Maximizing the post-release survival of angler-caught Yellowfin bream (Acanthopagrus australis) and Mulloway (Argyrosomus japonicus)

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Maximising the post-release survival of angler-caught yellowfin bream (*Acanthopagrus australis*) and mulloway (*Argyrosomus japonicus*).

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Master of Science Thesis

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Thesis Declaration

I certify that the work presented In this thesis is to the best of my knowledge and belief, original, except as acknowledged in the text and that the material has not been submitted, either in whole or in part, for a degree at this or any other university. I acknowledge that I have read and understood the University's rules, requirements, procedures and policy relating to my higher degree research award to my thesis. I certify that I have complied with the rules, requirements, procedures and policy of the University (as they may be from time to time).

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Date: 3 December 2018

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ABSTRACT

Recreational fishing is a popular activity in Australia that involves over three million participants who predominantly use hook and line (angling) to catch in excess of 170 species. Like in most countries, Australian recreational fisheries are managed by a combination of personal quotas (bag limits), minimum legal lengths and, to a lesser extent, spatial closures. The underlying assumption for the success of these arrangements is that few released fish die, and that there are minimal impacts on surviving individuals.

Studies have shown that rates of post-release survival are species specific, highly variable and dependent upon a multitude of factors including terminal gear type and configuration, anatomical hooking location, exercise, water temperature, post-capture handling (including air exposure) and angling environment. Not withstanding that mortality is likely the result of interactions between multiple factors, it is well known that there are distinct attributable causes. Further, the angling process may not itself result in fish mortality but may cause sublethal disruption (e.g stress) to individuals and as a consequence deleteriously impact fish populations. Overall, quantifying any deleterious effects of angling is an important component in the overall assessment of factors that contribute toward post-release survival of fish following capture by hook-and-line.

Two popular recreational species throughout southeastern Australia are yellowfin bream (*Acanthopagrus australis*) and mulloway (*Argyrosomus japonicus*). Owing to local regulations and the increasing popularity of catch-and-release fishing, more than eight million breams (*Acanthopagrus* spp.) and two hundred thousand mulloway are released nationally by anglers each year. These discards represent a high proportion of the estimated total recreational catch for these species and is of potential concern considering the possibility for angling-induced mortality.

The objectives of this study were to identify the deleterious hooking, handling and release procedures effecting the post-release survival of yellowfin bream and mulloway and examine ways to maximise the post-release survival for these species. Two field and six aquaria experiments were done to satisfy these objectives.

One field experiment used anglers to record the anatomical hooking location of various J-type and circle hooks during normal fishing operations targeting yellowfin bream. In all other experiments yellowfin bream and/or mulloway were hooked from an aquaria or the wild and subjected to various treatments that involved either removing the hook, cutting the line and leaving the hook imbedded or exposing individuals to air for different time periods. In addition, some hooked fish were released without air exposure or were subjected to intensive exercise following hooking. Following treatment fish were held in cages and monitored for up to ten days prior to euthanasia and autopsy for some surviving individuals to assess for the presence of hooks or wounds. To assess the relative stress of fish before and after the catch-and-release process in the cage experiments, blood samples were taken from fish prior to angling and at the end of the monitoring period.

The results from the various experiments examining factors contributing to mortality demonstrated post-release survival rates between 89 and 100% for yellowfin bream and 27 and 96% for mulloway. In all cases the majority of deaths occurred within the first 24 hours. Fish that had their ingested hooks removed experienced the highest mortalities and fish that were observed to be bleeding were more likely to die. Typically, these fish suffered damage from hook wounds to the oesophagus, liver and stomach or vital organs (e.g. gills). Some of the fish that were released with the hook in place were able to expel their hooks during the monitoring period with the hook shedding rate influenced by the original anatomical hooking location.

The experiments on yellowfin bream showed that most mouth-hooked individuals can withstand up to 30 s of exercise during line retrieval followed by 5 min of air exposure with few negative short-term impacts. In addition, relative to the size of the fish, the size of the hook used contributed to the anatomical hooking location. Specifically, irrespective of hook type and size, some fish were unable to ingest large hooks and as a consequence were nearly always hooked in the mouth. Further, in some instances the use of circle hooks mitigated the rate of hook ingestion for this species.

While there was considerable variability in the blood physiology results for both species, it is clear that a combination of capture, handling and confinement elicited a stress response. However, the magnitude of the variations in plasma cortisol and glucose concentrations was likely attributable to the method of blood sampling.

The study concluded that modifications to angling gear and practices have the potential to maximise the post-release survival of line-caught yellowfin bream and mulloway. Specifically, the results from all of the experiments demonstrated that to assist to minimise the mortality for (i) both species: the hooks should be removed from mouth-hooked fish and the line should be cut for hook-ingested individuals prior to release, and (ii) for yellowfin bream: air exposure should be avoided, especially if the fish is bleeding from hook-induced wounds; fish should be supported (underwater) until they regain their equilibrium and the appropriate sized hook, and preferably circle hooks, should be used to target fish at or above the legislated minimum legal length. Although these findings are unlikely to result in any regulatory change, the adoption of these recommendations by anglers may ultimately benefit the sustainability of recreational fishing in Australia.

1.0 INTRODUCTION

1.1 Recreational Fishing in Australia

Recreational fishing is a popular pursuit in Australia, involving participants of varying degrees of expertise, from a range of economic, social and cultural demographics. A National Recreational and Indigenous Fishing Survey estimated that in the year prior to May 2000 an estimated 3.36 million Australian residents (19.5% of the population) fished at least once with New South Wales (NSW) having the greatest rate of angler participation (Henry and Lyle, 2003). The primary motivation for recreational fishing in Australia was found to be relaxation or enjoyment (Henry and Lyle, 2003). This indicates that the majority of anglers surveyed were not driven by the need to harvest or retain their catch. Further, some fish species traditionally captured for their eating qualities are now popular sport-fishing targets and are targeted by anglers intent on practicing catch-and-release.

Recreational fisheries worldwide utilise a large range of gears to target a multitude of different species. Of the various recreational fishing methods used in Australia, line fishing (or angling) accounts for the majority of catch and effort (> 85%) and contributes towards a total expenditure of more than AU$1.8 billion per annum (Henry and Lyle 2003). Increases in angler skill levels and technological improvements in fishing gears (Steffe et al., 2005) coupled with the proliferation of information on where and how to fish in the recreational fishing media (Henry and Lyle, 2003) has probably led to anglers having a greater impact on the sustainability fish stocks in recent times. Further, recreational fishing accounts for a substantial proportion of the total annual catch of some fish species in Australia (Henry and Lyle, 2003).

Internationally, the majority of current management arrangements of recreational fisheries focus on controlling the landings of individual fishermen without restricting the number of individuals authorised to participate (Coleman et al., 2004). Similar to recreational fisheries worldwide, the recreational fisheries in Australia are managed by a complex suite of temporal and spatial closures combined with gear restrictions and quota (bag or possession) and size limits. The primary objective of these management arrangements, often defined in the relevant fisheries legislation, is the long-term sustainability of fisheries resources. However, from an individual angler's perspective, the desired outcomes of these arrangements may include an improvement in recreational fishing quality, high catch rates and availability of sufficient 'trophy-sized' fish (Muoneke, 1992). Not withstanding the above, the overall underlying assumption for the success of recreational fisheries management arrangements to achieve their objectives and desired outcomes is a high level of post-release survival (i.e. the proportion of fish surviving capture following release from angling), in addition to minimal impacts on surviving individuals (Muoneke and Childress, 1994).

The general perception for fishing to negatively impact upon fish populations regularly focuses upon the impact of commercial fisheries (Pauly et al., 2002). However, the existence of the above-mentioned management arrangements for recreational fisheries in Australia, in addition to similar arrangements elsewhere, validates that there is a general awareness that recreational fishing does have some impact upon fish populations (Arlinghaus et al., 2007) and the overall sustainability of fisheries resources. As a consequence catch-and-release fishing has increased in popularity in many countries, particularly in the United Sates of America (Muoneke and Childress, 1994) and Australia (McLeay et al., 2002). This, combined with the promotion and enforcement of the relevant legislation by fisheries jurisdictions and the development of government sponsored angler education programs are factors that may have contributed toward a higher level of ethics in modern recreational fishing. As an example, recent angling surveys in NSW have highlighted a trend of decreasing proportions of fish below the minimum legal length being retained by anglers (Steffe et al., 2005), possibly reflecting an awareness of the need to adhere to management arrangements in order to sustain recreational fishing quality. Conceivably, increasing numbers of fish are being released based on the unconfirmed assumption of high post-release survival when in fact the fate of the majority of Australian recreational fish species released following capture by hook-and-line is relatively unknown.

The contribution of catch-and-release practices to overall fishing mortality is rarely assessed (Millard et al., 2003). Furthermore, population models of Australian line-caught fish generally assume 100% post-release survival and consequently almost certainly underestimate mortality of non-harvested fish (McLeay et al., 2002). In Australia, yellowfin bream (*Acanthopagrus australis*) and mulloway (*Argyrosomus japonicus*) are two popular recreational fish species. Nationally, an estimated 13 million breams (*Acanthopagrus* spp.) and approximately 600000 mulloway are caught by recreational fishers annually, with approximately 63 and 46% of them released, respectively (Henry and Lyle, 2003). This discarded quantity represents a high proportion of the estimated total recreational catch for these species and is of potential concern considering the possibility for angling-induced mortality.

1.1.1 Recreational fishery for yellowfin bream

Yellowfin bream are endemic to Australia, inhabiting coastal and estuarine waters of the east coast from Townsville in Queensland to the Gippsland Lakes in Victoria (Kailola et al., 1993). Their abundance and accessibility to anglers make yellowfin bream one of the most popular angling species in estuaries and adjacent ocean waters throughout their distribution. Attaining a maximum size of approximately 45 cm, yellowfin bream are typically caught using various hook-and-line gear with baited hooks (size 1 – 2/0) attached to monofilament or braided line. Their aggressive nature, exceptional eating and strong fighting qualities make them a highly prized sport fish when targeted by anglers using hard bodied and soft plastic lures. The popularity of yellowfin bream as an angling species lends them to high rates of exploitation from recreational fishers.

As with the majority of Australian species, the recreational fishery for yellowfin bream is governed by personal quotas, size limits and, to a lesser extent spatial closures (encompassing marine protected areas). Management arrangements vary between state jurisdictions, with NSW, Queensland and Victoria enforcing minimum sizes of 25, 25 and 26 cm and possession limits of 10, 30 and 10 fish respectively. Victoria also enforces a spatially specific size limit in the Gippsland Lake and its tributaries of 28 cm.

1.1.2 Recreational fishery for mulloway

Mulloway is a near-shore coastal and estuarine species distributed in Pacific and Indian Ocean waters surrounding Australia, Africa, India, Pakistan, China, Korea and Japan (Silberschneider and Gray 2005). In Australia, mulloway inhabit ocean waters and estuarine environments from Bundaberg in Queensland, around southern coastline of the continent to North West Cape in Western Australia (Kailola et al., 1993).

Due to their large size and sport fishing qualities, adult mulloway are a highly prized trophy fish often targeted by anglers fishing at the mouths of rivers, in surf zones and inshore reef areas. Mulloway are caught by anglers using a suite of hook-and-line gear and terminal tackle configurations. Typically, hooks (size 5/0 – 10/0) baited with live or fresh baits are attached to monofilament line. Anglers also target mulloway by using metal jigs, hard bodied and soft plastic lures. The estimated recreational catches in several states (NSW, Vic. and WA) are of an equivalent or greater magnitude than those reported from commercial fisheries (Silberschneider and Gray 2005).

Similar to yellowfin bream the Australian recreational fishery for mulloway is managed by spatial closures, and quota and size limits. The broad distribution of mulloway crosses the management jurisdictions of five states, leading to a complex set of management arrangements. NSW, Qld, Vic., WA and SA enforce a minimum size limit of 45, 75, 50, 50 and 75 cm and a bag limit of 5(only 2 over 70 cm), 2, 10, 2 and 2 respectively. SA has a spatially specific regulation in place for Coorong Lagoon with a minimum size of 46 cm and a bag limit of 10 (only 2 over 75 cm).

1.2 Factors affecting the post-release survival of line-caught fish

The mortality of line-caught fish may be immediate through injury or delayed due to a combination of initial injury and successive deleterious stressors (Muoneke and Childress, 1994). Furthermore, rates of post-release survival are highly variable and dependent upon a multitude of factors (Muoneke and Childress, 1994; Bartholomew and Bohnsack, 2005; Cooke and Suski, 2005). Given the latter, some of the factors that contribute to the fate of released fish are intrinsic (e.g. species, physical condition and sexual maturity) or environmental (e.g. water or air temperature, depth, hypoxia and predator burden) and are generally outside the realm of influence by anglers (Cooke and Wilde, 2007). In contrast, the choice to use specific types and configurations of terminal gear, in addition to handling practices, is dependent upon angler preference.

Numerous international studies, particularly those done in the USA and Canada, have demonstrated that the survival of released line-caught fish is species specific and influenced by many inter-related mechanical, operational and environmental factors (Broadhurst et al., 2005). Specifically, post-release survival has been found to be dependent upon, but not restricted to, the terminal gear type (e.g. Cooke et al., 2003a) or configuration (e.g. Ostrand et al., 2005), bait type (e.g. Pauley and Thomas, 1993), anatomical hooking location (e.g. Lindsay et al., 2004) physical exertion (e.g. Wood et al,, 1983), water temperature (e.g. Nelson, 1998), air exposure following capture (e.g. Ferguson and Tufts, 1992), angler experience (e.g. Meka, 2004) and angling environment (e.g. Wilson and Burns, 1996). Not withstanding these factors, it is well known that they rarely act independently and potentially manifest as a series of cumulative influences (Cooke and Wilde, 2007).

International hooking mortality studies have traditionally focussed on salmonids, however concern about the potential impact of catch-and-release fishing has led to recent research being directed toward many other species (Arlinghaus et al., 2007). Depending on the species of fish and the specific circumstances of capture, hooking mortality rates have been demonstrated to be nil or greater than 90% (Arlinghaus et al, 2007), with estimates above 20% considered to be high (Muoneke and Childress 1994). Specifically, some studies have reported no (e.g. Cooke et al., 2001) or negligible mortality estimates (e.g. Cooke et al., 2005) while others have demonstrated that mortality is excessive under specific circumstances (e.g. Wilde et al., 2000). Irrespective of the particulars, the variable mortality estimates across studies highlight the importance of assessing specific factors influencing post-release survival for individual species.

The angling process may not itself be lethal to fish but may cause sublethal disruption to individuals and populations (Cooke et al., 2002). Sublethal effects of angling include physiological and behavioural responses of fish to angling, and can be categorised as either primary, secondary or tertiary (Mazeaud et al., 1977; Wedemeyer and McLeay, 1981). Primary responses involve stimulation of the endocrine pathway and alteration in the blood plasma concentrations of catecholamines and corticosteroids. As a consequence, secondary (metabolic) responses are induced that involve changes in haematological parameters in the blood and tissue (Mazeaud et al., 1977; Wedemeyer et al., 1990). Tertiary responses occur on both the individual and population level (Wedemeyer and McLeay, 1981) and may include behavioural modifications, reduction in reproductive success, effects on growth and susceptibility to disease (Pickering et al., 1982). Overall, quantifying any potential sublethal effects of angling is an important component in the overall assessment of factors that contribute toward post-release survival of fish following capture by hook-and-line.

One of the most important physiological responses affecting the post-release survival of line-caught fish is stress. Stress is the effect of any environmental alteration or force that extends homeostatic or stabilising processes beyond their normal limits, at any level of biological organisation (Esch and Hazen, 1978). Overall, the effects of stress on fish are likely to vary with the severity and duration of the stressor(s), as well as with species, size, age and condition of fish (Pope et al., 2007). Stressors may be broadly categorized as either chronic or acute, reflecting the time course as opposed to the severity of the stress (Pickering et al., 1982). The physiological stress response is a mechanism which enables fish to avoid or overcome potentially threatening, noxious or harmful situations (Pickering, 1993) and comprises components integrated from all three artificial divisions i.e. primary, secondary and tertiary (Pickering et al., 1982). Analysis of blood plasma cortisol concentration is generally accepted as a reliable measure of the primary stress response in teleost fish (Donaldson, 1981) and has been used to assess the response of fish to specific and multiple stressors including hooking (e.g. Gustaveson et al., 1991) angling duration (e.g. Meka and McCormick, 2005); handling (e.g. Cleary et al., 2002); confinement (e.g. Pankhurst and Sharples, 1992) and elevated water temperature and air exposure (e.g. Davis and Olla, 2001a). Secondary stress responses have been quantified by alterations in blood chemistry parameters such as glucose (Wedemeyer and McLeay, 1981) and used to assess the reaction of fish to stressors including hypoxia (e.g. Mazeaud et al., 1977) and confinement (e.g. Gustaveson et al., 1991). On an organism level, tertiary stress responses including behavioural impairment and cessation of feeding have been assessed by qualitative visual observation (e.g. Davis et al., 2001; Cooke et al., 2000; Cooke and Philipp, 2004) and length/weight measurement (Pope et al., 2007). In terms of populations, stress has inhibitory effects on reproduction in every species in which the relationship has been examined (Pankhurst and Van Der Kraak, 1997).

1.3 Objectives

Although the post-release survival of fish released after capture by hook-and-line has been well documented for many international species (Muoneke and Childress, 1994), there was a lack of research completed on Australian species at the time this study commenced (but see Diggles and Ernst, 1997; Broadhurst et al., 1999; Broadhurst and Barker 2000; Ayvazian et al., 2002). Fisheries jurisdictions in Australia have identified the collection of information on post-release survival of line-caught fish as one of the necessary performance indicators for reporting on the ecological sustainable development of fisheries and highlighted the importance of this information to the success of robust stock assessments and fishery management strategies (McLeay et al., 2002). Conceivably, this may have contributed to the increase in the number of recent studies conducted by Australian researchers (e.g. de Lestang et al., 2004; Broadhurst et al., 2005; Butcher et al., 2006, 2010 and 2011; Hall et al., 2009; McGrath et al., 2009). Furthermore, although the fate of released yellowfin bream and mulloway due to some mechanical (Broadhurst et al., 2005; Broadhurst and Barker 2000) factors of angling is known there has was little investigation of the effect on mortality attributed to operational aspects of the catch-and-release process for these species prior the commencement of this study.

The objectives of this study were to identify the deleterious hooking, handling and release procedures effecting the post-release survival of yellowfin bream and mulloway and examine ways to maximise the post-release survival for these species. The specific objectives of this study were to:

- Determine the effects of various hooking procedures on the post-release survival of yellowfin bream and mulloway;
- Determine the effects of different handling procedures on the post-release survival of yellowfin bream and mulloway;
- Investigate physiological responses of yellowfin bream and mulloway to capture and confinement,
- Determine the effects of exercise and air exposure on the post-release survival of yellowfin bream; and,
- Investigate and recommend strategies to maximise the post-release survival of yellowfin bream and mulloway.

This study is part of the broader NSW Department of Primary Industries research project - Estimating and maximising the survival of key species released by recreational fishers in NSW. Specifically, the work done is this thesis expands upon, made a significant contribution to, and in some instances formed the basis of, the publications contained in the Appendices of this thesis (see section 8 for my contribution to each of the journal publications). Further, all of the interpretation of results (with the exception of Chapter 4 that formed the basis of my primary authorship publication) is unique to this thesis.

2.0 GENERAL MATERIALS AND METHODS

The data presented in this thesis were obtained during two field and six aquaria experiments. Specific details of the methodology, data collected and statistical analyses used in each experiment are described in the Methods section of the relevant Chapters.

2.1 Study locations – field experiments

The first field experiment was done on the Hawkesbury River, NSW (33°42' S; 151° 15' E – Fig.1) during October and November 2004. The Hawkesbury River is located approximately 40 km north of Sydney and supports significant commercial and recreational fisheries (Gray et al., 1990). The study area was close to the town of Spencer, situated on the Mangrove Creek junction, approximately 30 km upstream from the river mouth (Fig. 1). The second field experiment was done over approx. 20 months, between October 2004 and June 2006 and involved collecting data from anglers fishing in estuarine and coastal waters throughout NSW. Data were obtained from numerous river catchments and adjacent coastal environments (Fig. 1).

2.2 Study Location – aquaria experiments

The aquaria experiments were done at the Industry and Investment NSW (I&I NSW) Cronulla Fisheries Research Centre (CFRC) aquaria located on Hungry Point, Cronulla, NSW (34° 4' S; 151° 9' E – Fig. 1). The main fish holding facility was a large outdoor concrete pool (30 m long x 14 m wide x 2.3 m deep), covered by an over-head shade structure. Six galvanised steel cables were fixed into the walls of the pool, 200 mm above the surface of the water. One cable separated the pool in half longitudinally while the remaining cables, spaced equidistantly from each other, laterally divided the pool into fifths. The cables allowed for sea cages to be hung in the pool by a system of stainless steel clips.

Surrounding the pool under a fixed roof were 14 circular 5000-l fibreglass tanks (2.4 m diameter x 1.2 m deep) made of gel-coated fibreglass, green on the interior and white on the exterior. These tanks were used in all aquaria experiments and were each fitted with an internal stand-pipe (50 mm diameter x 1 m deep), secured 100 mm from the tank wall. All tanks were covered by shade cloth straddling a dome-shaped aluminium frame with a semi-circular zipper fitted to allow tank access. Two reinforced holes through the cover allowed for air and water lines to supply each tank with aeration and seawater, respectively.

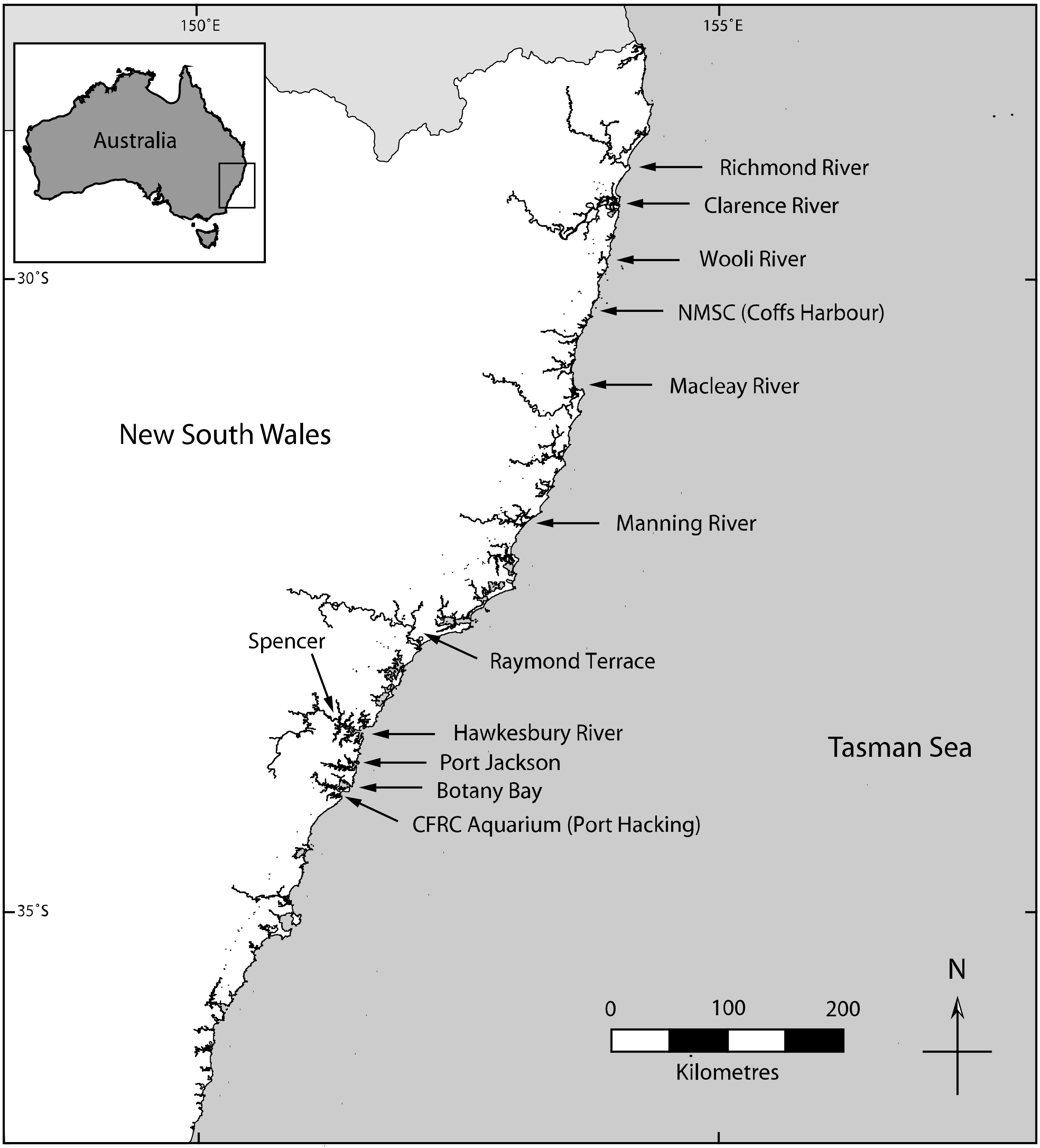

Fig. 1: Map of study sites, fish collection locations and river catchments used in long-term data collection.

