases in the swim bladder, and returning the fish to the bottom on a weighted line (shot-line). Fish treated by each method were tagged and placed in a vertical cage 15m deep for 3 days to check on their survival (see results of short-term survival experiment in table below). Information is continuing to be collected on longer term survival through a tagging experiment.

Treating Fish Suffering From Barotrauma

Fish showing signs of barotrauma should be vented if they are floating to help them get back down to the bottom. Venting resulted in an increase in the survival of Saddletail Snapper, but based on the short-term experiments results there seems to be little to be gained from treating Red Emperor.

Short-term (3-day) survival rates of released coral reef species, by treatment

	SHORT-TERM SURVIVAL RATE				
TREATMENT	CORAL TROUT	REDTHROAT EMPEROR	RED EMPEROR	CRIMSON SNAPPER	SADDLETAIL SNAPPER
No treatment	78.5 %	90.7 %	100.0 %	82.6 %	44.4 %
Shot-lined	78.1 %	79.6 %	94.8 %	80.5 %	47.4 %
Vented	84.8 %	85.6 %	100.0 %	84.3 %	60.2 %



Vent or Shotline

Venting involves using a clean fine hollow needle to release the gases that have expanded in the swim bladder. Venting methods can vary with species however in most cases the needle is inserted in line with the top of the pectoral fin and below the 4th dorsal spine.

Shotlining involves using a weighted line to return the fish to the bottom. The fish is attached to the weight by a barbless hook through the jaw. The fish is lowered to the bottom on a cord. When the fish reaches the bottom a small tug on the line is all that is required to release the fish. This procedure is recommended for large Rockcod and other species that may be difficult to vent successfully. A brochure on the Release Weight is available from the Released Fish Survival website.

Hooking

Hook design does not appear to have a significant effect on the rate of deep hooking of the reef species examined. It is recommended that fishers use smaller hooks (size 4/0) rather than large hooks (size 8/0) to reduce the amount of damage caused to target and non-target species during capture. Use of non-offset circle hooks cause fewer injuries. However the effects of hooking will vary with the species.

For fish hooked in the mouth a hookout or long nosed pliers can be used to help remove the hook. For deep hooked (throat or gut) fish cut the line outside the mouth.

Handling

Use wet hands or a wet cloth when handling fish for release and minimise handling time as much as possible. Place fish on a cool wet surface and avoid hot decks when handling fish, removing hooks or measuring.

Shallow hooked fish

Deep hooked fish

Other information products

The Released Fish Survival website is at **www.info-fish.net/releasefish** and contains a range of useful fact sheets and information products.

Technical reports outlining the results of the individual research projects can be downloaded from the website.

Some other information products that are available include posters promoting fish friendly tackle, results of the Barramundi research, Flathead survival poster and NSW fish survival poster. These posters are suitable for distribution through fishing clubs, tackle and boating shows, Fishcare volunteers and to schools with marine or fish studies.

Fisheries and related websites

Fisheries Research and Development Corporation
www.frdc.com.au

Queensland Department of Primary Industries and Fisheries
www.dpi.qld.gov.au/fishweb

New South Wales Department of Primary Industries
www.fisheries.nsw.gov.au/recreational

Department of Primary Industries - Victoria
www.dpi.vic.gov.au/dpi/

Department of Primary Industries and Water - Tasmania
www.dpiw.tas.gov.au

Inland Fisheries Service - Tasmania
www.ifs.tas.gov.au

Primary Industries and Resources - South Australia
www.pir.sa.gov.au

Department of Fisheries - Western Australia
www.fish.wa.gov.au/sec/rec/

Department of Primary Industries, Fisheries and Mines - Northern Territory
www.nt.gov.au/dbird/dpif/fisheries

Recfish Australia
www.recfish.com.au

Australian National Sportfishing Association
www.ansa.com.au

Australian Fishing Tackle Association
www.afta.net.au

Infofish Services
www.info-fish.net

Acknowledgements

Ross Winstanley and Released Fish Survival Steering Committee

The following organisations have contributed significantly to the National Strategy

Fishy Science

The captured, tagged and released reefies in their enclosure awaiting examination.

Releasing reefies

Queensland fisheries scientist DR IAN BROWN and his research team from the Southern Fisheries Centre report on the progress of research into the survival of tagged and released coral reef fish.