The water supply to the pool and tanks was maintained *via* a flow-through system. Water was pumped by a system of three centrifugal pumps directly from Port Hacking, filtered to either 150 or 250 µm, before entering each holding receptacle. Seawater entered the southern side of the pool through three 50-mm valves at a rate of 500-l min^{-1} and exited the northern side of the pool *via* a 1.2 m wide over-flow. Seawater entered each tank through a 20-mm flexible hose at a rate of 10-l min^{-1}. Aeration was provided by a compressor unit, *via* a system of air hoses with attached air diffusers.

2.3 Equipment used in experiments

Three types of floating cages constructed from black knotless polyamide mesh hung on the bar (so that the meshes were square shaped) were used in the experiments. The cages were either suspended in the pool (for aquaria experiments), or in the Hawkesbury River (for the appropriate field experiment). The first type of cage, used in some aquaria experiments only, was rectangular (7 m long x 7.5 m wide x 2 m deep, 35-mm mesh) and attached to the pool's cables with clips to secure them in place. The second type was cylindrical (2.3 m diameter x 2.5 m deep, 16-mm mesh). The cylindrical shape was maintained by two lengths of 15-mm PVC pipe set into a circle and either secured to the base of the cage by cable ties or enclosed within a 50-mm sleeve sewn around the circumference of the lid. To enable floatation, four 300-mm polystyrene floats, spaced equidistantly, were attached by rope to the lid of each cage and secured to the inside corners of 200-mm diameter PVC pipe set in a square shape. The third type of cage was also cylindrical (2 m diameter x 2 m deep, 19-mm mesh), with the shape maintained by a 6-mm stainless steel rod enclosed within a 50-mm sleeve sewn around the circumference of the lid. Four 200-mm polystyrene floats spaced equidistantly were attached to the sleeve with rope to enable floatation. Both types of cylindrical cages had zippers sewn into the lid to enable internal access and were secured in position by rope (aquaria experiments) or anchors (field experiment).

2.4 Fish collection and transport during experiments

When required, all control fish and the treatment fish used in the aquaria experiments were transported using a purpose-built fish transport trailer that comprised of two rectangular 500-l fibreglass tanks, each with a 'V' shaped false floor draining through an 80-mm hole, mounted on a box trailer. A hinged lid (0.7 m long x 0.6 m wide) allowed access to each tank. A 5-mm hole in the top of each tank allowed for a silicone air line, with air diffuser attached, to supply 100% oxygen from an oxygen cylinder mounted on the trailer.

For ease of handling and to minimise injury and stress to the fish (according to established I&I NSW animal care and ethics protocols), anaesthetics were used when transferring fish between their respective holding receptacles. Benzocaine (Ethyl-p-amino benzoate) was initially dissolved in 100% ethanol at a concentration of 100 g l^{-1} to form benzocaine solution. To induce light anaesthesia (as defined by Barker et al., 2002), the solution was added to each holding receptacle containing the fish at a concentration of 50 mg l^{-1}.

To prevent bacterial infection from potential injuries sustained during collection, handling and transport, fish were immersed in an Oxytetracycline Hydrochloride (OTC) solution. OTC was added to the water in the transporter tanks at a concentration of 100 mg l^{-1} before the introduction of the fish and the commencement of transport. All fish were handled with extreme care in order to minimise collection, handling and transport related injury. Fine (2-mm) knotless landing nets and 25-l buckets were used in all instances where fish had to be transferred among holding receptacles.

The fish used in both aquaria and field experiments were collected from a variety of locations using a range of methods. Yellowfin bream were collected from either (i) a commercial aquaculture operation in Botany Bay or (ii) the Clarence River. Fish collected from Botany Bay were scoop-netted from sea cages into aerated 500-l PVC containers and transported by boat to the shore (approx. 500 m) where they were transferred into the fish transporter and delivered to CFRC. An otter trawl rigged with a black polyamide knotless square-mesh codend (20-mm mesh) was used to collect fish from the Clarence River. Five-minute tows ensured minimal injury to the fish. Upon completion of each tow, the codend was lifted on deck and placed into 500-l aerated plastic containers for sorting. All yellowfin bream were retained, transferred into the fish transporter as above, and delivered to the National Marine Science Centre (NMSC), Coffs Harbour, NSW, before being transported to CFRC. Mulloway were collected from a commercial aquaculture operation at Raymond Terrace, NSW. The day prior to collection, fish were harvested from earthen ponds with fine (5-mm) knotless mesh seine nets and transferred into aerated 5000-l circular fibreglass tanks. The fish were immersed overnight in a 100 mg l^{-1} OTC solution before being transferred into the fish transporter and delivered to CFRC.

Upon arrival at CFRC or NMSC, fish were first acclimated to aquarium water temperature and salinity levels before being quarantined and subjected to a disease prevention treatment (described below). Acclimation involved seawater being introduced into both transporter tanks at a maximum rate of 5 l min^{-1}. This was maintained until the water temperature and salinity of each tank was within 1°C and 1 psu, respectively of the water temperature and salinity of the quarantine tank into which the fish were destined.

Following acclimation, fish were anesthetised and transferred, to 5000-l fibreglass quarantine tanks, each containing 1000 – 2000 l of water, dependent upon stocking density. Water flow to the quarantine tanks was stopped and the fish bathed in a 100 mg l^{-1} OTC solution for a period of 12 h to allow the uptake of the OTC (Barker et al., 2002) before water supply was resumed.

The day after immersion in OTC the fish in each tank were visually inspected for mortalities or transport-related injury and infection. Mortalities and seriously injured fish were removed from the tank. Fish were then subjected to a formalin treatment in order to prevent fungal and parasitic infection. Similar to OTC treatment, the influent water was stopped, formalin added to the water in each tank at a concentration of 200 mg l^{-1} for 1 h, followed by the resumption of water supply. This treatment was repeated every 2 days for 6 days. Following quarantine and disease prevention, treatment fish were transferred to their respective experimental holding receptacles (tank or cage). Fish were fed a mixed diet of school prawn and artificial pellet (at a rate of 2% biomass day^{-1}) prior to each experiment.

2.5 General data collected and analyses

The date and time of capture, total length to the nearest mm (TL), anatomical hooking location, time fish were played during angling and exposed to air during handling, and the presence or absence of bleeding was recorded for all fish. The anatomical hooking location was generally quantified as either mouth (upper or lower jaw, roof, floor or corner), ingested (throat, oesophagus or stomach) or gill arch. The hook type and manufacturer's size classification was recorded in the field and aquaria experiments that utilised anglers and researchers to assess anatomical hooking location.

The experimental treatment, cage number, time of release into cages, scale loss (to the nearest 25%) and daily survival was recorded for all fish in most experiments. In addition, water quality parameters, including temperature (C), dissolved oxygen (mg l^{-1}) and salinity (psu) were recorded, using a water quality logger (90-FL, TPS Pty Ltd, Brisbane, Australia), over the duration of these experiments. When required, air temperature (°C) was recorded using a digital thermometer while fish were exposed to experimental treatment.

2.5.1 Blood collection and analyses

To assess the acute and chronic physiological stress response of fish due to experimental treatment, blood plasma was assayed for cortisol (ng ml^{-1}) and glucose (mmol l^{-1}) concentration, respectively. Blood was collected from up to five fish chosen at random from each specific treatment group from all experiments investigating physiological disturbance.

Immediately following capture, fish were secured ventrally in a 0.4-m long plastic lined crevice cut into a soft foam block (0.5 m long x 0.3 m wide x 0.3 m deep). Blood was extracted from the caudal vein using a 3-ml prehepranised syringe fitted with a 21-gauge needle, immediately transferred into a 1.5-ml epindorph and stored on ice, for a maximum of 1 hr, until centrifugion for a maximum of 3 min. Following centrifugion, blood plasma was aspirated into a second epindorph using a plastic pipette and stored frozen at -20°C until assay. Blood cortisol concentrations were measured by radioimmunoassay (Pankhurst and Sharples, 1992) and glucose concentrations by the methods described by Moore (1983).

2.5.2 Statistical analyses

Depending on the experiment and where appropriate, several parametric and non-parametric analyses were used to analyse experimental data and subsequently test the significance of intra- and inter-specific treatment effects on anatomical hooking location and, if relevant, post-release survival and blood physiology.

Size-frequency distributions of treatment and control fish were compared using two-sample Kolmogorov-Smirnov tests. Two-tailed Fisher's exact tests were used to determine the independence of (i) the treatment of fish on mortality, (ii) replicate cages on mortality, (iii) the treatment on the presence of bleeding and scale loss, and (iv) the treatment of fish on hook location at the end of specific experiments. Where possible the independence of categorical and continuous variables on mortality of yellowfin bream was examined using exact logistic regression models (Hirji et al., 1987). Chi-squared analysis of contingency tables were used to test the independence of treatment on mortality of mulloway and chi-squared goodness-of-fit and Yates corrected chi square tests were used to test for differences in the anatomical hook location among relevant experiments. Where appropriate, to test the null hypothesis of no differences in blood physiology due to the confinement of hooked and control fish, Kruskal-Wallis tests or mixed model ANOVA (using the restricted maximum likelihood estimation method) were used to test for intra-specific differences in these variables. For all analyses, the null hypothesis was rejected at $p < 0.05$.

3.0 EFFECTS OF HOOK REMOVAL ON THE SHORT-TERM POST-RELEASE SURVIVAL OF YELLOWFIN BREAM AND MULLOWAY

3.1 Introduction

It is well documented that anatomical hooking location is the single most important predictor of hooking mortality for many species (Diggles and Ernst, 1997; Cooke et al., 2003b; Lindsay et al, 2004; Broadhurst et al., 2005). For example, during a field experiment, Diggles and Ernst (1997) reported that 50% of yellow stripey, *Lutjanus carponotatus* that were hooked in the oesophagus died. In recent field studies, Broadhurst et al., (2005) and Butcher et al., (2006) recorded mortality rates of 45 and 50% for yellowfin bream and sand whiting, respectively, that had ingested hooks. The specific mechanisms causing death among these hook-ingested fish include (i) physical damage from the hooking process, (ii) increased handling time to remove hooks, and (iii) hook removal (Bugley and Shepard, 1991; Barwick, 1985).

Studies evaluating factors that affect the post-release survival of line-caught fish have demonstrated that mortalities can be mitigated by simple modifications to post-capture handling practices, such as cutting the line and releasing fish with the hook left in place (Mason and Hunt, 1967; Warner and Johnson, 1978; Warner, 1979; Schill, 1996; Schisler and Bergersen, 1996; Aalbers et al., 2004). For example, Schisler and Bergersen (1996) demonstrated that the average mortality rate of rainbow trout hooked in a critical location (i.e. oesophagus or gill arch) was approximately 55% when the hook was removed compared to 20% when the fish were released without the hook being removed. Similarly, Aalbers et al., (2004) observed that 65% of white seabass, *Atractoscion nobilis* hooked posterior of the tongue died when hooks were removed compared with a 41% mortality rate when hooks were left embedded. In contrast to the above, other studies have reported higher rates of mortality for fish released with the hook left in place (e.g. Murphy et al., 1995). However, as was often the case, ingested hooks were not removed in an attempt to prevent further injury (Vincent-Lang et al., 1993; Nelson, 1998; Cooke et al., 2003c).

Although it is almost impossible to quantify all of the factors affecting post-release survival of any species in a single study, in addition to mortality often resulting from interactions between several factors (Muoneke and Childress, 1994), appropriate modifications to handling practices seem a simple and effective starting point for recreational fishers to maximise post-release survival. One of the best methods for investigating the utility of such modifications is to release fish into the wild and monitor their individual progress, via such methods as telemetry (Cooke et al., 2004) and tag-and-release (Graves and Horodysky, 2008). However, logistical and financial constraints commonly preclude such experimental methodologies. The incorporation of field and aquaria studies, whereby fish are released into cages, is often a feasible alternative and can more accurately reflect the handling experienced by wild fish during angling (Cooke et al., 2001).

Given the relative lack of information on the fate of fish released by recreational anglers in Australia compared to some countries, and the need to investigate strategies to maximise their survival, the objective of this study was to investigate the short-term post-release survival of line-caught mouth- and throat-hooked yellowfin bream and mulloway following different handling practices.

3.2 Methods

One field experiment and three aquaria experiments were done between October 2004 and May 2005. In all experiments, the same type of minor-offset barbed J-hook (size 1/0 – Fig. 2), baited with school prawns (*Metapenaeus macleayi*) and attached to 4 kg monofilament line, was used to catch either yellowfin bream or mulloway. Irrespective of anatomical hooking location, most hooked fish were exposed to air and handled according to two treatments that involved either (i) removing the hook or (ii) cutting the line (5 cm from the fish's mouth) and leaving the hook imbedded. Some hooked mulloway were subjected to a third handling treatment where the line was cut (as above) prior to being released without air exposure. The specific methods used in each experiment are outlined below.

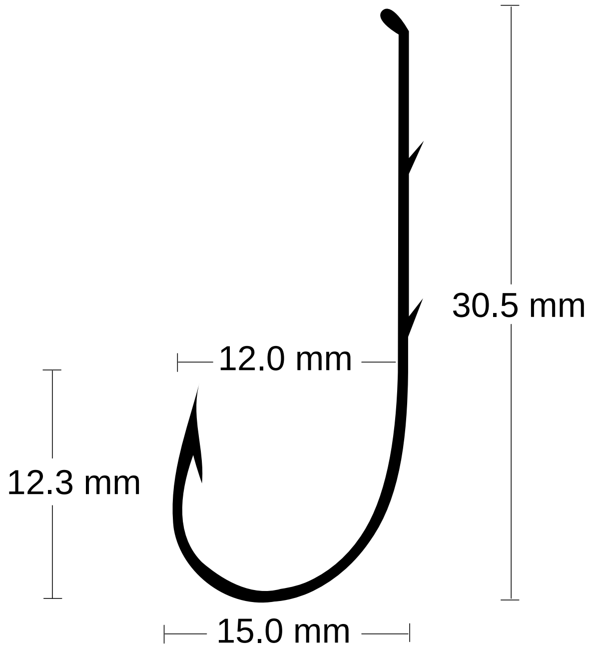

Fig. 2. Nominal dimensions (mm) of the hook used in this study.

3.2.1 Field experiment – post-release survival of yellowfin bream

This experiment used 24 recreational anglers (distributed among 12 boats) to target yellowfin bream and was done between October and November 2004. The anglers were divided into two groups according to treatments 1 (hook removed) and 2 (hook not removed) above and targeted yellowfin bream between 08:00 and 16:00 h on each of two consecutive days. After catching and subjecting a fish to one of the two treatments (as above), anglers were required to place the fish into aerated 70-l holding tanks, record relevant data (see below) and contact one of three marshal boats. Researchers onboard the marshal boats validated the angler's data, recorded information on the holding tanks (see below) before transferring the fish (using fine knotless-mesh scoop nets) into aerated 120-l tanks for transport and release into four sea cages (two replicate cages for each treatment). Two days after angling, approximately 150 yellowfin bream were transported from Botany Bay and randomly distributed among four separate sea cages, designated as control and stock cages (each with two replicates).

All caged fish were fed school prawns and monitored daily for five days. To maintain densities in the sea cages, mortalities were removed and replaced with individuals (fin clipped to facilitate identification) from the stock cages. At the cessation of the experiment, all surviving treatment fish were euthanased with a lethal dose of Benzocaine (100 mg l^{-1}), dissected and examined for the presence/absence of hooks or wounds.

3.2.2 Aquaria experiments 1 and 2 – post-release survival of yellowfin bream and mulloway

Aquaria experiments 1 and 2 used approximately 200 yellowfin bream and 400 mulloway and were done in November 2004 and January 2005, respectively. Fourteen days before the start of both experiments, fish were randomly distributed between eight of the 5000-l tanks. All fish were starved for two days prior to four researchers angling fish from six of the 5000-l tanks between 08:00 and 17:00 h on each of two consecutive days. Hooked individuals were then subjected to either treatment 1 or 2 (as above). Relevant data were recorded for each fish (see below) before they were released into four of the sea cages (two replicates for each treatment). Following the release of the last hooked individual, the appropriate number of control fish were transferred (using 25-l buckets) from the two unfished 5000-l tanks to the remaining two sea cages. All fish were fed school prawns and monitored twice daily for five days.

To maintain densities in the sea cages, mortalities were removed and replaced with fin clipped individuals from the two unfished 5000-l tanks. Surviving individuals from the fish that did not have the hook removed were euthanased (as above) and in addition to all mortalities, were dissected and examined for the presence/absence of hooks or wounds. Prior to dissection some of these fish were laterally x-rayed to assess the orientation and relative position of ingested hooks.

3.3.3 Aquaria experiment 3: post-release survival of mulloway (without exposure to air)

Aquaria experiment 3 used 600 mulloway and was done during May 2005. Four hundred fish were randomly distributed between eight 5000-l tanks and 200 individuals released into a rectangular sea cage situated in the pool. Fish were allowed to acclimate for twelve days prior to being starved for two days before the start of the experiment. The fish were then hooked by two researchers angling between 08:00 and 17:00 h on each of two consecutive days and subjected to treatments 1 and 2 (as above), and treatment 3 (water release). Fish from six of the 5000-l tanks were exposed to treatments 1 and 2. All of these individuals had their caudal fin clipped according to their anatomical hooking location (mouth or ingested) before being released into four sea cages (two replicates for each treatment). Individuals subjected to treatment 3 were hooked from the 5000-l tanks or the sea cage and brought close to the surface, avoiding any exposure to air. A 25-l bucket was then used to extract the fish and approximately 20 l of water from the pool or cage prior to line being cut (as above). The fish were released into four of the sea cages according to anatomical hooking location (two replicate cages for mouth and ingested individuals, respectively) by submerging the bucket in the sea cage and allowing the fish to swim out. Following angling the appropriate number of control fish were fin clipped and transferred (using 25-l buckets) into the remaining two sea cages. All fish were fed school prawns and monitored twice daily for five days.

3.2.4 Blood collection

Blood samples were collected from fish as per the methods described in Chapter 2. Blood was taken from eight wild-caught yellowfin bream immediately following capture from the Hawkesbury River and one individual of both species from each tank in the aquaria experiments, prior to angling on the day of experimentation. Up to five fish scooped from each of the treatment and control sea cages at the end of the experiments were also sampled for blood. Blood plasma was analysed for cortisol (ng ml^{-1}) and glucose (mmol l^{-1}) concentration.

3.2.5 Data collected and statistical analyses

The treatment, time of capture and release into the sea cages, TL, cage number, anatomical hooking location, time fish were played during angling and exposed to air during handling, scale loss (to the nearest 25%), daily survival and the presence or absence of bleeding was recorded for all fish. Anatomical hooking location was classed as either mouth (jaw, corner, gill arch, floor and roof), throat (oesophagus and stomach) or body. For the aquaria experiments, water temperature (°C) and dissolved oxygen concentration (mg l^{-1}) was recorded at 09:00 h each day for all tanks and the pool. For the field experiment, these water quality parameters were recorded from the angler's holding tanks each time a fish was collected.

Size-frequency distributions (1-cm TL intervals) of treatment and control fish were compared using two-sample Kolmogorov-Smirnov tests. Two-tailed Fisher's exact tests were used to determine the independence of (i) the treatment of fish, and (ii) replicate cages on mortality and (iii) the treatment of hooked fish on the presence of blood and scale loss after capture and hook location at the end of the experiment (within and between experiments).

Where possible, all variables describing the hooking and release of yellowfin bream were separated as either categorical or continuous variables. The independence of these variables on mortality was examined using exact logistic regression models (Hirji et al., 1987). Models were fitted using SAS (version 8, 2003), as described by Derr (2000) and compared using likelihood ratio tests and examination of deviance residuals. Owing to difficulties in identifying some individual mulloway during aquaria experiments 2 and 3, similar logistic regression analyses were not possible. Instead, chi-squared analyses of contingency tables were used to test the hypothesis of mutual independence between hook removal and the survival of (1) all mulloway (irrespective of their anatomical location) in aquaria experiment 2 (i.e. 2 x 2 contingency table) and (2) mouth-hooked and hook-ingested mulloway with and without air exposure in aquaria experiment 3 (i.e. 2 x 6 contingency table). A chi-squared goodness-of-fit test was used to test for intra-specific differences in anatomical hook location between relevant experiments.

All blood plasma cortisol and glucose concentrations are reported as mean ± se. Kruskal-Wallis tests were used to test for intra-specific differences in these parameters between wild yellowfin bream and undisturbed mulloway before starting the experiments, and both treatment and control fish sampled from cages following the completion of each five day monitoring period. For all analyses, the null hypothesis was rejected at $p < 0.05$.

3.3 Results

3.3.1 Water Quality

Water temperature and dissolved oxygen ranged between 18.1 to 23.5ºC and 3.5 to 8.4 mg l^{-1}, respectively in the angler's holding tanks during the field experiment. During the aquaria experiments, water temperature remained relatively constant (experiment 1: 19.6 – 20.4ºC, experiment 2: 21.3 – 22.0ºC and experiment 3: 17.8 – 18.2ºC) and dissolved oxygen ranged between 5.2 and 6.8 mg l^{-1}.

3.3.2 Capture of yellowfin bream

In all, 78 (mean TL ± se of 22.5 ± 0.6 cm) and 66 (26.2 ± 0.4 cm) yellowfin bream were hooked and released into the sea cages during the field and aquaria experiment 1, respectively. A Kolmogorov-Smirnov test did not detect any significant differences between the size-frequency distributions of treatment and control fish within or among experiments ($p>0.05$).

In the field experiment 84.6% of fish were played for less than 30 s, whereas all fish in aquaria experiment were played for less than 15 s. There was no scale loss on any fish and bleeding from hooking wounds was present in 2.6 and 19.7% of fish in the field and aquaria experiment, respectively. More than 95% of all individuals were exposed to air for less than 1 min. During the field experiment, 5 fish were exposed to air for between 1 and 3 min, and 1 fish was exposed to air for between 3 and 5 min.

Significant differences were detected in the anatomical hook location between experiments ($\chi^2 = 28.65$, $p < 0.01$). Overall, 67% of fish were mouth-hooked. Of these the majority (55 and 21% for the field and aquaria experiments, respectively) were hooked in the corner of the mouth. During aquaria experiment 1, similar numbers of yellowfin bream ingested hooks (53%) as those that were hooked in the mouth (47%), while more than 84% of the fish caught during the field experiment were mouth-hooked (Fig. 3A). One fish in each experiment was hooked in the gill arch.

3.3.3 Post-release survival of yellowfin bream

Four and seven treatment fish died during the field and aquaria experiments, representing overall post-release survival rates of 94.9 and 89.4%, respectively. In contrast, none of the control fish died. The mortality rates for the same treatments were not significantly different among cages or experiments (Fisher's exact test, $p > 0.05$). Similarly, Fisher's exact tests revealed no significant difference in the number of dead fish between the two treatments for data pooled across both experiments ($p > 0.05$).

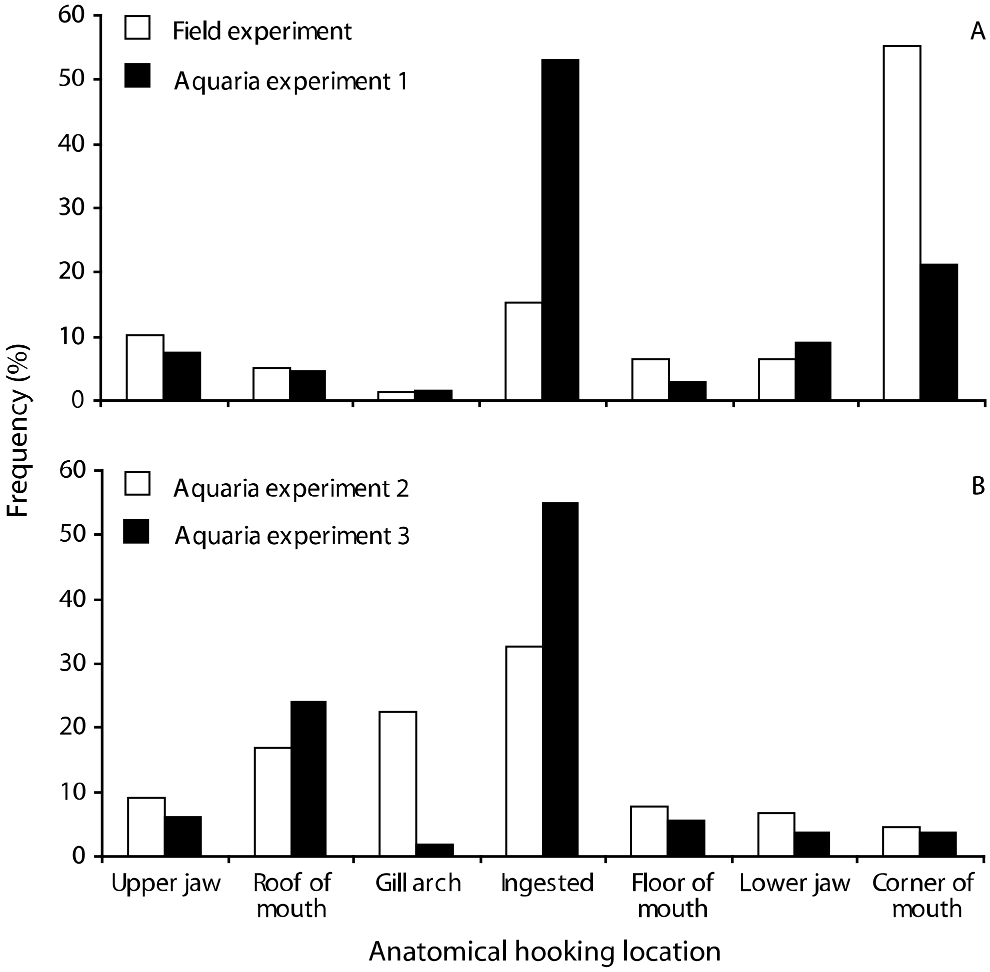

Fig. 3. Anatomical hooking location of (A) yellowfin bream and (B) mulloway during each experiment.

In both experiments, 72.7% of mortalities occurred within 6 h of release, and all within the first 24 h. The only mouth-hooked mortality was from a hook removed fish in the aquaria experiment that had been hooked in the gill arch. All 4 mortalities (1 hook removed and 3 hook not removed) in the field and six of the seven (all hook removed) mortalities in the aquaria were throat-hooked. In the majority of hook ingested mortalities, the hook had punctured the oesophagus wall and the point of the hook had lodged in the either the pericardial sac (heart) area or liver. In some instances, surviving fish showed signs of local infection in any penetrated organ adjacent to the point of hook penetration (Fig. 4). In contrast, the retained hook in one individual was totally encapsulated within healthy liver tissue (Fig. 5A). All hooks remaining in the majority of mouth-hooked fish had begun to oxidise particularly in the immediate area of the bait barbs (Fig. 5B).

Exact logistic regression revealed that the only significant main effect influencing mortality was the presence of bleeding at the hooking wound ($p < 0.01$). Fish that were observed to be bleeding once the hook had been removed were significantly more likely to die (75%) than those that showed no signs of blood (4%), or did not have the hook removed ($p < 0.01$; Table 1). There was also a significant interaction between hook removal and anatomical hook location (exact logistic regression, $p < 0.01$; Table 1). Specifically, those fish that had ingested hooks removed were more likely to die (mortality rate of 87.5%), than those that had hooks (i) left in the mouth and oesophagus/stomach (0 and 7.6 %, respectively) or (ii) removed from the mouth (1.7 %) ($p < 0.01$; Table 1). No other factors influencing post-release survival were detected (Tables 1 and 2).

Autopsy revealed that overall, approximately 81 and 13% of mouth-hooked and hook-ingested yellowfin bream had ejected their hooks (Table 3). Further, at least 3 of the mouth-hooked fish in the field experiment were found to have swallowed their hooks during the 5 d monitoring period. Fisher's exact tests failed to detect any significant difference in the rate of hook ejection between the field and aquaria experiments 1 ($p > 0.05$).

3.3.4 Capture of mulloway

Overall, 89 (32.7 ± 0.35 cm TL) and 162 (31.2 ± 0.42 cm TL) mulloway were hooked and released into the sea cages during aquaria experiments 2 and 3, respectively. No significant differences were detected between the size-frequency distributions of treatment

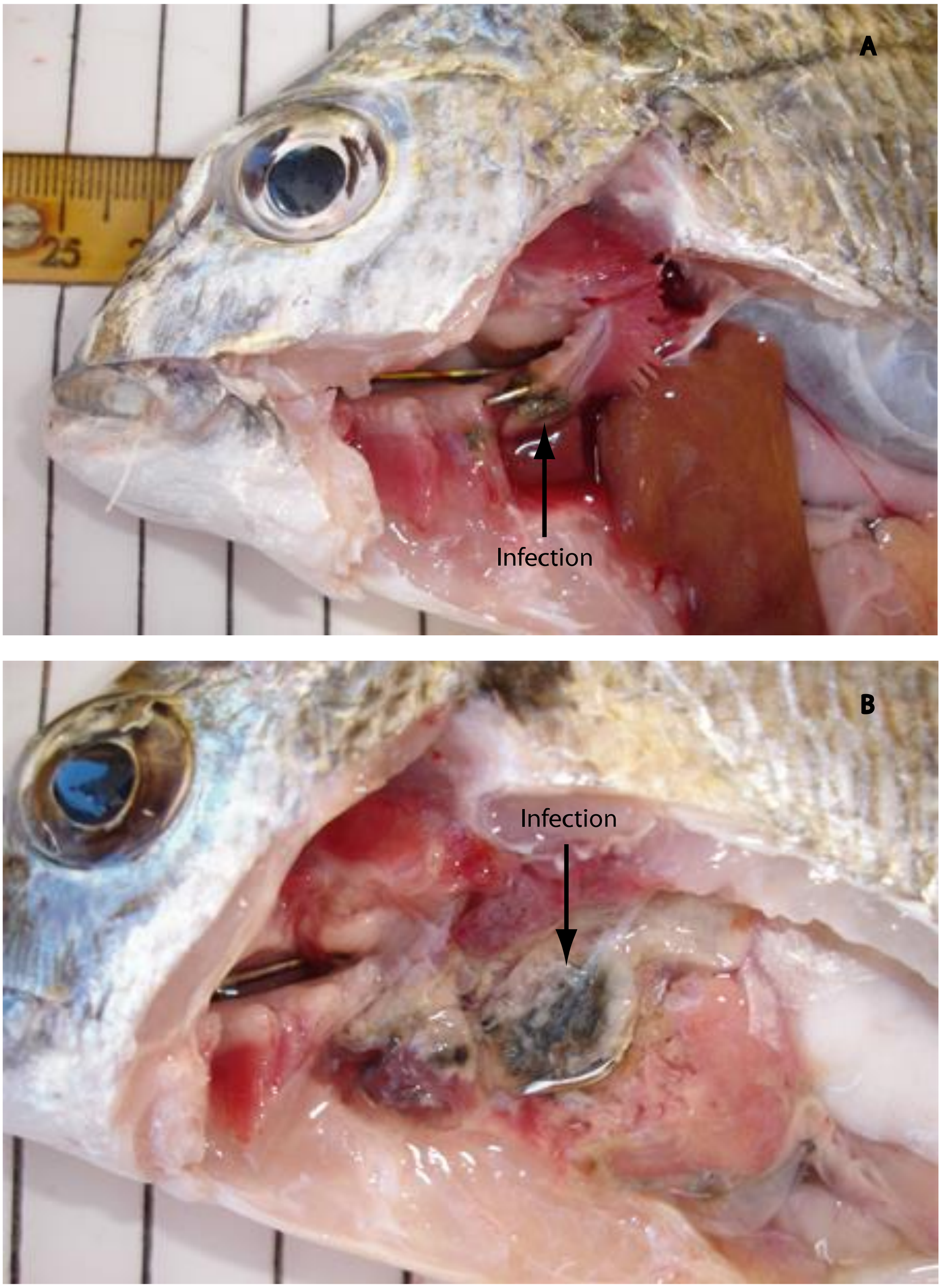

Fig. 4. Local infection adjacent to the hook in the gill arch (A) and liver (B) in surviving hook-ingested yellowfin bream from aquaria experiment 1.

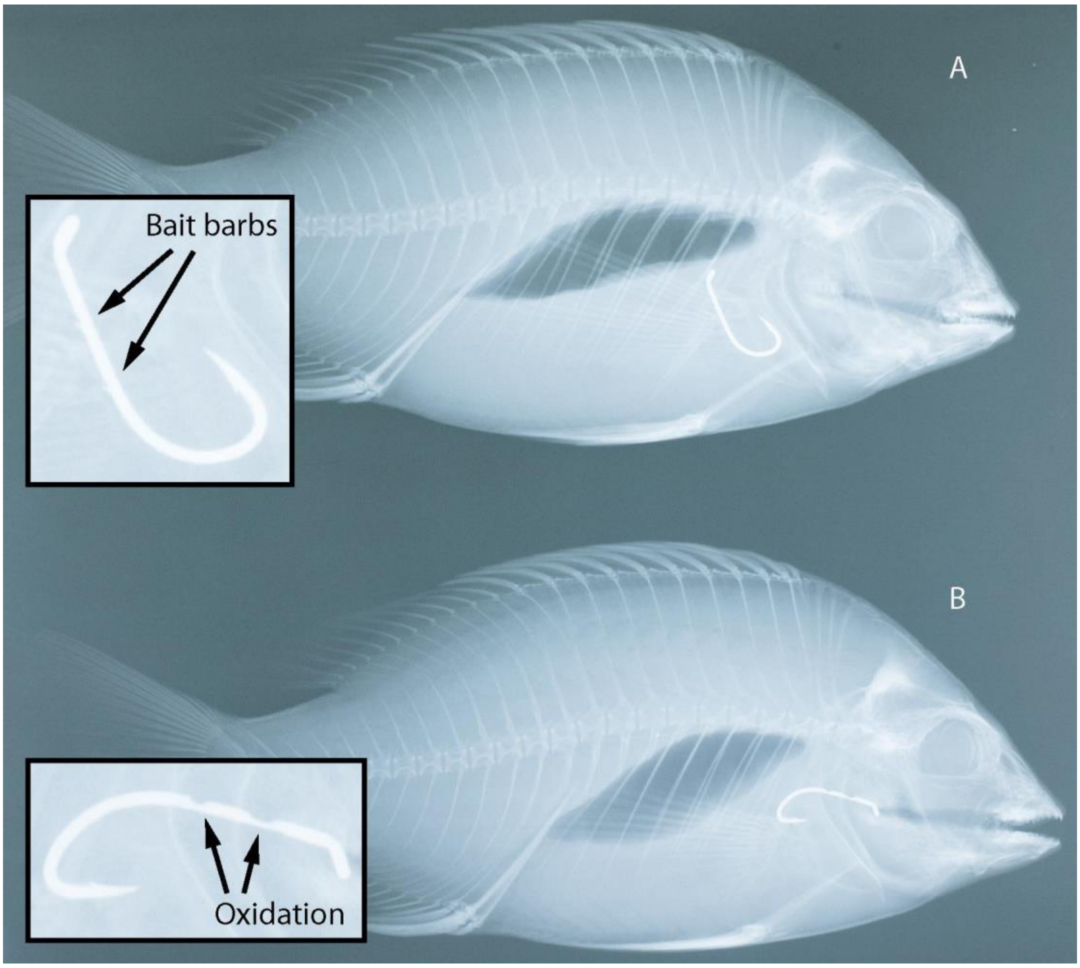

Fig. 5. Lateral x-ray of surviving hook-ingested yellowfin bream from aquaria experiment 1. Insets show the condition of each hook.

and control fish within or among experiments (Kolmogorov-Smirnov tests, $p > 0.05$). All fish in both experiments were played for less than 15 s, exposed to air for less than 1 min and lost no scales.

Similar numbers of fish were mouth- and throat-hooked (45.1 and 54.9%, respectively) in aquaria experiment 3. In contrast, the majority of mulloway (67.4%) were hooked in the mouth in aquaria experiment 2 (Fig. 3B). Apart from the fish that ingested

Table 1. Pooled categorical parameters collected at the end of the field and aquaria experiments for total numbers of live and dead yellowfin bream that had (i) the hook removed or (ii) the hook not removed. * Significant (p<0.01).

	Hook removed		Hook left in	
Parameter	Alive	Dead	Alive	Dead
Hook location*				
Mouth/Jaw/Gills	(59)	(1)	(37)	(0)
Upper jaw	10	0	3	0
Roof of mouth	5	0	2	0
Gill arch	1	1	0	0
Floor of mouth	5	0	2	0
Lower jaw	7	0	4	0
Corner of mouth	31	0	26	0
Ingested (oesophagus/stomach)	(1)	(7)*	(36)	(3)
Play period (sec)				
< 15	44	8	45	1
15 - 30	10	0	23	1
30 - 60	6	0	2	1
60 - 120	0	0	2	0
120 - 180	0	0	1	0
Exposure to air (min)				
< 1	59	7	69	3
1 - 3	1	1	3	0
3 - 5	0	0	1	0
Scale loss				
Yes	0	0	0	0
No		60	8	73
Blood at mouth or gills				
Yes	2	6*	7	0
No	58	2	66	3

Table 2. Mean (± se) continuous parameters used in the exact logistic regression analyses for yellowfin bream that either (i) had the hook removed (ii) or the line cut and the hook left in. Data are pooled across the field and aquaria experiments.

	Hook removed		Hook left in	
Parameter	Alive	Dead	Alive	Dead
TL (cm)	22.65 (0.52)	29.48 (1.28)	24.45 (0.61)	35.00 (1.16)
Line strength (kg)	3.47 (0.20)	3.60 (0.00)	3.14 (0.17)	4.53 (1.73)
Time in holding tank (min)	15.81 (2.48)	2.50 (1.94)	12.27 (1.69)	28.33 (8.30)
Temp. in holding tank (°C)	20.15 (0.20)	19.59 (0.09)	19.33 (0.11)	18.70 (0.50)
Oxygen in holding tank (mg l^{-1})	6.85 (0.26)	6.44 (0.04)	6.78 (0.11)	10.54 (0.50)
Water depth (m)	2.63 (0.39)	2.38 (1.38)	2.45 (0.28)	8.67 (1.77)

hooks, fish were hooked most frequently in the gill arch (22.5%) in aquaria experiment 2 and the roof of the mouth (24.1%) in aquaria experiment 3 (Fig. 4B). More than 24% were bleeding from hooking wounds, with significantly more bleeding after the hook was removed (37.5%), compared to when the hook was not removed (17.4%) (Fisher's exact test, $p < 0.01$). Of the individuals bleeding, significantly more fish (79.2%) were hooked in the throat or gill arch than all of the other mouth-hooked locations combined (Fisher's exact test, $p < 0.01$).

3.3.5 Post-release survival of mulloway

None of the control fish died. By comparison, 73.1 and 81.5% of mulloway survived hooking for aquaria experiments 2 and 3, respectively (Table 4). Contingency table analyses

Table 3. The total number of live yellowfin bream and mulloway by anatomical hooking location that did not have the hook removed at the beginning and end of the field and aquaria (1 and 2) experiments. Parentheses indicate the number of additional dead fish and where the hook was located. na indicates not applicable.

		Anatomical hooking location		
		Ingested	Mouth	Ejected
Yellowfin bream				
Field				
	0 days	10	31	na
	5 days	10(3)	6	22
Aquaria exp. 1				
	0 days	29	6	na
	5 days	24	1	10
Mulloway				
Aquaria exp. 2				
	0 days	20	25	na
	5 days	19(9)	3	13(1)

revealed that hook removal was independent of survival in aquaria experiment 2 ($\chi^2_1 = 1.2$, $p > 0.05$). In aquaria experiment 3, post-release survival was dependent on hook removal, with hook-ingested fish having a lower rate of post-release survival when the hook was removed ($\chi^2_5 = 32.1$, $p < 0.05$).

Table 4. Mortality rates of mulloway following specific treatment and release during aquaria experiments 2 and 3. *Indicates experiment 2.

No. of fish hooked	Air exposure (min)	Hook location	Hook removed	% mortality
22	< 1	Ingested	yes	72.7
44*	< 1	Unknown	yes	31.8
45*	< 1	Unknown	no	22.2
25	< 1	Ingested	no	16.0
19	< 1	Mouth	no	15.8
42	0	Ingested	no	9.5
31	0	Mouth	no	6.5
23	< 1	Mouth	yes	4.3

More than 59% of mortalities in both experiments occurred within 24 hours of capture. In this time period during aquaria experiment 2, similar numbers of mortalities occurred in each of the treatment groups (eight and seven for hook removed and hook not removed, respectively). In contrast, more than 65% of the mortalities during the first 24 hours in aquaria experiment 3 were throat-hooked fish that had hooks removed.

At the end of the experiments, autopsy revealed that a total of 88% of mouth-hooked mulloway had ejected their hooks (Table 3). However some mouth-hooked individuals were found to have swallowed their hooks. More specifically, prior to their release into the cages, 20 fish had ingested hooks, but at the end of the experiment, autopsy revealed that 28 fish (19 alive and nine dead) had retained ingested hooks, indicating that 8 of the mouth-hooked fish subsequently swallowed their hooks. In contrast, 5% of hook-ingested mulloway were free of hooks at the end of the experiments (Table 3). Similar to the bream, the majority of ingested hooks had punctured the oesophagus wall and the point of the hook had penetrated the liver or protruded into the intraperitoneal cavity (Fig. 6). All hooks remaining in surviving hook-ingested fish showed signs of oxidation. Generally, the degree of oxidation was observed to be dependent upon the length of the hook protruding anterior of the oesophagus (Fig. 7).

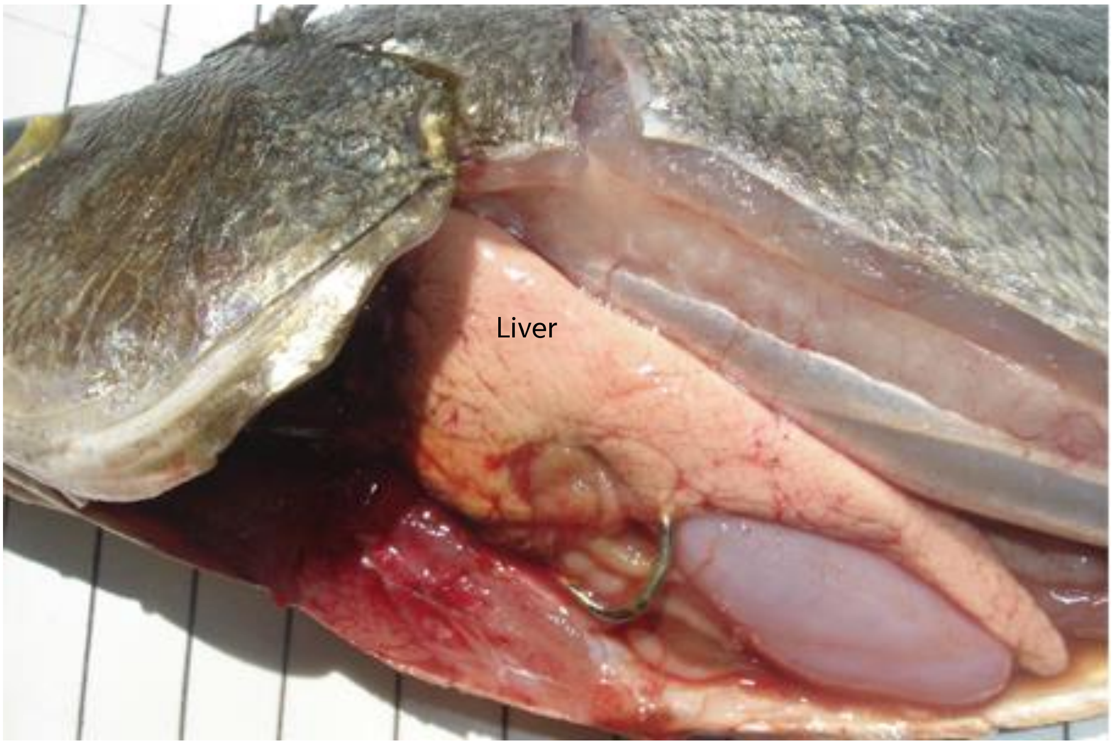

Fig. 6. Hook penetrating the liver of a surviving hook-ingested mulloway from aquaria experiment 2.

3.3.6. Blood physiology

Overall, Kruskal-Wallis tests failed to detect any significant intra-specific differences in the mean (± se) concentrations of plasma cortisol and glucose between any of the treatment and control fish at the end of all the experiments ($p > 0.05$). However, except for mulloway during aquaria experiment 3, all caged fish had concentrations of cortisol that were significantly greater than initial levels, (Kruskal-Wallis tests, $p < 0.05$; Figure 8).