STUDIES in Australia and overseas have shown about half the fish caught by anglers are released because they are below the minimum legal size, above the bag limit, or caught and tagged by catch & release anglers. However until recently we've had little idea of how many fish survive being caught and released.

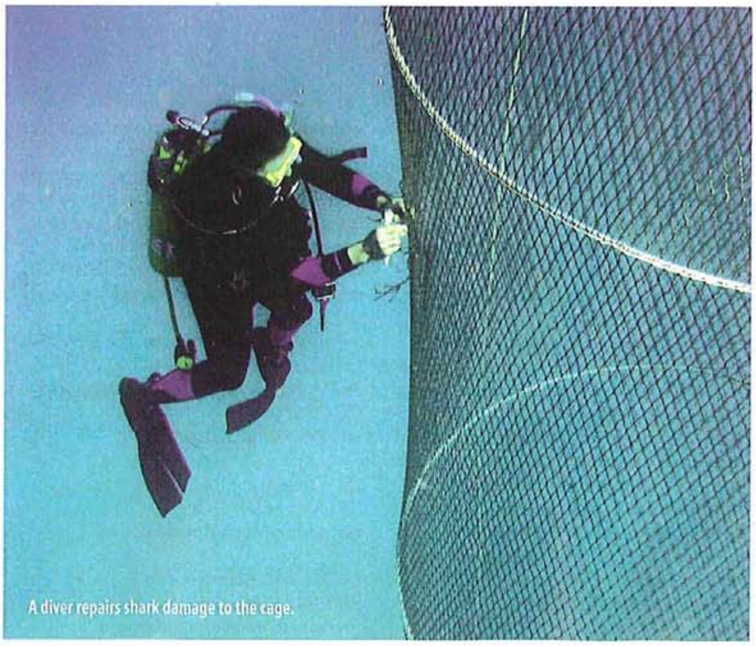
Our project focused on six key Australian tropical reef fish species: coral trout, red emperor, redthroat emperor, spangled emperor, and crimson and saddletail snapper. It was funded by the Fisheries Research and Development Corporation (FRDC), and is one of a suite of projects Australia-wide coming under the banner of the national strategy for increasing the survival of released line-caught fish. The project examined the effects of different hook designs and release methods on survival rates of the key species, which will help to identify best practice techniques for catching and releasing tropical reef fish.

We found that hook design or pattern has different effects on the incidence of hook-related injury in various species, and no effect in others. The injury rate among crimson snapper caught on non-offset circle hooks (4.7 per cent) was very much lower than in fish taken on conventional J-hooks (13.3 per cent) or offset circles (14.4 per cent). On the other hand, the injury rate among saddletail snapper caught on offset circle and J-hooks was zero, but more than 8 per cent in fish taken on non-offset circle hooks. In the three remaining species tested (red emperor, redthroat emperor and coral trout) the design of the hook did not appear to be a major factor in the incidence of hook-related injury.

We also examined the effect of hook size

74 FISHING WORLD NOVEMBER 2007

A red throat emperor is released into the cage. Shot-lining these fish seems to ensure a healthier release.



A diver repairs shark damage to the cage.

on injury to see whether there are any general trends that could help maximise the survival of released reef species. Significantly less hook damage was seen in coral trout when small hooks were used, and there was a similar (but not statistically significant) tendency in crimson and saddletail snapper. However hook size had no apparent effect on injury rates in redthroat emperor or red emperor.

The results of our hook damage experiments indicate that to maximise survival of released coral reef fish, and depending on the species being targeted, anglers should consider using smaller (e.g. 4/0 or 5/0) rather than larger (8/0) hooks. It could also be of some conservation benefit to use circle hooks (preferably non-offset) rather than J-hooks, as the former were implicated in fewer instances of deep hooking, where the hook becomes lodged in the throat or gut.

The use of circle hooks has sometimes been shown to reduce catch rates, possibly because of the slightly different technique required to fish them effectively, but we did not find substantial

NOVEMBER 2007 **FISHING WORLD** **75**

A coral trout is "vented" prior to release. Anglers should reduce barotrauma to any fish caught and released in deep water.

differences in the catch rates of any of the main species that could be attributed to hook design or pattern. We did find, however, that catch rates of crimson snapper were higher when small hooks (4/0 and 5/0) were used than when larger sized hooks (8/0) were used, but hook size did not influence the catch rates of any of the other key species.