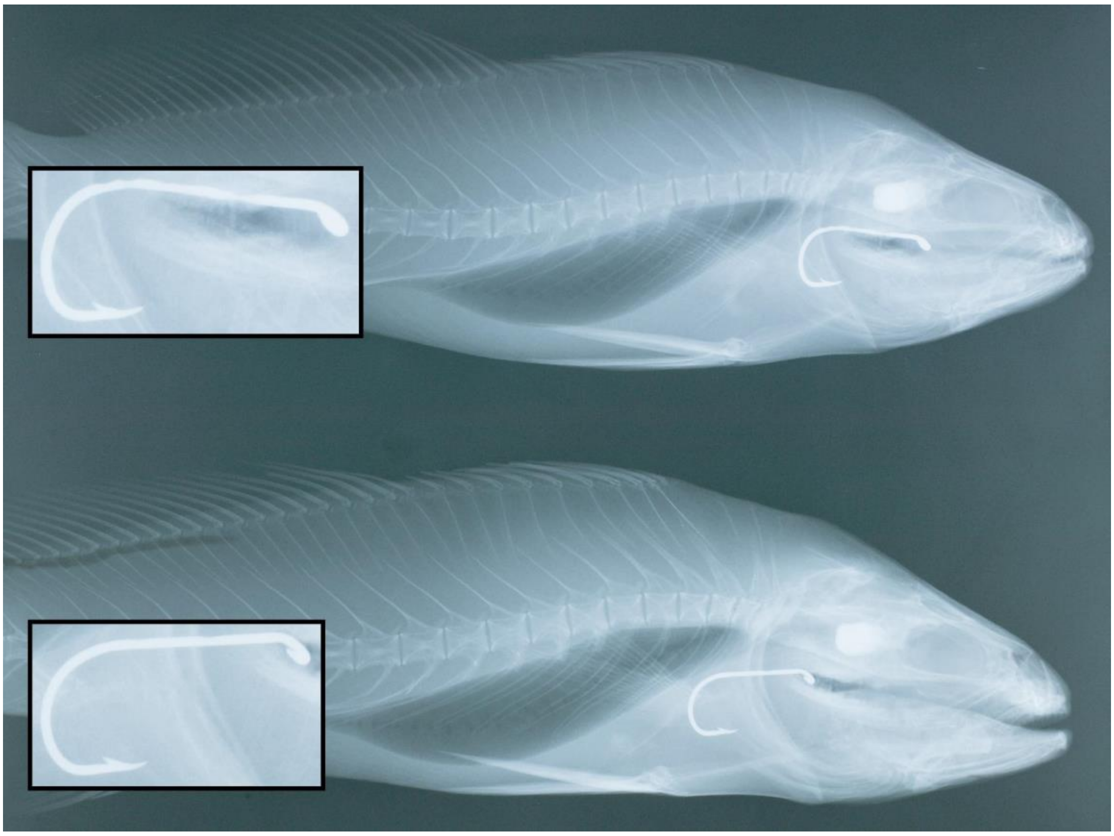

Fig. 7. Lateral x-ray of surviving hook-ingested mulloway from aquaria experiment 2. Insets show final hook condition.

Concentrations of glucose were also significantly elevated in all mulloway (Kruskal-Wallis tests $p < 0.05$; Figure 8).

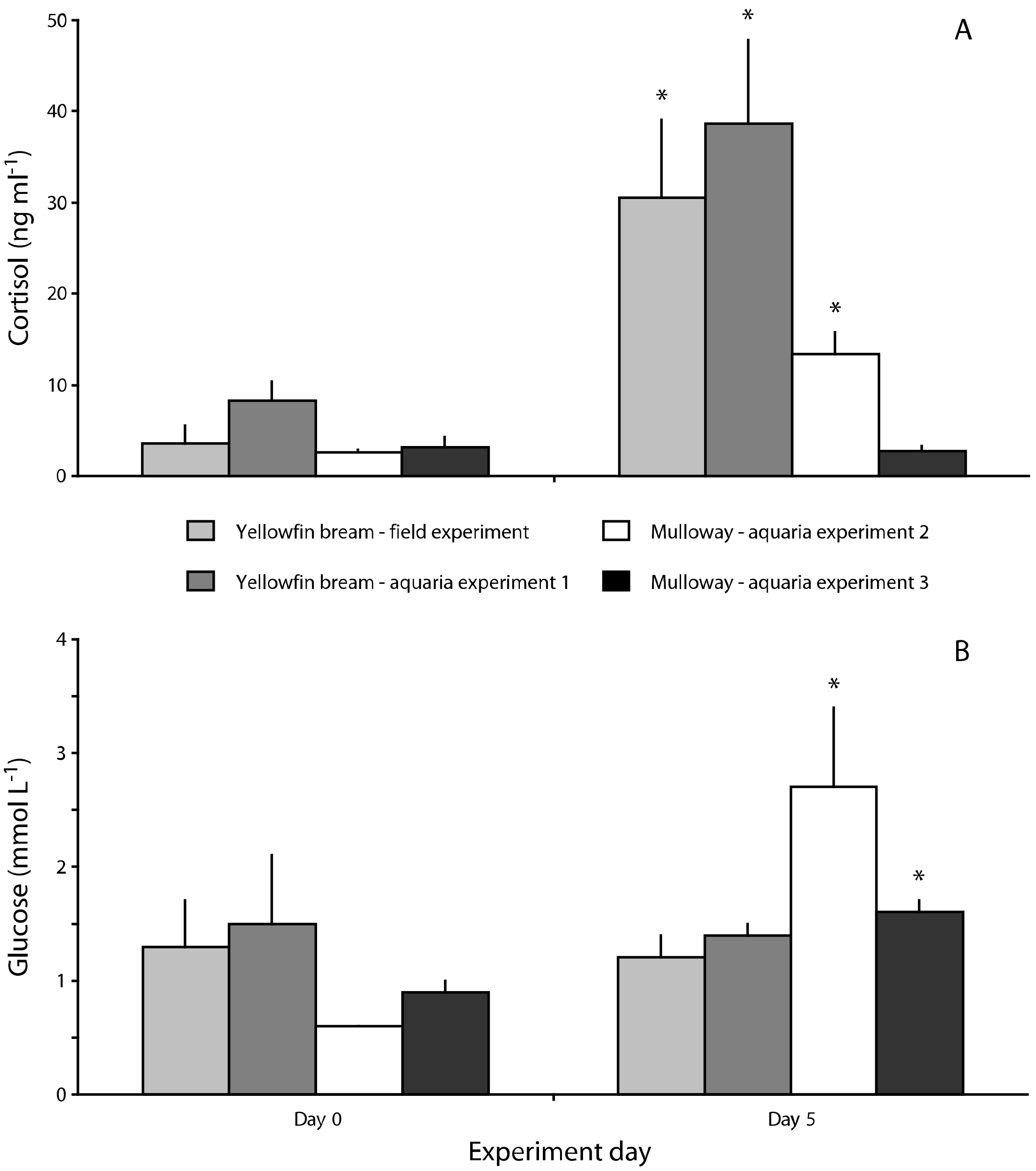

Fig. 8. Mean (± SE) concentrations of blood plasma (A) cortisol (ng ml^{-1}) and (B) glucose (mmol l^{-1}) for yellowfin bream and mulloway prior to (Day 0) and at the end of experiments (Day 5). * Significant (p<0.05).

3.4 Discussion

This study demonstrated clear treatment-dependent mortalities. Specifically, more than 72 and 87% of mulloway and yellowfin bream died after having their ingested hooks removed. Conversely, releasing both species with ingested hooks not removed or releasing mouth-hooked fish (irrespective of removing the hook or not) was associated with few short-term mortalities. These trends in mortalities support those reported by authors assessing post-release survival of several other Australian (Ayvazian et al., 2002; Butcher et al., 2006; St John and Syers, 2005) and overseas species (Barthel et al., 2003; Cooke and Suski, 2004). For example, Butcher et al., (2006) demonstrated that the majority of sand whiting died after having their ingested hooks removed, while mortalities to hook-ingested rainbow trout *Oncorhynchus mykiss* were significantly reduced when individuals were released with the line cut (Schill, 1996). More recently, Broadhurst et al., (2007) reported a short term (up to 8 d) survival rate of 85% for hook-ingested yellowfin bream released with the hook in place in an aquaria experiment that assessed both mortality and hook ejection rates. Other studies have demonstrated low mortalities to mouth-hooked individuals of numerous species, irrespective of their handling prior to release (e.g. Murphy et al., 1995; Taylor et al., 2001; Aalbers et al., 2004).

In addition to the greater mortalities caused by the removal of ingested hooks in this study, significantly more fish died when there was bleeding present from hooking wounds. It has been well demonstrated that the rate of hooking mortality is directly proportional to the presence of blood from hooking injury (e.g. Warner and Johnson, 1978; Nelson, 1998; Cooke et al., 2003c; Lindsay et al., 2004; Butcher et al., 2006). In support of this, Dextrase and Ball (1991) reported that only lake trout, *Salvelinus namaycush* that showed signs of bleeding prior to release died. The greater proportion of mulloway with blood present compared with that of yellowfin bream was potentially due to the higher incidence of deep hooking for the former species. More specifically, the group of mulloway in experiment 2 had the highest proportion of fish hooked in the gills and bleeding from hook wounds. The delicate gill structure of fish is extremely susceptible to trauma and has been reported as the origin of severe bleeding associated with hook damage (Nuhfer and Alexander, 1992). When fish are not hooked in a vital location such as the gills, the frequency of bleeding is typically low (e.g. Cooke et al., 2001; Dunmall et al., 2001). Furthermore, greater bleeding from a given wound could be expected at higher temperatures because of higher metabolic rates and slower blood coagulation rates (Nuhfer and Alexander, 1992).

Some of the fish in this study were able to expel their hooks during the 5 d monitoring period with the hook shedding rate influenced by the original anatomical hooking location. More specifically, mouth-hooked yellowfin bream and mulloway were more likely to regurgitate or pass their hooks compared to hook ingested fish of both species. Other studies that have assessed the retention of hooks following release have reported higher rates of hook shedding in hook-ingested fish, although these were done over longer periods. For example, Aalbers et al., (2004) reported that 39 % of white sea bass passed their ingested hooks over 150 d, while Schisler and Bergersen (1996) recorded a shedding rate for rainbow trout of 25% over 21 d. Additionally, Schill (1996) found ejection rates of 74 and 60% for the latter species in an aquaria (60 d monitoring) and field (30 d monitoring) experiment, respectively. In contrast, although the number of hook ingested fish was low (5), Bugley and Shepard (1991) reported that two hook ingested black sea bass *Centropristis striata* did not have a hook present two d post release. In corroboration of the above results for other species, Broadhurst et al., (2007) documented that 76% of hook ingested yellowfin bream ejected their hooks between 6 and 56 d post-release. Although no data exist on the longer term hook retention rates for mulloway, it appears that overall, some individuals of both of the study species are able to expel hooks and the rate of hook shedding is more likely to increase over time. Not withstanding the above, this study provides evidence that if fish are released by cutting the line and leaving the hook in place some will ingest hooks that were originally lodged in the mouth supporting the removal of hooks from the mouth prior to release.

As was the case in numerous prior investigations of post-release survival (for reviews see Muoneke and Childress, 1994; Bartholomew and Bohnsack, 2005; Cooke and Suski, 2005), the most mortalities observed in this study occurred within 24 h of each angling event.

Autopsies revealed that, similar to the findings of catch-and-release studies on rainbow trout (e.g. Diodati and Richards, 1996; Schill, 1996) and striped bass *Morone saxatilis* (e.g. Nelson, 1998), the mortalities were likely the result of ingested hooks protruding through the oesophagus and penetrating the pericardium or liver. Removing the hook probably exacerbated the initial injury by inflicting further trauma to these vital organs. Previous studies have reported that, compared with the scenario above, the mortality of deeply-hooked fish where the hook has not lodged in these organs is lower (e.g. Pelzman, 1978). Schill (1996) found that following autopsy of surviving rainbow trout that had not had the hook removed prior to release, 79% of fish had hooks penetrating the oesophagus and anterior portion of the stomach wall and 16% of fish had hooks penetrating the anterior portion of the liver. It is apparent that some fish can survive hooking damage to the liver as evidenced by a surviving yellowfin bream in this study that autopsy revealed had the hook totally embedded within a healthy liver with no sign of infection or peritonitis. Furthermore, Broadhurst et al., (2007) has demonstrated that some hook ingested yellowfin bream can survive being released with the hook left in place and subsequently retain that hook for up to 105 d without any sign of infection in addition to maintaining the digestive capability and condition of unhooked control fish.

Although there were no significant differences in the concentrations of plasma cortisol and glucose between any of the hooked and control fish at the end of the experiments, there was considerable variation in primary and secondary stress responses within and between experiments. The experimental design did not allow for assessment of the acute stress response caused by being hooked and released, however any physiological disturbance may have been restricted to the short term as reported in previous studies on similar species. For example, Pankhurst and Sharples (1992) and Cleary et al., (2000) demonstrated that plasma cortisol concentrations of snapper *Pagrus auratus* began to decline 48 and 24 h post catch-and-release, respectively. Although a significant problem in comparing the stress responses of fish to specific treatments is the determination of baseline plasma cortisol concentrations (Pankhurst and Sharples, 1992; Clearwater and Pankhurst, 1997; Sumpter, 1997; Haddy and Pankhurst; 1999), the baseline concentrations of plasma cortisol (2.5 – 8.5 ng ml^{-1}) were similar among mulloway and yellowfin bream at the beginning of each experiment. Furthermore, the baseline concentrations were comparable to earlier estimates for mulloway (Broadhurst and Barker, 2000) and below that (< 10 ng ml^{-1}) reported for other unstressed sparids, including black bream *Acanthopagrus butcher* (Haddy and Pankhurst, 1999) and snapper (Pankhurst and Sharples, 1992; Broadhurst et al., 2005). Unlike these studies, which showed a return to baseline estimates within 5 d of capture (Pankhurst and Sharples, 1992; Haddy and Pankhurst, 1999; Broadhurst et al., 2005; Broadhurst and Barker, 2000), significantly higher concentrations of cortisol were recorded in caged yellowfin bream (field and aquaria experiment 1) and mulloway (aquaria experiment 2) at the end of the experiments. The exact cause of the elevated plasma cortisol concentrations for these fish is unknown. However, it is clear that a combination of capture, handling and confinement elicited a stress response and the magnitude of the increase in plasma cortisol concentration could be attributed to the method of sampling (Clearwater and Pankhurst, 1997). A possible explanation of the low plasma cortisol concentration for mulloway in aquaria experiment 3 may be the extended acclimation period. These aquacultured fish were collected at the same time as those utilised in aquaria experiment 2 and may have become accustomed to domestication within the aquaria environment during the four-month period prior to experimental treatment. Woodward and Strange (1987) reported that plasma cortisol and glucose concentrations in wild rainbow trout showed more extreme responses to a variety of stressors than in hatchery reared trout.

Not withstanding any physiological disturbance caused by the hooking and handling treatments of this study or the minimal impact such treatment had on any protracted mortalities, it is likely that the logistical constraints of experimental design and methodologies may have contributed to the elevation of some of the final cortisol concentrations. For instance, the relatively close proximity of the seacages to one another in the aquaria meant that during blood sampling the initial disturbance to the pool may have evoked a stress response in those fish yet to be sampled. It is well known that disturbances lead to stress responses (Pankhurst and Sharples, 1992) and studies have demonstrated that elevated plasma cortisol concentrations may result from prolonged sequential sampling (Strange et al., 1977) or sampling disturbance (Pickering et al., 1982; Chopin et al., 1995). Although chronic stress can be attributed to confinement (Clearwater and Pankhurst, 1997), the plasma glucose concentrations of yellowfin bream were lower at the end of both the field and aquaria experiments than at the start, providing further evidence that the elevated cortisol was probably an acute stress response from the sampling procedure.

The similarity in the physiological responses of yellowfin bream among the aquaria and field experiments coupled with the same trend in treatment-specific effects, support the utility of either type of experiment for estimating the factors influencing post-release survival. The incorporation of field and aquaria experiments contribute to experimental methodologies more accurately reflecting angling and handling practices experienced by wild fish (Cooke et al., 2001). However, it is also apparent that the experimental designs of this study had some limitations in terms of providing realistic estimates of post-release survival. In particular, it is unlikely that the mechanical and behavioural responses of fish to presented bait in the aquaria experiments accurately reflected that of those conventionally angled in the wild. The cumulative effect of social hierarchies that may have developed between the fish in the aquaria environment (Martins et al., 2005) coupled with the cessation of feeding 2 d prior to the experiment may have altered the intensity of the hooking response, potentially leading to proportionally more fish ingesting hooks with subsequent greater injuries. The insulation of fish in the aquaria from environmental conditions such as tidal flow may have also had an effect. Schill (1996) attributed similar increases in rates of hook ingestion by rainbow trout between field (16 - 17%) and aquaria (40 - 87%) experiments to a reduction in line tension during fishing.

It is likely that the use of anglers of various levels of experience in the field experiment represented conventional angling practices, however this may have come at a cost to a more accurate assessment of post-release survival following specific treatment. In addition, reflecting conventional angling practices requires the assumption of independence in angler behaviour. Conceivably, some anglers may have been reluctant to remove as many hooks as normal, because they recognised that this could lead to inflated overall mortality rates. Further, the conventional angler may see cutting the line and releasing a fish with the hook left in a wasteful or costly practice due to the desire to reuse, or avoid having to spend time to retie, terminal gear. Previous studies (e.g. Broadhurst et al., 2005) have placed observers with anglers to minimise such biases since this is a reliable method of quantifying catches (Liggins et al., 1996).

This study has demonstrated that anglers can maximise the probability of post-release survival via simple handling-and-release practices. More specifically, irrespective of air exposure, anglers should remove the hook from mouth-hooked fish (to prevent subsequent ingestion), and cut the line and release hook-ingested individuals.

4.0 EFFECTS OF EXERCISE AND AIR EXPOSURE ON THE SHORT-TERM POST-RELEASE SURVIVAL OF YELLOWFIN BREAM

4.1 Introduction

During normal angling operations, mouth-hooked fish are inevitably subjected to various stressors, especially exhaustive exercise and air exposure; both of which may contribute towards their eventual death (for reviews see Muoneke and Childress, 1994; Bartholomew and Bohnsack, 2005). The level of exercise depends on factors such as angler expertise, gear limitations and the rate of line retrieval (Cooke and Hogle, 2000; Cooke et al., 2001). The duration of air exposure is determined by handling factors such as ease of hook removal as well as the time required to take photographs, length and/or weight measurements (Muoneke and Childress, 1994). Oxygen deprivation during handling significantly disturbs endocrine and metabolic processes and is likely to be the major factor affecting post-release survival in many fish species (Macleay et al., 2002), primarily because the delicate gill structures (lamellae) collapse during air exposure, inhibiting subsequent gas exchange (Ferguson and Tufts, 1992).

Numerous studies have investigated the specific effect of air exposure or exercise, and the cumulative effect of both factors, on the post-release survival of line-caught fish, although much of this work is largely restricted to salmonids (Ferguson and Tufts, 1992; Schisler and Bergersen, 1996) and centrarchids (Cooke et al., 2001). Specifically, in an aquaria study, air exposure following exercise resulted in higher mortality of rainbow trout, *Oncorhychus mykiss* than when air exposure was avoided (Ferguson and Tufts, 1992). Similarly, mortality was highest for pikeperch, *Sander lucioperca* exposed to air for periods between 60 and 240 s compared to individuals not exposed to air (Arlinghaus and Hallermann, 2007). Studies in the field have attributed behavioural impairments and subsequent post-release predation to extended air exposure (Cooke and Philipp, 2004; Danylchuk et al., 2007). Irrespective of the species, air exposure is harmful for fish and has been identified as a prominent factor affecting fish survival and physiological changes associated with catch-and-release angling (Bartholomew and Bohnsack, 2005; Cooke and Suski, 2005; Arlinghaus et al., 2007). In addition, the duration of air exposure influences the recovery time of physiological variables (Cooke et al., 2001) which can lead to impairments in behaviour such as swimming performance (Schreer et al., 2005).

Although the effects of air exposure on angled Australian fish have not been addressed, previous studies demonstrate significant physiological and behavioural implications of air exposure that is further exacerbated when combined with exercise (Cooke et al., 2001). Understanding the tolerance of mouth-hooked yellowfin bream to different levels of exercise and hypoxia should facilitate the development of strategies to improve their chances of surviving catch and release. The aims of this study were to contribute towards this information by quantifying the short-term mortality of individuals after (i) short and long playing times (5 vs. 30 s) followed by (ii) different extremes in air exposure (2.5 vs. 5 min). Specifically, it was predicted that individuals exposed to the longest periods of exercise and air exposure would experience the highest levels of mortality.

4.2 Methods

The objectives were addressed during two aquaria experiments done at the CFRC between February and July 2005. In both experiments yellowfin bream were hooked from 5000-l tanks (See Chapter 2 for details of the aquaria facility) or a sea cage situated in the pool, using barbed minor-offset circle hooks (size 1/0 – Fig. 10) attached to 4 kg monofilament line and baited with school prawns. Only mouth-hooked fish (excluding the gill arch) were used in the experiments. All angled fish were subjected to two treatments that involved exposing individuals to air at ambient temperature for either (i) 2.5 or (ii) 5 min. Some hooked fish were subjected to an additional treatment that involved 30 s exercise following hooking. All hooked-and-released fish were held in cylindrical sea cages, located in the pool, and monitored twice daily for five or ten days. The specific methods used in each experiment are described below.

4.2.1 Experiment 1: post-release survival of yellowfin bream following a 5-s playing time and two durations of air exposure

The first experiment was done in February 2005 using 205 yellowfin bream. Two weeks before the start of the experiment, equal numbers of fish were randomly distributed among five of the 5000-l tanks (i.e. 41 fish $tank^{-1}$). All fish were starved for two days prior to 44 being hooked from four of the tanks. All fish were played for 5 s, removed from their tanks and had their hook extracted, placed onto a dry, rectangular 100-l plastic tray and subjected to either 2.5 or 5 min of air exposure, before being released into one of the four designated cylindrical sea cages (two replicates for each treatment with 11 fish $cage^{-1}$). After the release of the last treatment fish, 22 control fish were transferred (using 25-l buckets) from the unfished 5000-l tank into the remaining two sea cages (11 fish $cage^{-1}$). All fish were fed school prawns and monitored twice daily over 10 days.

4.2.2 Experiment 2: post-release survival of yellowfin bream following 30 s of playing time and two durations of air exposure

The second experiment was done in July 2005 using approx. 400 yellowfin bream. The methods and treatments (i.e. 2.5 vs. 5 min air exposure) followed those detailed above for experiment 1, except that fish were distributed among the rectangular sea cages in the pool (two weeks prior to the start of the experiment) and 31 were angled and played for 30 s rather than 5 s before being released into four of the cylindrical sea cages. All fish were monitored as above (but only over five days) and, to maintain stocking densities, any dead fish were replaced with fin-clipped individuals from the 5000-l holding tanks.

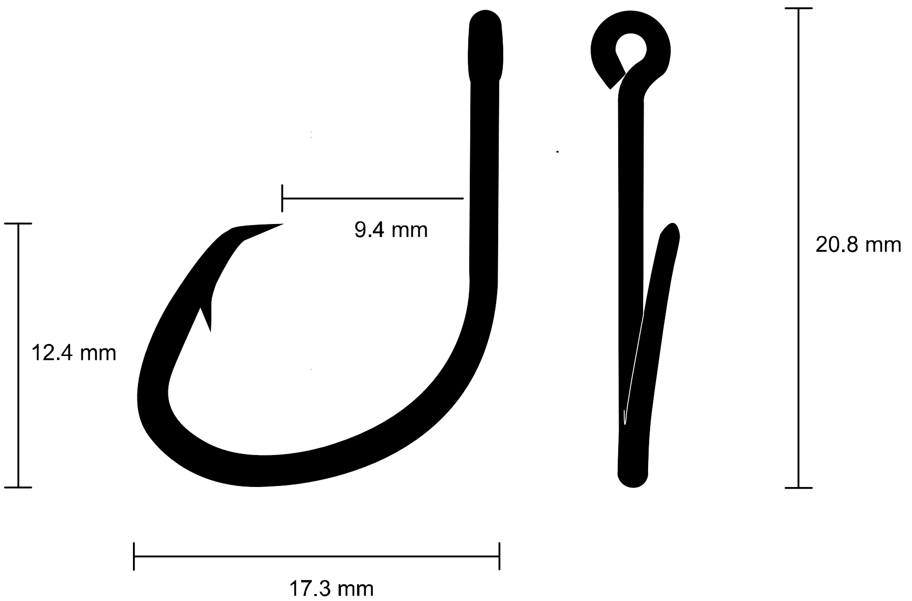

Fig. 9. Nominal dimensions (mm) of the circle hook used in both experiments.

4.2.3 Data collected and analyses

The time of capture and release into the sea cages, TL, cage number, anatomical hooking location, treatment, time taken to remove the hook and the presence/absence of blood were recorded for all fish. Air temperature was recorded every 30 min during angling, and water temperature (ºC), salinity (psu) and dissolved oxygen (mg l^{-1}) concentrations were recorded at 0900 each day during both experiments.

Size-frequency distributions (0.5-cm TL intervals) of treatment and control fish were compared within and between experiments using two-sample Kolmogorov-Smirnov tests. Two-tailed Fisher's exact tests were used to test the independence of the treatment of fish on the presence of bleeding (within and between experiments) and mortality. To assess relative stress of fish before and after the catch-and-release process, blood samples were taken (using the methodology described in section 2.5.1) from one individual from each 5000-l tank (experiment 1) and up to three individuals from each rectangular sea cage (experiment 2), prior to fishing on the day of angling. Up to five fish were then scooped from each of the treatment and control sea cages at the end of the experiments (i.e. following the 10 and 5 day monitoring period for experiments 1 and 2, respectively). Blood plasma was analysed for concentrations of cortisol (ng ml^{-1}) and glucose (mmol l^{-1}). Plasma cortisol and glucose concentrations were log transformed to account for the non-normality (significant kurtosis). All blood plasma cortisol and glucose concentrations are reported as mean ± se and, for all analyses, the null hypothesis was rejected at $p < 0.05$. The design of both of the experiments used the random factor of cages nested in treatment (which is equivalent to the random intercept model for a multilevel analysis with fish being nested in cages). The mixed model ANOVA (SPSS version 11.5) using the restricted maximum likelihood estimation method was fitted in order to account for this structure.

4.3 Results

4.3.1 Air temperature and water quality

The air temperature ranged from a minimum of 22.0 and 12.1ºC at the start of angling to a maximum of 25.2 and 17.6ºC following the hooking of the last treatment fish in experiment 1 and 2, respectively. Water temperature remained relatively constant during both experiments (experiment 1: 21.9 – 22.4ºC and experiment 2: 14.3 – 14.5ºC). Salinity ranged between 34.6 and 35.0 psu and dissolved oxygen between 5.0 and 6.8 mg l^{-1} during both experiments.

4.3.2 Fate of angled-and-released yellowfin bream

Overall, most fish (38.5 and 46.5%, respectively) were hooked in the right corner of the mouth (Fig. 10). Three and two fish ingested the hook in experiments 1 and 2 respectively, and were excluded from further treatment. No significant differences were detected between the size-frequency distributions of treatment (overall mean TL ± s.e.of 22.3 ± 0.3 cm) and control (23.2 ± 0.6 cm) fish within or between experiments (pairwise

Kolmogorov-Smirnov tests, $p > 0.05$). In both experiments, the time taken to remove the hook from each individual was < 5 s.

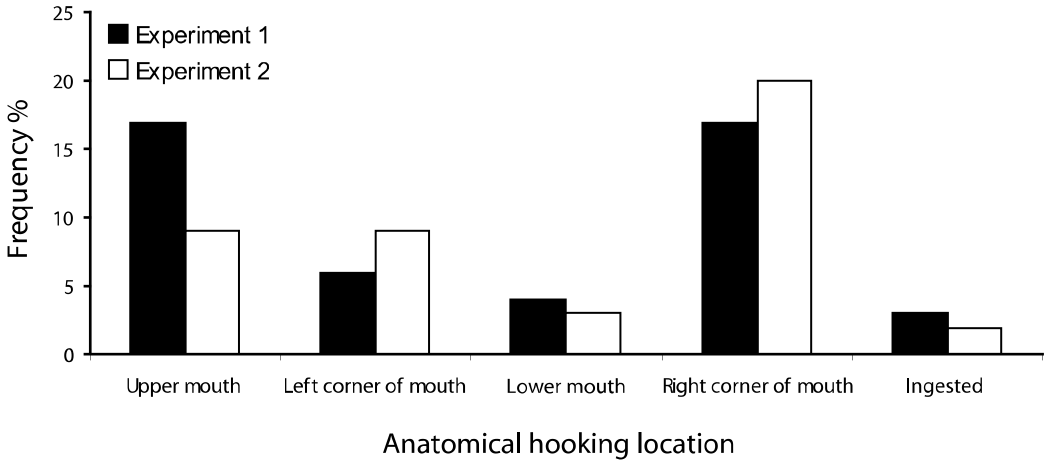

Fig. 10. Anatomical hooking location of yellowfin bream angled in this study.

None of the control fish died in either experiment, and there were no mortalities to treatment individuals in experiment 1. In contrast, one fish from each air exposure treatment in experiment 2 died, however these deaths were not significant (Fisher's exact test; $p > 0.05$). Both dead fish were observed to be bleeding heavily from the mouth after hook removal and died within 1-h of release. Post-mortem inspection revealed clotted blood surrounding the lamellae. There was no significant difference in the numbers of fish bleeding in each treatment, within and between experiments (Fisher's exact test, $p > 0.05$).

Prior to hooking, mean plasma cortisol and glucose concentrations of fish were 5.6 ± 3.2 ng ml-1 and 1.4 ± 0.8 mmol l-1, and 1.0 ± 0.6 ng ml-1 and 2.83 ± 0.1 mmol l-1 for experiments 1 and 2, respectively (Fig. 12a and b). There were no significant differences in the mean plasma cortisol ($F_{2,2.9}$= 1.28, $p > 0.05$ and $F_{2,3}$= 0.13, p>0.05) or glucose ($F_{2,3.1}$= 0.35, $p > 0.05$ and $F_{2,2.8}$= 0.55, $p > 0.05$) concentrations between treatment and control fish at the end of experiment 1 or 2 (Fig. 12a and b).

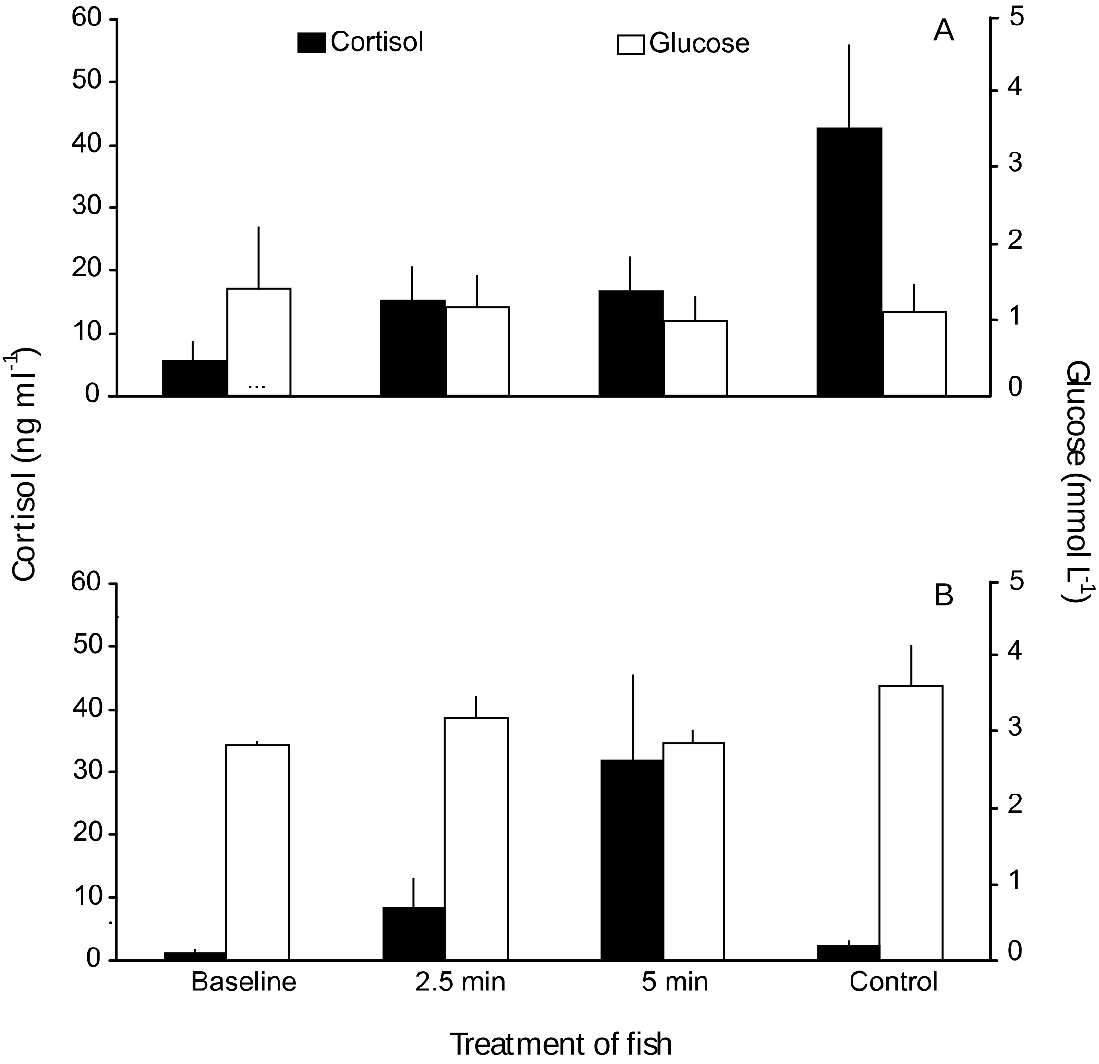

Figure 11. Mean plasma cortisol and glucose (± s.e.) concentrations of yellowfin bream sampled prior to (baseline), and at the end of (A) experiment 1 and (B) experiment 2.

4.4 Discussion

This study showed that most mouth-hooked yellowfin bream can withstand up to 30 s of exercise during line retrieval followed by 5 min of air exposure before release, with few negative short-term impacts. These results confirm the resilience of this species for withstanding general interactions with recreational fishing gears (Broadhurst et al., 1999; Broadhurst et al., 2005), and support observations for some overseas species like lake trout, *Salvelinus namaycush* (Loftus et al., 1988), Atlantic salmon, *Salmo salar* (Dempson et al., 2002) and rock bass, *Ambloplites rupestris* (Cooke et al., 2001). Furthermore, the high frequency of mouth-hooking and subsequent survival of fish in this study support an overall strategy of promoting mouth-hooking as a means for mitigating unwanted mortalities during catch-and-release angling.

It is almost inevitable that angled fish are exposed to air for a brief period to facilitate hook removal and different terminal tackle types may affect the ease of this operation and influence air exposure durations (Cooke et al., 2001). Furthermore, air exposure may become protracted depending on the experience of the angler in handling fish (Cooke et al., 2000), or if photography is involved (Muoneke and Childress, 1994). The two air exposure times used in this study were chosen to represent extreme periods of post-capture handling by anglers during normal angling operations. Studies utilising recreational anglers to catch fish have typically reported shorter periods of air exposure. For example, Butcher et al., (2006) and Broadhurst et al., (2005) observed that 95, 97.5 and 81.5% of sand whiting (*Sillago ciliata*), yellowfin bream and snapper (*Pagrus auratus*), respectively were exposed to air for less than 1 min during catch and release.

It is widely accepted that the presence of bleeding due to hook related injury significantly decreases the likelihood of post-release survival (Warner and Johnson, 1978; Nuhfer and Alexander, 1992; Nelson, 1998; Butcher et al., 2006) and that most fish suffer heavy bleeding as a result of puncture wounds to the cardiovascular system or organs, such as the liver (Cooke and Suski, 2004, Butcher et al., 2006) following hook ingestion. All of the fish that ingested the hook in this study were excluded from further treatment so as to not confound the mortality estimates attributable to air exposure. Of the 75 angled-and-released fish in both experiments only two died, and both during experiment 2. These mortalities may be attributed to the interactive effects of air exposure and the physical response of individuals. Specifically, the dead fish bled heavily from hook wounds in the right side of the mouth and post-mortem examination revealed extensive clotting. This bleeding was not caused by the extended playing time, since there were no significant differences in the rate of occurrence between experiments. The periods of air exposure were sufficient to allow the blood to begin clotting around the collapsed lamellae and, after release, it seems the fish were unable to clear their gills, which potentially inhibited gaseous exchange and caused death. Ferguson and Tufts (1992) found that brief air exposure of rainbow trout causes an almost complete inhibition of gaseous exchange across the gills. If such effects contributed towards mortalities, this can be easily addressed by limiting air exposure. Alternatively, if the hook can be easily removed, any bleeding individuals could be released underwater (Arlinghaus and Hallermann, 2007).

Although other studies have demonstrated that higher water temperatures increase probability of post-release mortality (e.g. Thorstad et al., 2003), both mortalities in the present study occurred at lower water and air temperatures. High water temperature is correlated with increased physiological disturbances, and the probability of immediate or delayed mortality (reviewed in Cooke and Suski, 2005). All fish in this study were exposed to air away from direct sunlight and, while individuals were free to flail on a plastic tray did not come into contact with any abrasive surface or article. Irrespective of angler expertise, fish handled by anglers under normal circumstances may suffer dermal disturbance, potentially leaving them more susceptible to opportunistic pathogenic infections (e.g. Saprolegnian lesions), especially at higher temperatures, and may contribute to faster mortality (Gingerich et al., 2007). No delayed mortality occurred in this study, however, had the handling treatments been more severe, higher mortality may have been experienced via infection that is known to be exacerbated by excessive handling and epidermal trauma (Cooke and Hogle, 2000).

Although the examined treatments did not cause significant short-term mortalities, these practices may have contributed toward sublethal disturbances that affected recovery and/or had undetected, longer-term deleterious impacts. Other studies have reported that angling and handling duration evoked cardiac disturbances, which subsequently extended the time required for released fish to recover (e.g. Tomasso et al., 1996; Nelson, 1998; Cook et al., 2001). Although not quantified in the experiments, it was observed that after release, many yellowfin bream suffered short periods of locomotory impairment before descending to the bottom of their sea cage. Generally, individuals were observed to lose equilibrium for a short period and exhibited uncontrolled bursts of circular motion for between 5 – 20 s. Similar behavioural changes have been reported by other authors (e.g. Cooke et al., 2001) and it has been demonstrated that the probability of equilibrium loss and length of time required for recovery (Gingerich et al., 2007), in addition to the magnitude of physiological disturbance (Killen et al., 2006), depend on the duration of air exposure. A reduction in locomotory activity is commonly employed to conserve energy under hypoxia (Wu, 2002) and fish released into the wild suffering momentary immobility would be at a disadvantage in terms of their inability to avoid predators. The potential for such behavioural impairment highlights one of the limitations of using aquaria and/or cage experiments to assess the post-release survival of line-caught fish, especially since mortality due to predation can represent a large component of the overall catch-and-release mortality model (Cooke and Philipp, 2004; Broadhurst et al., 2006).

A circle hook was used in this study in an attempt to minimise the rate of throat hooking. Overall, the rate of hook ingestion was low (5.6%) and is similar to the findings of many studies that have found that circle hooks are more likely to result in mouth hooking than J hooks (see Cooke and Suski 2004 for review). Similar to other species studied (reviewed in Muoneke and Childress, 1994; Bartholomew and Bohnsack, 2005) the mortality of yellowfin bream is significantly influenced by anatomical hooking location (Broadhurst et al., 2005). Studies on this species that have utilised J type hooks, including the experiments described in the previous chapter, have demonstrated hook ingestion rates of 17.4 – 31% and 53% for field and aquaria experiments, respectively (Broadhurst et al., 2005). Although further investigation is required for an accurate assessment, the results of this study seem to support the potential utility of circle hooks to improve post-release survival via a reduction in the rate of hook ingestion.

There were few clear patterns of sublethal disturbances in terms of the physiological responses of treatment individuals at the end of both experiments. While there were no significant differences in the concentrations of plasma cortisol and glucose between treatment and control fish, overall cortisol concentrations were highly variable for all fish, and elevated above those reported for unstressed sparids (typically <10 ng ml^{-1}; Pankhurst and Sharples, 1992) including yellowfin bream (Broadhurst et al., 2005). During an aquaria experiment, Broadhurst et al., (2007) observed similar physiological responses for hook-ingested and control yellowfin bream, which were attributed to the inherent requirements of the experimental design. In the present study, individuals had to be held in groups and were sequentially sampled from within and among the sea cages (all in the same pool) at the end of the experiment. Disturbing fish within and among cages may have been sufficient to evoke acute, short-term responses that manifested as variable elevations in cortisol as handling to take blood may result in elevated and within group variations in cortisol in fish sequentially sampled if the sampling time is prolonged and if fish are repeatedly disturbed (Chopin et al., 1995).

Conversely, glucose remained comparable to baseline levels within each experiment. In addition to physiological disruptions following stress events being cumulative (Barton et al., 1986), variations in glucose are a function of many factors including water temperature (Bettinger et al., 2005), size (Meka and McCormick, 2005) metabolism (Barton et al., 1986; Thorstad et al., 2003) age and season (Wedemeyer et al., 1990). The maintenance of glucose levels among the treatment and control fish at levels similar to baseline observed here and in the previous chapter (e.g. up to 3.8 m mol l^{-1}) suggests minimal protracted or chronic stress associated with the treatments and/or confinement.

This study is evidence that the accurate analysis of physiological disturbances from angling under aquaria conditions is limited by the ability to isolate individuals from stressful influences, including those generated from experimental methodologies. Further, hormone levels in fish manipulated in captivity may not correspond to those in wild fish (Lowe and Wells, 1996), and as such caution is advocated when extending the results of this study to wild populations. Notwithstanding the above, the lack of delayed mortality in both experiments demonstrates that the post-capture handling and confinement of yellowfin bream in this study was within the tolerance limit of this species.

Although this study has demonstrated that yellowfin bream can apparently tolerate an extended period of air exposure following capture by hook-and-line, anglers can nevertheless increase the likelihood of post-release survival of this species via simple handling practices. More specifically, it is recommended that (i) air exposure be kept to a minimum and where possible fish be released without exposure to air, especially if the fish is bleeding from hook-induced wounds, and (ii) prior to release, fish be supported (underwater) until they regain their equilibrium. Such strategies should contribute towards the sustainability of yellowfin bream as a recreational species.

5.0 UTILITY OF HOOK DESIGN FOR MINIMISING HOOK INGESTION BY YELLOWFIN BREAM

5.1 Introduction

Multitudes of different hook styles and sizes are used by recreational anglers worldwide, to the target a variety of species. Given that anatomical hooking location is clearly the most important factor affecting the post-release survival of line-caught fish (Muoneke and Childress, 1994), and the increasing popularity of catch-and-release angling, hook manufacturers have developed novel designs that attempt to minimise hooking injury (Ostrand et al., 2005). One hook design that has been widely used in commercial-line fisheries to minimise discard mortality (Trumble et al., 2002), and extensively promoted as a conservation tool for recreational fisheries, is the circle hook.

Circle hooks differ to conventional J hooks in that they are generally circular in shape and the point of a circle hook is oriented perpendicular to the shank of the hook rather than parallel to the shank (Cooke and Suski, 2004). The orientation of the point of the circle hook assists it to roll around the bend of the hook and potentially increase the probability of mouth hooking (Aalbers et al., 2004). Specifically, circle hooks are designed to move toward the anterior area of the mouth and lodge in the jaw or maxillary region rather than penetrating the oesophagus (Cooke and Suski, 2004). Fish hooked in critical locations (e.g. oesophagus) are more likely to suffer from bleeding and damage to vital organs (e.g. heart and liver) and, as consequence, are at greater risk of dying (Muoneke and Childress, 1994).

International studies done on numerous species, including chinook salmon (Orsi et al., 1993), striped bass (Lukacovic and Uphoff, 2002), bluefin tuna (Skomal et al., 2002), largemouth bass (Cooke et al., 2003c), white seabass (Aalbers et al., 2004), red drum (Beckwith Jr. and Rand, 2005) and sailfish (Prince et al., 2002; Prince et al., 2007) have demonstrated that, compared to J hooks, circle hooks are ingested at a lower rate. This trend has been corroborated by recent Australian studies. For example, Van Der Walt et al., (2005) demonstrated that a significantly lower percentage of silver perch (*Bidyanus bidyanus*) ingested circle hooks than J hooks. Furthermore, a recent review of studies comparing circle to J hooks by Cooke and Suski (2004) concluded that although circle hooks were more than 80% less likely to be ingested than J hooks, the performance of various hook designs tended to be species- and size-specific. In addition, the effect of different hook types on anatomical hooking location is dependent upon the morphology and feeding behaviour of each species (Cooke et al., 2003b).

Similar to J hooks, there are many different designs of circle hooks available. One important characteristic is the degree to which the hook point is offset. The degree of offset refers to the amount of deviation in the plane of the hook relative to that of the shank and may result in differing hook ingestion and mortality rates (Cooke and Suski, 2004). Given the personal preference of individual anglers to use unique combinations of terminal tackle configurations and bait, the objective of this study was to investigate whether the use of circle hooks minimised the rate of hook ingestion by yellowfin bream. Specifically, this study investigated the anatomical hooking location of a variety of different-sized offset circle and J hook styles when angling for this species. The data presented in this chapter were part of a more comprehensive study by Butcher et al., (2008) (see appendix 6 for details) that collected additional technical, operational and environmental data to test the relationship between anatomical hooking location and different types of hooks attached to various tackle configurations.

5.2 Methods

One field and one aquaria experiment were done between October 2004 and June 2006. In each experiment a variety of conventional J and circle hooks were used to catch yellowfin bream (Fig. 12). The specific methods used in each experiment are described below.