Fish brought to the surface from depths more than about 10m often suffer from barotrauma, the name given to an array of injuries resulting from a rapid decrease in pressure. Common visible symptoms include a swollen body, bulging eyes, parts of the gut protruding from the fish's mouth, and an inability to swim down from the surface because of the expanded swim bladder's increased buoyancy.

If the buoyancy issue can be overcome, the fish is better able to swim down from the sea surface, and thus avoid predation by seabirds, sharks and large pelagic fish. Barotrauma symptoms can be relieved by deflating or "venting" the swim-bladder with a clean hollow needle, or forcing the fish back to its capture depth with a shot-line. Our project set out to determine experimentally whether venting or shot-line releasing improves fish survival, and if so, by how much.

In a series of short-term experiments line-caught fish were treated by venting or shot-lining, after which they were individually tagged and released into large floating enclosures 15m deep x 2m diameter. Tagged control fish were also released into the enclosures without any treatment. After three days the enclosures were lifted and the numbers of fish surviving from the treatment and control groups compared.

Of all the species tested, saddletail snapper was the most susceptible to capture and handling-related mortality, with only 44 per cent of the untreated fish surviving the three-day experiment. However 47 per cent of the fish released by shot-line and 60 per cent of vented fish survived, clearly showing the benefit of treating the symptoms of barotrauma, particularly with the venting technique. In each of the other key species survival of vented fish was only marginally higher than that of shot-line released fish.

One of the obvious advantages of barotrauma treatment is to remove the fish as quickly as possible from the risk of mortality from predation. As the enclosures protect the captive fish from natural predators, the short-term experiments cannot account for this factor in estimates of survival rates. This is the reason for complementing the enclosure experiments with a parallel long-term experiment in which treated fish are released into the wild.

The success of the long-term experiments continues to depend on the assistance of recreational anglers tagging and releasing fish back into the ocean after applying the release treatments. Our results so far indicate that barotrauma relief procedures seem to work best for members of the "reds" group (red emperor, crimson snapper and saddletail snapper). Of the two procedures, venting had the greater positive effect on survival. On the other hand the survival of coral trout released by shot-line appeared slightly better than those released after venting. Amongst the emperor group there were only minor differences in recapture rates between untreated, vented and shot-line-released individuals, suggesting (at this stage) that barotrauma relief treatment has little effect on improving the survival of the emperor species.

Of course predators are not restricted to the surface, so releasing a fish with a shot-line or after venting does not necessarily mean that it will be totally immune from this source of mortality. Nevertheless, barotrauma relief can benefit the fish in other ways, by reducing the physical pressure exerted on its internal organs by the over-inflated swim-bladder, and by minimising the exposure of the fish's eyes to potentially harmful ultraviolet light. Soft tissue compaction, twisting and lesions are common signs of barotrauma, but they are rarely seen except by careful dissection and inspection of internal organs. This type of damage may take some time – perhaps weeks or months – to have an effect on the fishes' survival, which makes the results of the long-term tagging experiment even more important.

If a fish that's about to be released shows any signs of barotrauma, we recommend that it be carefully vented using a clean hollow needle to release the gas from its swim-bladder, or "recompressed" using a weighted releasing shot-line. Both techniques seem to work well, and neither significantly increases post-release mortality. For some key reef species the data already points to a longer-term benefit from these procedures, either because of reduced surface predation or because soft-tissue damage is minimised.

The tag release-recapture results outlined above are provisional, and more detailed analyses still need to be done. The project has several more months during which to accumulate more release and recapture data. To ensure the best chance of achieving a statistically reliable outcome from this work, we urge all anglers to be on the lookout for tagged reef fish, and to report any recaptures as quickly and accurately as possible using the free-call number printed on the tag.

For further information on the project please contact:
Dr Ian Brown (principal investigator)
(07) 3817 9580
ian.brown@dpi.qld.gov.au

Dr Wayne Sumpton
(07) 3817 9584
wayne.sumpton@dpi.qld.gov.au

Mr Mark McLennan
(07) 3817 9596
mark.mclennan@dpi.qld.gov.au