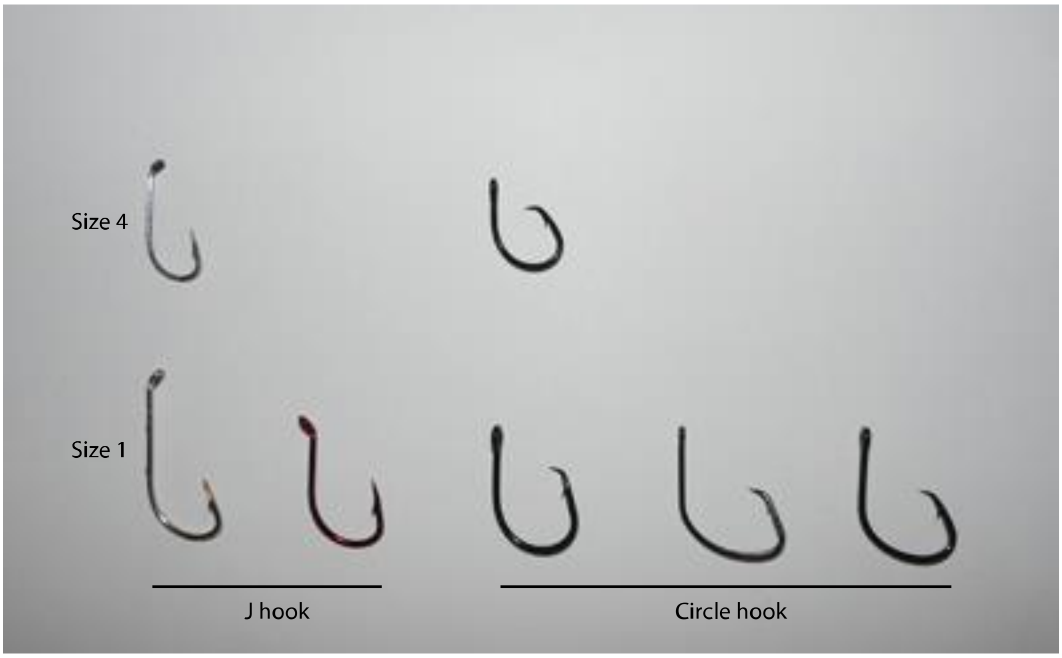

Figure 12. The seven hook types used in the experiments.

5.2.1 Field experiment: anatomical hooking location of yellowfin bream

This experiment was done between October 2004 and June 2006. A total of 51 anglers that expressed interest in response to advertisements in the recreational fishing media were supplied with a random selection of minor-offset hooks from three circle (Mustad Demon, model 39952NPBL, sizes 1/0 and 4; VMC Sure Set, model 7381BN, size 1/0 and Gamakatsu Nautilus; size 1/0) and two J- hook (Mustad Big Red, model 92554NPNR, size 1/0 and Mustad Allround, model 9555B, sizes 1/0 and 4) designs (Fig. 12). Anglers were instructed to record specific biological and capture-related information (see below) on data sheets when targeting yellowfin bream using one of the seven hook configurations.

5.2.2 Aquaria experiment: anatomical hooking location of yellowfin bream

The aquaria experiment was done over five consecutive days in May 2005 using approximately 600 yellowfin bream. Two weeks before the start of the experiment, equal numbers of fish were randomly distributed between two rectangular cages in the pool and fed on a mixed diet of school prawns and manufactured 6-mm pellets. All fish were starved for two days prior to two researchers angling fish from the cages between 08:00 and 18:00 h on each of five consecutive days.

Researchers alternated between using one of the hook configurations above; the only difference was that one of each type of circle (VMC Sure Set) and J (Mustad Big Red) hooks were not used in this experiment. Hooks were baited with school prawns and attached to a 5.5 kg fluoro-carbon leader and 2.7 kg braided line. Without looking at the fish, the unweighted hook was cast into one of the cages at random and any slack taken out of the line. When weight was felt on the line, the rod tip was gently lifted to set the hook and the fish was reeled in. If a fish was not caught within 3 min of the bait entering the water, the line was retrieved, the hook rebaited if necessary, and the process was repeated. Specific capture-related data were collected for each fish hooked (see below).

5.2.3 Data collected and statistical analyses

The date and time of capture, hook type and manufacturer's size, TL and anatomical hooking location was recorded for all fish. Anatomical hooking location was classed as either mouth (jaw, corner, gill arch, floor and roof), throat (oesophagus and stomach) or body. Hooks were separated into four categories according to their type (circle or J) and manufacturer's size (1/0 or 4).

All data were analysed separately within each experiment. Size-frequency distributions (1.0-cm TL intervals) of hooked fish between experiments, and fish angled with the same-sized hook category within experiments were compared using two-sample Kolmogorov-Smirnov tests. The Yates corrected chi square test was used to determine if the same-sized circle and J hook categories differed in their probability of hooking a fish in the mouth or throat within experiments. For all analyses, the null hypothesis was rejected at $p < 0.05$.

5.3 Results

A total of 771 (mean TL ± se of 24.8 ± 1.9 cm) and 295 (21.7 ± 1.3 cm) yellowfin bream were hooked in the field and aquaria experiments, respectively. A Kolmogorov-Smirnov test found that the fish angled in the field were significantly larger than those hooked in the aquaria ($p < 0.05$). However, no significant differences were detected between the size-frequency distributions of fish hooked with the same-sized J and circle hook configurations within experiments (Kolmogorov-Smirnov tests, $p > 0.05$). Overall, more than 80% of fish in each experiment were mouth hooked. Of these, fish were most frequently hooked in the corner of the mouth (55 and 47% in the field an aquaria experiment, respectively) (Fig. 13). No fish were hooked in the jaw or gill arch by any hook type in the aquaria experiment, and twelve fish were hooked in the body in each experiment (Fig. 13). None of the size 4 hooks hooked any fish in the gill arch or body in the field and aquaria experiment, respectively.

Yates corrected chi square tests failed to detect any significant difference in the proportion of fish that ingested size 4 and 1/0 circle hooks compared with the same-sized J hooks in the field and aquaria experiments, respectively ($p > 0.05$) (Fig. 14). In contrast, a significantly lower proportion of size 1/0 and 4 circle hooks were ingested in the field and aquaria experiment, respectively (Yates corrected chi square tests, $p < 0.05$) (Fig. 14). Few fish angled in each experiment ingested circle hooks (2 and 1% in the field and aquaria

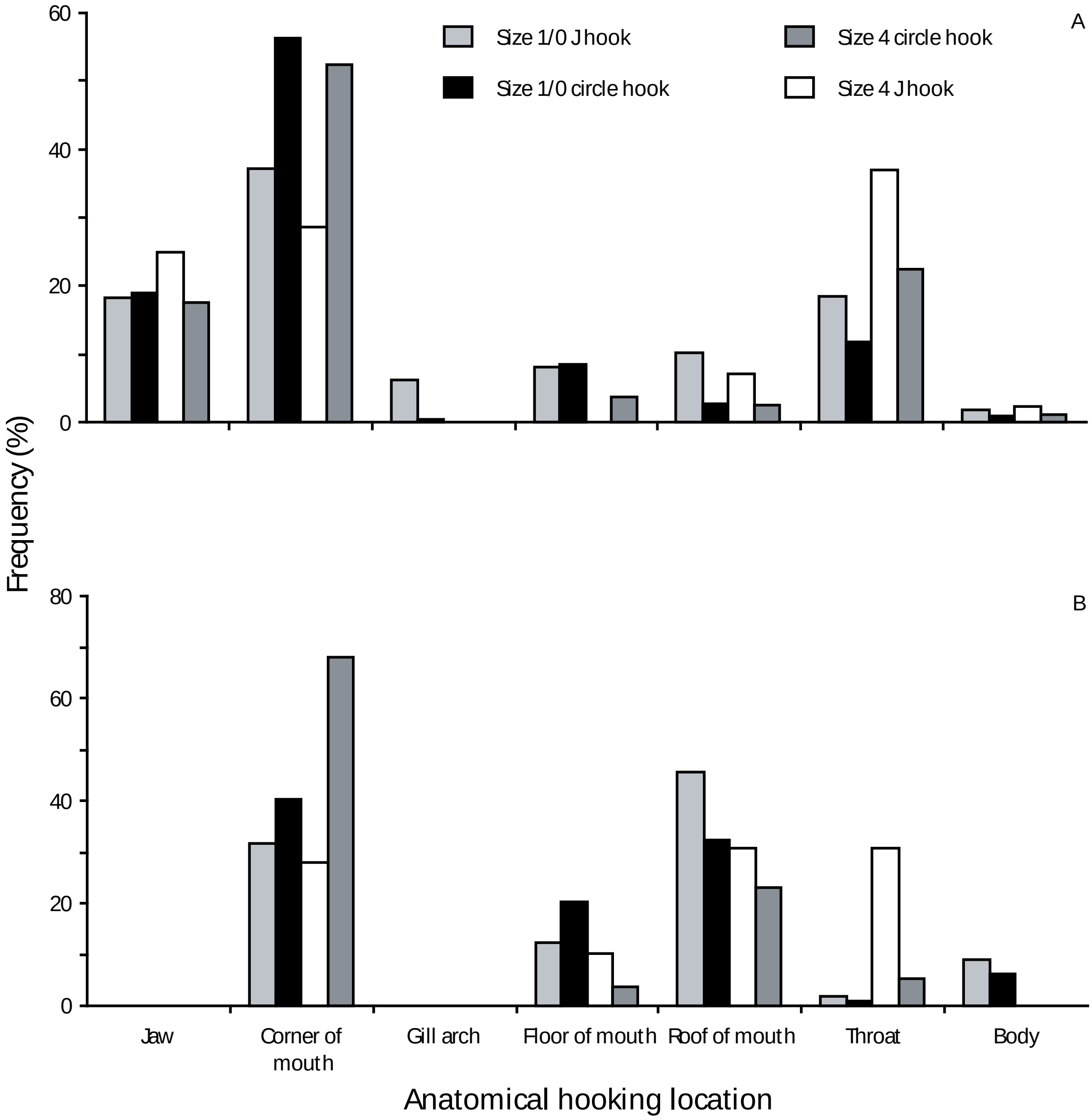

Fig. 13. Anatomical hooking location of yellowfin bream angled using the four hook classifications in the (A) field and (B) aquaria experiment.

experiment, respectively). In comparison, 13% of fish in the field experiment and 7% of fish in the aquaria experiment ingested J- hooks. The size 4 J-hook had the highest incidence of throat hooking in the field (37%) and aquaria (31%) experiment. The size 1/0 circle and J-type hooks were ingested by only one individual each in the aquaria experiment, representing ingestion rates for each hook type of 1 and 2%, respectively. Over 50% of fish caught with circle hooks in each experiment were hooked in the corner of the mouth.

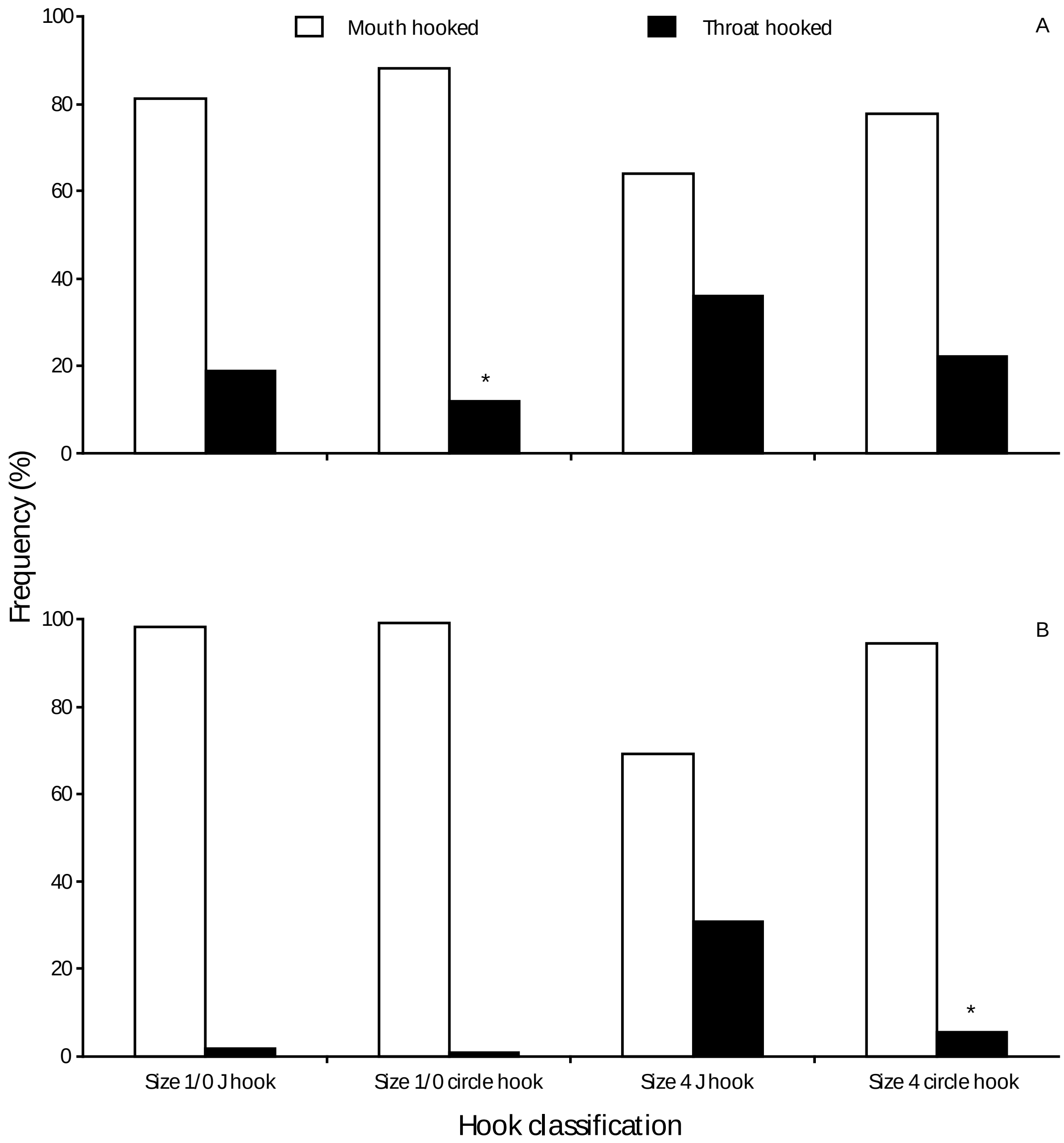

Fig. 14. Percent frequency of yellowfin bream mouth- and throat-hooked using the four hook classifications in the (A) field and (B) aquaria experiment. * Significant (p<0.05).

5.4 Discussion

This study has demonstrated that in some instances the use of circle hooks can mitigate the rate of hook ingestion by yellowfin bream. Specifically, although not significant in the field experiment, a lower proportion of fish ingested size 4 circle hooks in the aquaria experiment compared with the same size J hooks. Similarly, the significantly lower incidence of throat hooking by size 1/0 circle hooks compared with size 1/0 J hooks in the field was not found in the aquaria. Collectively, these results suggest that anatomical hooking location may be size dependent and are most likely attributable to the larger size of yellowfin bream hooked from the wild compared to the smaller-sized fish angled from the aquaria.

Irrespective of hook type and size, the higher rates of hook ingestion in the field, coupled with the high incidence (>98%) of fish mouth-hooked by size 1/0 hooks in the aquaria suggest that the latter fish may have been unable to ingest the larger hooks and as a consequence were nearly always hooked in the mouth. Similar observations have been made for other species. For example, studies with bluegill (Cooke et al., 2005) and red drum (Beckwith Jr. and Rand, 2005) showed that the low incidence of circle hook ingestion compared to J hooks was further improved by the use of larger-sized circle hooks. Grixti et al., (2007) also found that the frequency of J hook ingestion by black bream (*Acanthopagrus butcheri*) was greater than six times more likely for small hooks as opposed to larger hooks. Although increasing the size of the hook does not eliminate the capture of small fish (Ottway and Craig, 1993) and in some instances larger hooks inflict greater injury to smaller fish (Cooke et al., 2003b), the size 1/0 hooks in this study were ingested less frequently than their size 4 counterparts.

Compared to J hooks, circle hooks were generally ingested at a lower rate. This trend supports that observed for other species in several studies that have compared anatomical hooking location between these two hook types. For example, Cooke et al., (2003b) and Bacheler and Buckel, (2004) found that no bluegill and fewer than 1% of groupers (*Epinephelus morio*), swallowed circle hooks. In addition, the use of circle hooks has resulted in low (<5%) hook ingestion rates for Pacific halibut (Trumble et al., 2002), largemouth bass (Cooke et al., 2003c), Pacific sailfish (Prince et al., 2002) and Atlantic bluefin tuna (Skomal et al., 2002). Conversely, higher (>10%) rates of circle hook ingestion were reported for white seabass (Aalbers et al., 2004) and striped bass (Lukacovic and Uphoff, 2002).

Given the above, it appears that the results of this study support the general assertion that circle hooks have the mechanical ability to more frequently lodge in superficial locations in a fish's mouth. Specifically, the majority of yellowfin bream caught on circle hooks were hooked in the corner of the mouth, a comparable result to the performance of circle hooks for other species (e.g. Ostrand et al., 2005, Cooke et al., 2003c). The inward orientation of the point of the circle hook means that as fish attempt to consume the bait and tension is applied on the line by the angler or the fish moving away, the hook is pulled to the side of the mouth (Cooke and Suski, 2004). As the tension increases the circular configuration of the hook assists it to rotate and catch the fish in the mouth rather than other potentially lethal locations (e.g. oesophagus or gill arch). Although the gill arch was classed as a mouth-hooked location in this study, and is known to be a critical hooking location that is associated with bleeding and high likelihood of mortality (Muoneke and Childress, 1994), a circle hook was lodged in this location in only one instance.

Not withstanding the above, Butcher et al., (2008) investigated the relationship between anatomical hooking location and forty-one (11 circle and 30 J) different hooks attached to various terminal rig configurations and found that factors independent of hook design influenced hook ingestion by yellowfin bream. Specifically, irrespective of the hook type, the use of artificial baits rather than natural baits, and angling with rig configurations that comprised short (< 50 cm) leaders or a running sinker to the hook, each minimised the rates of hook ingestion by this species (Butcher et al., 2008). In addition, the frequency of hook ingestion was lower when fish were angled from a lake or lagoon environment as opposed to those caught from river, beach or rocky headland environments. Ultimately, it is apparent that advocating a particular hook design as a strategy to mitigate hook ingestion by any species requires consideration of all the possible influences on anatomical hooking location.

Although circle hooks were ingested less frequently than J hooks in this study generally, the choice of appropriate hook size seems to be a logical step in the overall strategy to mitigate the rate of hook ingestion for yellowfin bream. In particular, this study has shown that the use of size 1/0 hooks are suitable for targeting this species at sizes at or above the legislated NSW minimum legal length (25 cm). Furthermore, given the clear relationship between anatomical hooking location and mortality for yellowfin bream demonstrated in previous chapters, the use of appropriately size circle hooks can improve their chances of post-release survival. In any case, the use of any specific hook type or size is governed by an angler's personal preference. Irrespective of whether the broad scale adoption of circle hooks by anglers may only succeed if they are demonstrated to match or better the hooking efficiency of conventional J hooks (Cooke and Suski, 2004), the promotion of their use will assist to benefit the sustainability of recreational fishing.

6.0 CONCLUSIONS AND RECOMMENDATIONS

This study has demonstrated that subtle modifications to angling gear and practices have the potential to maximise the post-release survival of line-caught yellowfin bream and mulloway. Specifically, it is clear from the results of each of the study experiments that the adoption of the following recommendations by recreational fishers is likely to alleviate some negative impacts that angling may have on these species.

For both species:

(i) the hooks should be removed from mouth-hooked fish to prevent subsequent ingestion; and

(ii) the line should be cut for hook-ingested individuals prior to release.

For yellowfin bream:

(i) air exposure should be avoided, especially if the fish is bleeding from hook-induced wounds;

(ii) fish should be supported (underwater) until they regain their equilibrium; and

(iii) the appropriate sized hook (1/0), and preferably circle hooks, should be used to target fish at or above the legislated minimum legal length.

Although this study can demonstrate that the probability of post-release survival of yellowfin bream and mulloway can be increased by the adoption of the recommendations above by anglers, the results should be considered conservatively.

As a consequence of the operational nature of the recommendations above, it is unlikely that they will result in any amendment to the statutory provisions that govern the harvest of fish by anglers in Australian fisheries jurisdictions. Irrespective of this, the dissemination of the study results in the popular fishing media and scientific literature (see appendices for details) has provided fisheries managers and the angling community with strategies that assist to minimise the mortality of released line-caught yellowfin bream and mulloway. Further investigation of the utility of these strategies for other species is required to ultimately benefit the long-term sustainability of Australian recreational fisheries.

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8.0 APPENDICES

Appendix 1: Butcher, P. A., Broadhurst, M. K., Reynolds, D., Reid, D. D., Gray, C. A., 2007. Release method and anatomical hook location: effects on short-term mortality of angler-caught *Acanthopagrus australis* and *Argyrosomus japonicus*. Diseases of Aquatic Organisms 74, 17-26.

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Release method and anatomical hook location: effects on short-term mortality of angler-caught *Acanthopagrus australis* and *Argyrosomus japonicus*

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ABSTRACT: One field and 3 aquaria experiments were done to quantify the short-term mortality of yellowfin bream *Acanthopagrus australis* and mulloway *Argyrosomus japonicus* after being angled and subjected to 3 general handling treatments. Anglers were supplied with identical J-type hooks and asked to handle hooked fish by either (1) physically removing the hook or (2) cutting the line (5 cm from the mouth of the fish) and leaving the hook in. Some hooked *A. japonicus* were subjected to a third handling treatment where the line was cut underwater without exposing the fish to air. Technical and biological data were collected before all fish were released into sea cages and monitored for 5 d. Control fish were seined and similarly caged and monitored. Concentrations of plasma glucose and cortisol were collected from a sample of fish on the first and last day of the experiments. Significant predictors of mortality for both species involved the presence of blood at the mouth and an interaction between anatomical hook location and hook removal. *A. australis* and *A. japonicus* that had their ingested hooks removed experienced the greatest mortalities (87.5 and 72.7%, respectively). Typically, these fish suffered damage to their oesophagus, stomach wall and vital organs. Mortality rates of *A. australis* and *A. japonicus* were significantly decreased to 1.7 and 16%, respectively, when they were released with their lines cut, with some of these fish free of hooks after 5 d. In contrast, few mortalities occurred in either species when the hooks were removed or the lines cut on mouth-hooked fish or in *A. japonicus* when it was released with no air exposure. For *A. australis*, the field- and aquaria-based experiments provided comparable results in terms of identifying treatment-specific effects, but there were potential biases in rates of hook ingestion. Irrespective of the treatment of fish, all experiments caused physiological changes measured as elevations in either plasma cortisol or glucose. We concluded that anglers should cut the line from hook-ingested *A. australis* and *A. japonicus*, but remove the hook from mouth-hooked individuals to prevent subsequent ingestion. Further research is required to examine the longer-term consequences of these handling practices on fish health.

KEY WORDS: Yellowfin bream · *Acanthopagrus australis* · Mulloway · *Argyrosomus japonicus* · Catch-and-release · Hooking mortality · Recreational anglers

INTRODUCTION

Recreational angling is popular throughout Australia, with over 3 million people (20% of the total population) catching more than 58 million fish annually (Henry & Lyle 2003). As in many developed countries (Pitcher & Hollingsworth 2002), Australia's recreational fisheries are largely managed by imposing legal sizes and personal quotas, which contribute towards a total catch release of approximately 44%

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(Henry & Lyle 2003). While these regulations limit harvest rates, their ultimate utility in terms of conserving stocks requires that most of the released fish survive. This prerequisite has long been recognised internationally and resulted in more than 600 studies published in the primary literature since 1970 that have estimated the fate of released angler-caught fish (for reviews see Muoneke & Childress 1994, Bartholomew & Bohnsack 2005, Cooke & Suski 2005). But while the management of Australian recreational fisheries requires this same sort of quantitative information, relatively little work has been done for local species (Diggles & Ernst 1997, Broadhurst et al. 1999, 2005, Broadhurst & Barker 2000, Ayvazian et al. 2002, St John & Syers 2005, Butcher et al. 2006).

Previous international studies indicate that many factors contribute towards the mortality of released fish, including the types of gears used and their operation (Willis & Millar 2001, Cooke & Suski 2004), post-capture handling methods (Jordan & Woodward 1994, Neal & Lopez-Clayton 2001) and environmental conditions (Keniry et al. 1996, Wilde et al. 2000). While in many cases the actual mechanisms causing mortalities often result from interactions between several factors, it is clear there are single determinate causes. In particular, hook ingestion and subsequent post-capture handling have been isolated as main predictors of mortality for several species (e.g. Schill 1996, Taylor et al. 2001, Aalbers et al. 2004, Bartholomew & Bohnsack 2005).

The few studies done on Australian species corroborate the influence of anatomical hook location on mortality (Broadhurst et al. 1999, 2005, Broadhurst & Barker 2000, Ayvazian et al. 2002, Butcher et al. 2006). For example, during a recent catch-and-release event, Broadhurst et al. (2005) noted that more than 45% of yellowfin bream *Acanthopagrus australis* (an important coastal and estuarine species; Henry & Lyle 2003) died after ingesting hooks, compared with <4% of fish that were hooked in the mouth. In support of the latter result, Broadhurst et al. (1999) also recorded no significant mortalities to individuals of this species after being hooked in the mouth and held in tanks in a laboratory. Further, Broadhurst & Barker (2000) similarly observed no deaths to another important recreational species, mulloway *Argyrosomus japonicus*, after being mouth-hooked and then released under the same conditions. No concomitant data are available on the fate of *A. japonicus* after ingesting hooks; however, based on anecdotal information from anglers, McLeay et al. (2002) proposed that, as for *A. australis*, anatomical hook location and subsequent handling after capture probably have major influences on their mortality.

Although the rates of hook ingestion by *Acanthopagrus australis* and *Argyrosomus japonicus* during conventional recreational angling are unknown, the potential for at least some mortalities warrants examination of mitigation strategies. Previous studies have shown that this issue can be simply addressed by modifying either (1) the fishing methods and gears in order to reduce the rates of hook ingestion (Cooke et al. 2003, Jenkins 2003, Beckwith & Rand 2005), or (2) post-capture handling techniques, such as cutting the line and releasing fish with their hooks still ingested (Schill 1996, Schisler & Bergersen 1996, Taylor et al. 2001, Aalbers et al. 2004). For species where there is a clear predisposition to hook ingestion as a consequence of particular bait and/or hook types (Payer et al. 1989, Cooke & Suski 2004), appropriate terminal gear modifications could reduce associated mortalities. However, because the above criterion is rarely satisfied for the majority of species, the second option is often a more practical starting point for anglers. This strategy is supported by a general trend of fewer short-term mortalities (27 to 42%) followed by protracted rates of hook ejection for several species (Hulbert & Engstrom-Heg 1980, Schill 1996, Schisler & Bergersen 1996).

Ideally, the utility of modified post-capture handling techniques would be best assessed by releasing angler-caught fish back into the wild, so that they are subjected to the full range of factors influencing their mortality, and then by tracking their individual progress (e.g. Bettoli & Osborne 1998, Thorstad et al. 2003). However, severe logistical constraints preclude such an approach for the majority of species. The simplest and most common methods are to release angled fish into cages or tanks located in the field (e.g. Broadhurst et al. 2005, Butcher et al. 2006) or aquaria (e.g. Lowe & Wells 1996, Albin & Karpov 1998, Broadhurst et al. 1999). Because such field studies typically involve recreational anglers catching and releasing fish under normal environmental conditions, they are usually the preferred option. Their main disadvantages are that they can be expensive, not easily replicated or controlled in space and time and involve confining fish in a dynamic environment, thus effectively preventing any natural migrations in response to changes in water quality (e.g. salinity and temperature). Conversely, while aquaria studies do facilitate adequate replication, appropriate controls and stable environmental conditions (thereby enabling clearer assessment of the effects of different treatments), they are conducted under artificial conditions and therefore may not provide definitive estimates of absolute mortality. Clearly, to assess the full effects of different treatments, both types of studies should be done where possible.

Given that there is very little information available on the fate of fish released by recreational anglers in Australia, and the need to examine simple strategies that maximise their survival, our main aim was to quantify the mortality of *Acanthopagrus australis* and *Argyrosomus japonicus* after being hooked in the mouth or ingesting hooks and then released by different methods. Also, by repeating the same experiment in the aquaria and field, we sought to validate this information for *A. australis*.

MATERIALS AND METHODS

One field and 3 aquaria experiments were done between October 2004 and May 2005. In all experiments, the same size and type of conventional J-hooks (Fig. 1), baited with school prawns *Metapenaeus macleayi*, were used to catch either *Acanthopagrus australis* or *Argyrosomus japonicus*. Most angled fish were exposed to air and handled according to 2 treatments that involved either (1) physically removing the hook or (2) cutting the line (5 cm from the mouth of the fish—according to conventional angling practices) and leaving the hook in place. Some hooked *A. japonicus* were subjected to a third handling treatment where the line was cut (5 cm from the mouth) and the fish released with no exposure to air. All hooked-and-released fish were held in cylindrical sea cages made from 16 mm knotless polyamide netting which measured 2.3 × 2.5 m (see Butcher et al. 2006 for details) and were monitored daily. The specific methods used in each experiment are described below.

Field experiment: post-release mortality of *Acanthopagrus australis* after air exposure. The field experiment was conducted in the Hawkesbury River, NSW (33° 42′ S, 151° 15′ E) during October and November 2004 using 8 sea cages, 24 anglers distributed among 12 boats, and 9 researchers on 3 boats. The anglers were randomly separated into 2 groups and asked to target and handle *A. australis* according to Treatments 1 (hook out) and 2 (hook in) (as above), irrespective of anatomical hook location. Anglers placed their fish into identical aerated 70 l fish-holding tanks, recorded relevant data (see below) and contacted the researchers by hoisting a flag. Researchers travelled to the boats, confirmed the data, and measured the temperature (°C) and dissolved oxygen levels (mg l^{-1}) in the holding tanks before transporting (in 120 l aerated tanks) and releasing the fish into 4 of the sea cages (2 replicate cages were assigned to each treatment). Two days after the last *A. australis* was hooked and released into the sea cages, approximately 150 individuals (originally collected using a commercial beach seine; Broadhurst et al. 2005) were transported from Botany Bay (34° 00′ S, 151° 14′ E) according to the general methods described by Barker et al. (2002), and released into 4 separate sea cages designated as control and stock cages (each with 2 replicates).

All caged *Acanthopagrus australis* were fed chopped school prawns (at a rate of 1% biomass d^{-1}) and monitored daily over 5 d. To maintain stocking densities, dead fish were removed and replaced with individuals (fin clipped for identification) from the stock cages. All surviving treatment fish at the end of the experiment were assessed for the presence of hooks or wounds. To determine levels of stress, blood was taken from 8 wild-caught individuals on the first day of the experiment and then from 4 fish in each treatment and control cage at the end of the 5 d monitoring period, using the procedures described by Broadhurst et al. (2005).

Aquaria experiments: collection of fish. Three experiments were conducted using the aquaria facility at the Cronulla Fisheries Research Centre (CFRC), NSW (34° 4′ S, 151° 9′ E) between November 2004 and May 2005 using either 6 (Expts 1 and 2) or 10 (Expt 3) of the cylindrical sea cages distributed throughout a 30 × 14 × 2.5 m pool and 8 adjacent 5000 l fibreglass holding tanks. The pool and tanks were supplied with flow-through seawater (500 and 5 l min^{-1}, respectively) at ambient temperature (17 to 22°C) and aerated with stone diffusers. Approximately 200 wild-caught *Acanthopagrus australis* (originally seined in Botany Bay; Broadhurst et al. 2005) and 800 first-generation cultured *Argyrosomus japonicus* (supplied by an aquaculture farm at Maitland; 32° 45′ S, 151° 35′ E) were used in the experiments.

Prior to starting each experiment, the required fish were transported to the CFRC according to the handling procedures described by Barker et al. (2002), and placed into 2 of the 5000 l tanks. During the first 3 d, fish were fed to satiation with 6 mm commercially available pellet, before being weaned onto a diet of pellet and school prawns (ratio of 5:1) for 5 d, followed by a diet of 100% school prawns (at rates of 1% biomass d^{-1}). Fish were allowed to acclimatise in the two 5000 l holding tanks for a minimum of 18 d before being used in the experiments.

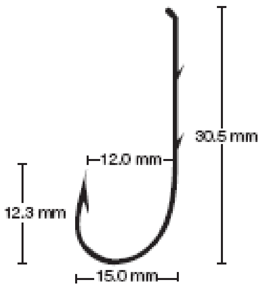

Fig. 1. Nominal dimensions of J-hooks used during this study

Aquaria Expts 1 and 2: post-release mortality of *Acanthopagrus australis* and *Argyrosomus japonicus* after air exposure. Aquaria Expts 1 and 2 were run in November 2004 and January 2005 using approximately 175 *A. australis* and 400 *A. japonicus*, respectively. Two weeks before the start of both experiments, fish were distributed among 8 of the 5000 l holding tanks. All fish were starved for 2 d prior to being hooked from 6 of the 5000 l holding tanks via small openings in the lids. Hooked individuals were then subjected to either Treatment 1 (hook out) or 2 (hook in) as above. Relevant catch data were recorded for each fish (see below) before they were released into 4 of the sea cages (2 replicates for each treatment). On the same day that fish were angled, appropriate numbers of control fish were transferred (using 25 l buckets) from the 2 unfished 5000 l holding tanks into the remaining 2 sea cages. All individuals were fed school prawns and monitored twice daily for 5 d. To maintain stocking densities, dead fish were replaced with fin-clipped individuals from the 2 unfished 5000 l holding tanks. Blood was taken from 1 fish in each tank prior to fishing on the first day of the experiment and then from up to 5 fish in each treatment and control cage at the end of the 5 d monitoring period, using the procedures described by Broadhurst et al. (2005). All surviving fish that had the hooks left in were then euthanased with benzocaine (100 mg l^{-1}) and examined for the presence/absence of hooks or wounds.

Aquaria Expt 3: post-release mortality of *Argyrosomus japonicus* after water release. The third aquaria experiment was conducted during May 2005 and involved distributing 400 *A. japonicus* among the eight 5000 l holding tanks and releasing 200 *A. japonicus* into a rectangular cage (made from 40 mm mesh and measuring 7 × 5 × 2.5 m) located in the pool. Fish were left to acclimate for 2 wk before being subjected to Treatments 1 (hook out), 2 (hook in) and 3 (water release). Treatments 1 and 2 were applied to fish hooked from 6 of the 5000 l holding tanks, and as per the methodology described above. The only difference was that all individuals had their caudal fin clipped for identification according to their anatomical hook location (mouth or ingested) before being released into the 4 appropriate sea cages (2 replicates for each treatment). Fish subjected to Treatment 3 were hooked from either the rectangular cage or the 5000 l holding tanks and brought close to the surface, but not out of the water. A 25 l bucket was placed under each fish and then lifted along with approximately 20 l of water. The line was cut without touching the fish or exposing it to air (simulating release in water). The fish were then released into 4 of the sea cages according to their anatomical hook location, with 2 replicate cages for mouth-hooked and hook-ingested fish, respectively. The release process involved submerging the 25 l bucket into the cage and allowing the fish to swim out. Appropriate numbers of control fish were also fin-clipped and transferred from 2 unfished 5000 l holding tanks into the remaining 2 cages. All fish were fed and monitored as per aquaria Expts 1 and 2 described above. Blood was taken from 1 fish in each tank and 4 fish in the pool on the first day of the experiment, and then again from up to 5 fish in each treatment and control cage at the end of the 5 d monitoring period.

Data collection and analyses. The time of capture and release into cages, treatment, total length (TL), cage number, and daily survival were recorded for all fish. Catch information included the line strength and depth fished, anatomical hooking location, the time that fish were played, exposed to air during hook removal or held in tanks, their scale loss (to the nearest 25%), and the presence/absence of blood. The water temperature (°C) and dissolved oxygen (% saturation mg l^{-1}) levels were recorded in the holding tanks and buckets.

To test the null hypothesis (H_0) of no differences in stress owing to the confinement of hooked and control fish, the collected blood samples were analysed for concentrations of cortisol (ng ml^{-1}) and glucose (mmol l^{-1}) using the methodologies described by Pankhurst & Sharples (1992) and Moore (1983), respectively. Non-parametric Kruskal-Wallis tests were then used to test for intra-specific differences in these variables between wild *Acanthopagrus australis* and undisturbed *Argyrosomus japonicus* before starting the experiments and between both hooked and control fish sampled from cages at the end of the experiments.

Size-frequency distributions (1 cm TL intervals) of treatment and control fish were compared using 2-sample Kolmogorov-Smirnov tests. Two-tailed Fisher's exact tests were used to determine the (1) independence of the treatment of fish on mortality, (2) independence of replicate cages on mortality and (3) treatment of hooked fish on the presence of blood and scale loss after capture and hook location at the end of the experiment (within and between experiments).

Where possible, all variables describing the hooking and release of *Acanthopagrus australis* were separated as either categorical or continuous variables. The independence of these variables on mortality was examined using exact logistic regression models (Hirji et al. 1987). Models were fitted using SAS (version 8, 2003) as described by Derr (2000), and compared using likelihood ratio tests and examination of deviance residuals. Owing to difficulties identifying some individual *Argyrosomus japonicus* during aquaria Expts 2 and 3, similar logistic regression analyses were not possible. Instead, chi-squared analyses of contingency tables were used to test the hypothesis of mutual independence between hook removal and the survival of (1) all

A. japonicus (irrespective of their anatomical location) in aquaria Expt 2 (i.e. 2 × 2 contingency table) and (2) mouth-hooked and hook-ingested *A. japonicus* with and without air exposure in aquaria Expt 3 (i.e. 2 × 6 contingency table). A chi-squared goodness-of-fit test was used to test for intra-specific differences in the anatomical hook location among relevant experiments.

Table 1. *Acanthopagrus australis*. Pooled categorical parameters collected at the end of field and aquaria experiments for total numbers of live and dead fish that had (1) the hook removed or (2) the hook left in and the line cut, prior to release

Parameter	Hook removed		Hook left in	
	Alive	Dead	Alive	Dead
Hook location				
Mouth/jaw/gills	59	1	37	0
Upper jaw	10	0	3	0
Roof of mouth	5	0	2	0
Gill arch	1	1	0	0
Floor of mouth	5	0	2	0
Lower jaw	7	0	4	0
Corner of mouth	31	0	26	0
Ingested (oesophagus/ stomach)	1	7[a]	36	3
Play period (s)				
<15	44	8	45	1
15–30	10	0	23	1
30–60	6	0	2	1
60–120	0	0	2	0
120–180	0	0	1	0
Exposure to air (min)				
<1	59	7	69	3
1–3	1	1	3	0
3–5	0	0	1	0
Scale loss				
Yes	0	0	0	0
No	60	8	73	3
Blood at mouth or gills				
Yes	2	6[a]	7	0
No	58	2	66	3

[a]Significant main or interaction term for predicting mortality, identified from exact logistic regression analyses ($p < 0.01$)

RESULTS

Post-release mortality of *Acanthopagrus australis*

A total of 78 (mean ± SE: 22.5 ± 0.64 cm TL) and 66 (26.2 ± 44 cm TL) *Acanthopagrus australis* were hooked and released into the sea cages during the field experiment and aquaria Expt 1, respectively. No significant differences were detected between the size-frequency distributions of treatment and control fish within or among experiments (Kolmogorov-Smirnov test, $p > 0.05$). In all, 84.6 and 100% of field- and aquaria-caught *A. australis*, respectively, were played for less than 30 s, and more than 95.8% of all individuals were exposed to air for less than 1 min (Table 1). During the field experiment, 1 fish was exposed to air for 3 to 5 min. Fish were held in holding tanks for 1 to 40 min and at water temperatures of 16.1 to 23.5°C (Table 2). There was no evidence of scale loss on any fish, but more than 10% had blood at their mouth or gills (Table 1).

Significant differences were detected in the anatomical hook location among experiments ($\chi^2 = 28.65$, $p < 0.01$) (Fig. 2a). During aquaria Expt 1, similar numbers of *Acanthopagrus australis* ingested hooks (53%) or were hooked in the mouth (47%), while 84.6% of the fish caught during the field experiment were mouth-hooked. In most of these latter fish, the hook had penetrated the corner of the mouth (Fig. 2a).

None of the control *Acanthopagrus australis* died. In contrast, 4 and 7 treatment fish died during the field and aquaria experiments, respectively, providing total mortality rates of 5.1 and 10.6%. Fisher's exact tests failed to detect significant differences in the rates of mortalities for the same handling treatments among cages or experiments. Similarly, there were no significant differences in mortalities between the different handling treatments for data pooled across experiments (Fisher's exact test, $p > 0.05$).

Exact logistic regression revealed that the only significant main effect influencing mortality was the presence/absence of blood at the mouth ($p < 0.01$). Once

Table 2. *Acanthopagrus australis*. Mean (±SE) continuous parameters used in exact logistic regression analyses for fish that had (1) the hook removed or (2) the line cut and the hook left in. Data pooled across field and aquaria experiments

Parameter	Hook removed		Hook left in	
	Alive	Dead	Alive	Dead
Total length (cm)	22.65 (0.52)	29.48 (1.28)	24.45 (0.61)	35.00 (1.16)
Line strength (kg)	3.47 (0.20)	3.60 (0.00)	3.14 (0.17)	4.53 (1.73)
Period in holding tank (min)	15.81 (2.48)	2.50 (1.94)	12.27 (1.69)	28.33 (8.30)
Temperature in holding tank (°C)	20.15 (0.20)	19.59 (0.09)	19.33 (0.11)	18.70 (0.50)
Oxygen in holding tank (mg l^{-1})	6.85 (0.26)	6.44 (0.04)	6.78 (0.11)	10.54 (0.50)
Water depth (m)	2.63 (0.39)	2.38 (1.38)	2.45 (0.28)	8.67 (1.77)

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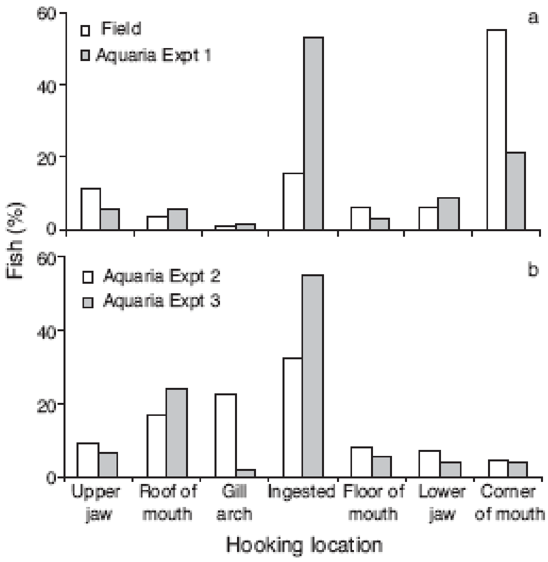

Fig. 2. *Acanthopagrus australis* and *Argyrosomus japonicus*. Anatomical hooking location of (a) *A. australis* and (b) *A. japonicus* during each experiment

the hook had been removed, fish that had visibly bled were significantly more likely to die (75%) than those that showed no signs of blood (4%) or had the line cut ($p < 0.01$; Table 1). There was also a significant interaction between hook removal and anatomical hook location (exact logistic regression, $p < 0.01$; Table 1). Specifically, those fish that had ingested hooks removed were more likely to die (mortality rate 87.5%) than those that had hooks (1) left in the mouth and oesophagus/stomach (0 and 7.6%, respectively) or (2) removed from the mouth (1.7%) ($p < 0.01$; Table 1). No other predictors of mortality were detected (Tables 1 & 2).

In both the field and aquaria experiments, most deaths (72.7%) occurred within 6 h of release, and all deaths occurred within the first day (Fig. 3a). All 4 dead fish (1 × hook removed and 3 × hook left in) in the field and 6 of the 7 (all hook removed) dead fish in the aquaria had ingested their hooks. Inspections of the 4 dead fish from the field experiment revealed that 2 individuals had hooks in their posterior gastrointestinal tract, with fishing line protruding from their anuses. The hook in the third fish had penetrated the stomach wall and liver, whereas the fish that had the hook removed from the stomach had a lesion in the roof of its mouth. In the aquaria, removal of the hook caused all 6 stomach-hooked mortalities, with obvious damage to the lining of the stomach and oesophagus. The only mouth-hooked mortality was from a fish that had been hooked in the gills.

At the end of both 5 d experimental periods, all surviving fish that had been released with the line cut were euthanased, dissected and examined for the presence of hooks (Table 3). In all, approximately 81 and 13% of mouth-hooked and hook-ingested *Acan-*

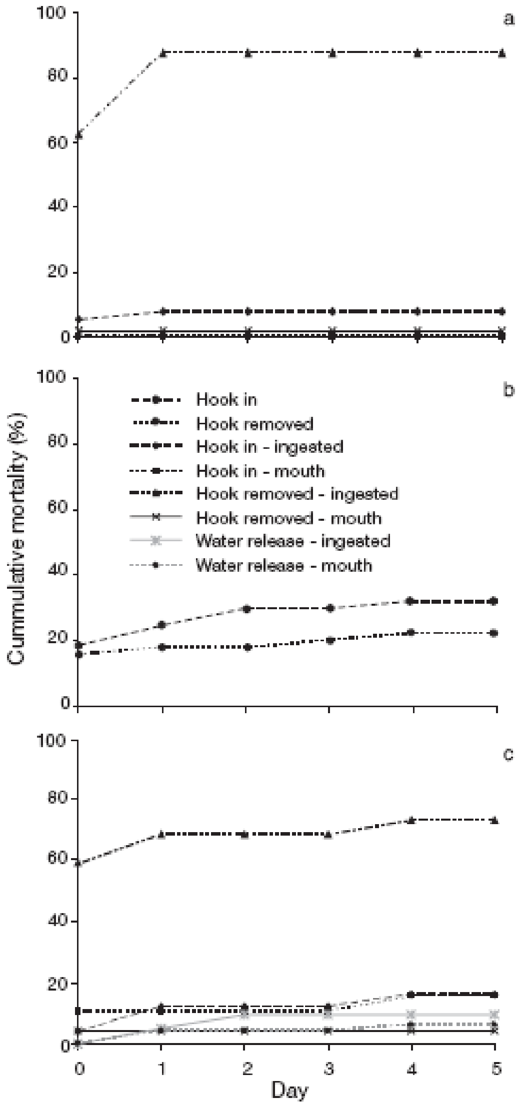

Fig. 3. *Acanthopagrus australis* and *Argyrosomus japonicus*. Daily cumulative mortality of *A. australis* during (a) Expts 1 and 2 (pooled results), and *A. japonicus* during (b) Expt 2 and (c) Expt 3

Table 3. *Acanthopagrus australis* and *Argyrosomus japonicus*. Anatomical hook location for the total number of live fish that had the line cut and the hook left in at the beginning and end of the field experiment and aquaria Expts 1 and 2. Parentheses indicate the number of additional dead fish and where the hook was located. na: not applicable

	Day	Anatomical hooking location Ingested	Mouth	Lost
A. australis				
Field	0	10	31	na
	5	10 (3)	6	22
Aquaria Expt 1	0	29	6	na
	5	24	1	10
A. japonicus				
Aquaria Expt 2	0	20	25	na
	5	19 (9)	3	13 (1)

thopagrus australis had managed to eject their hooks. There was no significant difference in the rate of hook ejection between the field experiment and aquaria Expt 1 (Fisher's exact tests, $p > 0.05$). At least 3 of the mouth-hooked fish in the field experiment subsequently ingested their hooks during the 5 d post-release period.

Post-release mortality of *Argyrosomus japonicus*

Eighty-nine (32.7 ± 0.35 cm TL) and 162 (31.2 ± 0.42 cm TL) *Argyrosomus japonicus* were hooked and released into the sea cages during aquaria Expts 2 and 3, respectively. Kolmogorov-Smirnov tests failed to detect any significant differences between the size-frequency distributions of treatment and control fish within or among experiments ($p > 0.05$). All fish in both experiments were played for less than 15 s, exposed to air for less than 1 min and did not lose scales. More than 24 % had blood at their mouth or gills, and fish bled significantly more after the hook was removed (37.5 %) than when the line was cut and the hook left in (17.4 %) (Fisher's exact test, $p < 0.01$)

During aquaria Expt 2, most *Argyrosomus japonicus* (67.4 %) were hooked in the mouth (Fig. 2b). To obtain more information on the effects of the anatomical hook location on survival, we aimed to release similar numbers of mouth-hooked (45.1 %) and hook-ingested (54.9 %) fish during Expt 3. Excluding those fish that we allowed to ingest hooks, the most common hooking location was in the roof of the mouth (aquaria Expts 2 and 3) and the gill arch (aquaria Expt 2) (Fig. 2b).

There were no deaths among any of the control *Argyrosomus japonicus*. In comparison, 24 and 30 of the hooked-and-released fish died, providing total survival rates of 73.1 and 81.5 % for aquaria Expts 2 and 3, respectively (Table 4). Contingency table analyses revealed that hook removal was independent of survival in aquaria Expt 2 ($\chi^2_1 = 1.2$, $p > 0.05$). There was a significant dependence in aquaria Expt 3, with hook-ingested fish experiencing a greater rate of mortality when the hook was removed ($\chi^2_1 = 32.1$, $p < 0.05$). The relevant cells of the table contributed towards 73 % of the total chi-squared value.

In aquaria Expts 2 and 3, most mortalities (59.3 %) occurred during the first 24 h of release (Fig. 3b,c), before stabilizing at 4 d. In the first 24 h during aquaria Expt 2, similar numbers of deaths occurred in each of the handling treatment groups. In contrast, in aquaria Expt 3, the majority of the mortalities during this period were fish that had ingested hooks removed.

All fish that had the hook left in during Expt 2 were dissected at the end of the 5 d monitoring period (Table 3). A total of 88 and 5 % of mouth-hooked and hook-ingested *Argyrosomus japonicus*, respectively, were free of hooks. However, like *Acanthopagrus australis*, some mouth-hooked *A. japonicus* eventually ingested their hooks. Specifically, prior to their release into the cages, 20 fish were recorded as having ingested hooks; yet, at the end of the experiment, dissection of all individuals revealed that 28 fish (19 alive and

Table 4. *Argyrosomus japonicus*. Mortality rates after being handled and released according to specific treatments during aquaria Expts 2 and 3

No. of fish hooked	Max. air exposure (min)	Hook location	Hook removed	% mortality
22	<1	Ingested (oesophagus/stomach)	Yes	72.7
44[a]	<1	Unknown	Yes	31.8
45[a]	<1	Unknown	No	22.2
25	<1	Ingested (oesophagus/stomach)	No	16.0
19	<1	Mouth	No	15.8
42	0	Ingested (oesophagus/stomach)	No	9.5
31	0	Mouth	No	6.5
23	<1	Mouth	Yes	4.3

[a]Results of aquaria Expt 2 (all other values are from Expt 3)

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Table 5. *Acanthopagrus australis* and *Argyrosomus japonicus*. Mean (±SE) concentrations of plasma cortisol (ng ml^{-1}) and glucose (mmol l^{-1}) in the blood of fish sampled prior to (Day 0) and at the end of experiments (Day 5). *Significant at $p < 0.05$

	Cortisol		Glucose	
	Day 0	Day 5	Day 0	Day 5
A. australis				
Field Expt	3.60 (2.00)	30.50 (8.60)*	1.30 (0.40)	1.20 (0.20)
Aquaria Expt 1	8.30 (2.00)	38.70 (9.20)*	1.50 (0.60)	1.40 (0.10)
A. japonicus				
Aquaria Expt 2	2.50 (0.40)	13.40 (2.30)*	0.60 (0.00)	2.70 (0.70)*
Aquaria Expt 3	3.10 (1.20)	2.70 (0.50)	0.90 (0.10)	1.60 (0.10)*

9 dead) had ingested hooks, indicating that 8 of the mouth-hooked fish subsequently swallowed their hooks.

Physiological effects of caging

There were no significant intra-specific differences in the mean (±SE) concentrations of plasma cortisol and glucose between any of the caged hooked and control fish at the end of the 4 experiments (Kruskal-Wallis test, $p > 0.05$). However, irrespective of their treatment, all caged fish had concentrations of cortisol that were significantly greater than initial baseline levels, except for *Argyrosomus japonicus* during aquaria Expt 3 (Kruskal-Wallis test, $p < 0.05$; Table 5). Concentrations of glucose were also significantly elevated in all *A. japonicus* (Kruskal-Wallis test, $p < 0.05$; Table 5).

DISCUSSION

This study demonstrated clear treatment-specific differences in mortalities, with more than 72 and 87 % of *Argyrosomus japonicus* and *Acanthropagrus australis* dying after having their ingested hooks removed. Conversely, releasing both species with ingested hooks (irrespective of air exposure for *A. japonicus*), or removing or leaving hooks in the mouth, was associated with few short-term mortalities. These trends in mortalities support those observed for other species in several previous local (Ayvazian et al. 2002, St John & Syers 2005, Butcher et al. 2006) and international studies (Barthel et al. 2003, Cooke & Suski 2004). For example, Butcher et al. (2006) demonstrated that most sand whiting *Sillago ciliata* died after having their ingested hooks removed, while mortalities to hook-ingested rainbow trout *Oncorhynchus mykiss* were significantly reduced when individuals were released with the line cut (Schill 1996). Other studies demonstrated low mortality rates of mouth-hooked individuals of numerous species, irrespective of their handling prior to release (e.g. Murphy et al. 1995, Schill 1996, Taylor et al. 2001, Aalbers et al. 2004).

In addition to the greater mortalities caused by the removal of ingested hooks in the present study, significantly more fish died when there was concomitant blood in their mouths. Autopsies revealed that in most cases, and as observed for similarly handled species in other studies (Warner 1976, Schill 1996, Schisler & Bergersen 1996, Diggles & Ernst 1997, Aalbers et al. 2004), the hook barb lodged into the oesophagus or pierced through the stomach wall and penetrated vital organs such as the heart or liver. Removing the hook probably exacerbated these injuries and may have caused osmoregulatory dysfunction owing to saltwater entering the coelomic cavity (Aalbers et al. 2004). Cutting the line and leaving ingested hooks apparently avoided such injuries and, even though the longer-term fate of these released hook-ingested individuals remains unknown, there was evidence to indicate that some were able to regurgitate or pass their hooks. Specifically, approximately 13 and 5% of hook-ingested *Acanthropagrus australis* and *Argyrosomus japonicus* were free of hooks 5 d after being released. Other studies that monitored hook-ingested fish for longer periods corroborate these observations. For example, Aalbers et al. (2004) reported that 39% of white seabass *Atractoscion nobilis* passed their ingested hooks over 150 d, while Schisler & Bergersen (1996) and Schill (1996) recorded ejection rates of 25 and 74% over 21 and 60 d, respectively, for *Oncorhynchus mykiss*.

The rates at which hooks were ejected also appeared to be influenced by their original anatomical location, with relatively greater percentages of line-cut, mouth-hooked *Acanthropagrus australis* and *Argyrosomus japonicus* (81 and 88%, respectively) free of hooks after 5 d. However, there was evidence to suggest that a few of these individuals subsequently ingested their hooks. This latter result supports the removal of hooks from the mouth prior to release.

As was the case in other relevant studies (for reviews see Muoneke & Childress 1994, Bartholomew & Bohnsack 2005, Cooke & Suski 2005), the majority of mortalities observed in this study occurred within 24 h of fish being released into the cages. Similarly, because there were no significant differences in the concentrations of plasma cortisol and glucose among any of the hooked and control fish at the end of the experiments, any concomitant physiological effects of being hooked and released also appear to have been restricted to the short term. However, irrespective of their treatment, there was some influence of the overall experimental design on the physiological responses of fish. Baseline concentrations of plasma cortisol (2.5 to 8.5 ng ml^{-1}) and glucose (0.6 to 1.5 $mmol^{-1}$) were similar among individual *Argyrosomus japonicus* and *Acanthropagrus australis* at the beginning of each experiment and comparable with earlier estimates for *A. japonicus* (Stone 1995, Broadhurst & Barker 2000) and sparids in general, including black bream *Acanthopagrus butcher* (Haddy & Pankhurst 1999) and snapper *Pagrus auratus* (Pankhurst & Sharples 1992, Broadhurst et al. 2005). Unlike these studies, which showed a return to baseline estimates within 5 d of capture (Pankhurst & Sharples 1992, Haddy & Pankhurst 1999, Broadhurst & Barker 2000, Broadhurst et al. 2005), significantly greater concentrations of cortisol were recorded in both hooked and control *A. australis* (field and aquaria Expt 1) and *A. japonicus* (aquaria Expt 2) at the end of the experiments. Possible explanations for these anomalies include some acute stress evoked during the catching and sampling of fish or, alternatively, negative effects of confinement in the sea cages and/or stocking densities (Rottlant & Tort 1997). Notwithstanding these differences, it is apparent that such effects had minimal impact on any protracted mortalities, and they did not elucidate the key factors contributing towards the observed deaths.

The physiological responses of *Acanthopagrus australis* were also similar between the aquaria and field experiments. These results, combined with the same trend in treatment-specific effects, support the utility of either type of experiment for estimating the factors influencing mortality. However, it is also apparent that both experimental designs had some limitations in terms of providing more quantitative estimates of absolute mortality. In particular, it is unlikely that the aquaria experiment accurately represented the responses of fish to conventional angling. To encourage hooking, feeding was stopped 2 d before the experiment, which may have increased the intensity of the hooking response and lead to proportionally more fish ingesting hooks and incurring greater injuries. The considerably different environmental factors probably also had an effect, especially the lack of current in the aquaria: Schill (1996) attributed similar increases in rates of hook ingestion by *Oncorhynchus mykiss* between field (16 to 17%) and aquaria (40 to 87%) experiments to a reduction in line tension during fishing. The field experiment might be expected to more accurately represent conventional angling practices; however, this assumes the independence of angler behaviour. Conceivably, anglers may have been reluctant to remove as many hooks during their participation in this study as they would in normal circumstances if they recognised that this could cause more fish to die and inflate overall mortality rates. The potential for such biases could be addressed in future studies by placing observers with anglers (Broadhurst et al. 2005), because this is the most reliable method of quantifying catches (Liggins et al. 1996).

In addition to the above, the potential for confounding interactions between handling practices and artificial environments requires some consideration in any discussion of the limitations of the sorts of aquaria and field experiments examined in the present study. For example, we demonstrated no significant reduction in mortality associated with water release for *Argyrosomus japonicus*. However, fish that are released underwater in the wild (with no air exposure) may have a greater opportunity to avoid avian predation, and so such a handling practice might reduce other unaccounted mortalities. Similarly, by holding fish in cages, we ignored the potential for an increased susceptibility to marine predation and/or negative effects on health associated with a reduced ability to acquire food. Such issues require detailed quantification to provide a more holistic assessment of the fate of fish after being released by anglers.

While quantitative information on the anatomical locations of hooks in *Acanthropagrus australis* and *Argyrosomus japonicus* during conventional angling is unavailable, this study demonstrated that anglers can at least significantly decrease short-term mortality via simple handling-and-release practices. More specifically, irrespective of air exposure, anglers should remove the hook from mouth-hooked fish (to prevent subsequent ingestion) or cut the line and release hook-ingested individuals. Further research is required to examine the longer-term consequences of these handling practices on the health of fish and the utility of other simple procedures for improving survival.

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Appendix 2: Reynolds, D. P., Broadhurst, M. K., Butcher, P. A., Rolfe, M., 2009. Effects of angler-induced exercise and air exposure on the mortality of mouth-hooked yellowfin bream (*Acanthopagrus australis*). Journal of Applied Ichthyology 25, 100-103.

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Effects of angler-induced exercise and air exposure on the mortality of mouth-hooked yellowfin bream (*Acanthopagrus australis*)

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Appendix 3: Butcher, P. A., Broadhurst, M. K., Reynolds, D., Cairns, S., 2008. Influence of terminal rig configuration on the anatomical hooking location of line-caught yellowfin bream (*Acanthopagrus australis*). Fisheries Management and Ecology 15(4), 303-313.

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Influence of terminal rig configuration on the anatomical hooking location of line-caught yellowfin bream, *Acanthopagrus australis*

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Appendix 4: Butcher, P., Broadhurst, M., and Reynolds, D. 2005. Keeping bream alive. Fishing World. April 2005.

The science of C&R

A research boat heading out to collect fish.

Keeping bream ALIVE

It seems hooks have a big impact on the survival of yellowfin bream. A mouth-hooked fish has a much better chance than one hooked down deep. NSW Fisheries scientists PAUL BUTCHER, MATT BROADHURST and DARREN REYNOLDS report on the latest results of their catch & release experiments.

IN December 2003, the NSW Department of Primary Industries started a two-year research project entitled "Using recreational anglers to estimate and maximise the survival of released line-caught fish". This research is being funded by NSW DPI and the Saltwater and Freshwater Trust (using money from recreational fishing licences). The project aims to use recreational anglers and fishing events in NSW to determine the fate of key species that are hooked and released and then, if required, examine subtle modifications to existing tackle and handling practices that might maximise survival.

The first experiment was done as part of an event called the 2004 Botany Bay Research Challenge in February 2004 and assessed the fate of released snapper, trevally and yellowfin bream (see March 2004 *Fisho* for details). The survival rates of fish released during this work ranged between 63 and 98 per cent and were influenced by different factors. For example, the time spent in onboard live holding tanks strongly affected the survival of trevally, with fish more likely to die the longer they were held. In contrast, anatomical hook location was a determining factor for the survival of yellowfin bream, with gut hooked fish seven times more likely to die than those that were hooked in the mouth.

The second experiment was completed in the Hawkesbury River, as part of the Del Rio Catch-and-Release event held in late 2004. This event involved 20 fishos onboard 12 boats, three marshal boats and eight cylindrical sea cages (located in the river close to Spencer). All angler boats had identical on-board 70 l fish-holding tanks (supplied by NSW DPI). All anglers used exactly the same type and size of J-hooks (Mustad Allrounder 1/0) baited with school prawns to target mulloway and bream, and were divided into two groups. The first group (termed the "hook-in group") were asked to cut their lines and leave their hooks in their fish, while the second group (the "hook-out group") removed their hooks from their fish after capture, regardless of the hook location.

ABOVE: A 38cm bream caught by recreational angler Chris Partyka during the research program.

All anglers placed their fish into the on-board holding tanks and then signalled a marshal boat. Researchers on the marshal boat collected relevant data for each fish and then transported and released them into the cages.

Two days after all fish (a total of 82 yellowfin bream and one mulloway) were hooked and released (into the sea cages);

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ABOVE: The fibreglass tanks (left) and the sea cages (right) that yellowfin bream were caught from and released into. **LEFT:** A bream being transferred to a holding tank.

control fish (collected from Botany Bay) were transported and released into the sea cages. All fish were then monitored for five days.

None of the control fish and only four bream that were hooked-and-released died (three dying within four hours and one dying 36 hours after being placed in the cages), providing a total survival rate greater than 95 per cent (see Table 1).

Two weeks after the Del-Rio event was completed, we repeated the same experiment in the aquaria facility at the Cronulla Fisheries Centre in southern Sydney. During this work, six of the sea cages were placed into a large flow-through pool. About 175 bream (collected from Botany Bay) were distributed among seven 5000l fibreglass tanks positioned around the pool. Sixty-eight bream were hooked out of the tanks, via small openings in their lids, and released into four of the sea cages. Appropriate numbers of control fish were transferred to the remaining two sea cages. None of the control fish and only seven hooked-and-released bream died (survival rate of 89.7 per cent). Similar to the work done in Botany Bay and the Hawkesbury River, the dead fish had been gut-hooked (hook-removed group) and died within 12 hrs of

TABLE 1

Anatomical hook location for alive and dead yellowfin bream in each group at the end of the Del-Rio experiment in the Hawkesbury River.

	Hook in		Hook out	
Hook location	Alive	Dead	Alive	Dead
Gut (swallowed)	9	3	2	1
Mouth or jaw	31	0	36	0
Total	40	3	38	1

TABLE 2

	Hook in		Hook out	
Hook location	Alive	Dead	Alive	Dead
Gut (swallowed)	29	0	0	7
Mouth or jaw	6	0	26	0
Total	35	0	26	7

capture (see Table 2).

Like studies done on other fish overseas, the results from the three experiments described above clearly indicate that gut-hooked bream have a lower chance of survival than mouth-hooked fish, and that this short-term survival is even further reduced if the hook is removed.

We will be doing further research in the aquaria and as part of fishing events in NSW to (1) examine the longer-term survival of gut-hooked fish and (2) determine the extent to which different designs of hooks (e.g. traditional "J" and new "circle" designs) and configurations of terminal tackle influence anatomical hook location.

This information should provide positive direction for maximising the survival of key C&R species such as yellowfin bream.

Appendix 5: Butcher, P., Reynolds, D., and Broadhurst, M. 2005. Catch and release jewies. Fishing World. August 2005.

Fish survival

Catch & Release jewies

Info from a study into hooked mulloway reveals C&R of jewies could be a feasible management option, writes NSW Fisheries scientists PAUL BUTCHER, DARREN REYNOLDS and MATT BROADHURST.

MULLOWAY (*Argyrosomus japonicus*) are distributed throughout the Atlantic, Indian and Pacific Oceans. In Australia, they occur along the southern coast from Bundaberg in Queensland to Exmouth in WA. Their popularity and accessibility in estuaries means that they are targeted in several NSW recreational and commercial fisheries, with a total combined annual catch of about 1100 tonnes. In addition to this landed catch, large numbers of mulloway are also discarded or released from several commercial and recreational fisheries. The fate of many of these unwanted individuals is unknown, but the potential for at least some mortalities has raised concerns over possible negative impact on stocks.

In some commercial fisheries, these concerns have led to modifications to fishing gears and practices designed to reduce the mortality of unwanted juveniles. For example, during the past 10 years in NSW, bycatch reduction devices (BRDs) specifically designed to allow mulloway to escape from estuarine prawn trawls were developed and legislated for use by relevant fishers. These BRDs allow the majority of fish to escape during fishing, with up to 100 per cent survival.

In addition to the capture and discarding of mulloway by commercial fishers, a recent national fishing survey estimated that, owing to legal size and bag limits, during 12 months in 2000/2001 more than 270,000 mulloway (representing about 46 per cent of the total recreational catch) were released by anglers throughout Australia. Unfortunately, very little information is available on the subsequent fate of these fish, or the utility of subtle modifications to existing tackle and handling practices that might maximise their survival. This issue is now being closely addressed in NSW via a research project funded by the NSW Department of Primary Industries and the Saltwater Trust (using money from recreational fishing licences) entitled "Using recreational anglers to estimate and maximise the survival of released line-caught fish".

As part of this project, an experiment was recently completed at the Cronulla Fisheries Centre aquarium facilities. The aim of this work was to determine the short-term survival of mulloway after being released with either (i) the hook removed as per normal fishing practices or (ii) the line cut and the hook left in the fish. About 250 mulloway (between 25 and 45cm total length) were distributed among seven 5000l fibreglass tanks positioned around a large flow-through pool (30 x 14 x 2.5m) containing six cylindrical sea cages (2.5 x 2.3m). Ninety one mulloway were hooked from five of the 5000 tanks using the same type and size of J-hooks (Mustad Allround 1/0) baited with school prawns, and then released into four of the sea cages. During capture, most fish were observed to either swallow the hook or were hooked in the gill arch or upper mouth/jaw. Immediately after being caught, 45 of the hooked fish were randomly selected and had their hooks removed prior to being released into two sea cages. The remaining 46 fish had the line cut and their hooks left in before being placed into two separate sea cages. Once all hooked fish were released, 46 control fish were transferred (using scoop nets) from two of the 5000l tanks to the remaining two sea cages. Fish in all sea cages were monitored and fed prawns for five days.

All of the mulloway in the control group survived. In comparison, 24 of the hooked and released fish died, providing a total survival rate of 73.6 per cent. Mortalities remained similar between those fish that had the hook removed (14 deaths) or left in (10 deaths), with survival rates of 68.8 and 78.2 per cent, respectively. Irrespective of the treatment, most fish that died did so during the first and second days after release. Because those fish that were observed to swallow hooks were euthanased after the experiment (to assess

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ABOVE: NSW DPI aquaria manager Darren Reynolds with a mulloway hooked from a 5000 litre tank at the Cronulla Fisheries Centre.
RIGHT & OPPOSITE: The line is cut before the mulloway is released into a sea cage.

hook location and any damage to internal organs), no information is available on their longer-term survival.

Although considered preliminary, the results provide important information. For example, if the observed survival rates are representative of those that occur in the wild, then a large proportion of the estimated 276,567 fish caught and released by recreational fisheries throughout Australia in 2000/2001 might have survived. Considerable additional research is required to more closely examine the factors that might influence the short and long-term survival of hooked-and-released mulloway, including the effects of anatomical hook location (i.e. hook ingestion vs hooked in the mouth), terminal gear type, depth of capture and handling and exposure to air following landing.

NSW DPI will be examining some of these issues, particularly the extent to which different designs of hooks and configurations of terminal tackle influence anatomical hook location, as well as changes to handling procedures that might minimise mortalities. Like similar work done with commercial prawn fisheries in NSW, this information should contribute towards improving the survival of mulloway released by recreational anglers.

Appendix 6: Butcher, P., Broadhurst, M., and Reynolds, D. 2006. How to keep jew alive. Fishing World. February 2006.

Jewie research

How to keep jew alive!

Here's some updated information on the survival of juvenile mulloway after being released from capture by hook and line from NSW Fisheries boffins Paul Butcher, Matt Broadhurst and Darren Reynolds.

IN the August 2005 issue of *Fishing World*, we presented some results from a research project (funded by NSW DPI and the Saltwater Trust - using money from recreational fishing licences) to show that more than 68 per cent of hooked mulloway survived being released with either (i) the hook removed as per normal fishing practices or (ii) the line cut and the hook left in the fish. While these results were very encouraging, we lacked information on some of the factors contributing towards the few observed mortalities, such as the effects of anatomical hook location and/or exposure to air during capture.

We aimed to address these issues in a recent experiment at the Cronulla Fisheries Research Centre in southern Sydney. During this work, mulloway (between 21 and 42cm) were hooked from a 5000 L tank or a cage (5 x 5 x 2.5 m) located in a large pool. Fish were then released in three different ways that included (i) being left in the water and the line cut, or being pulled from the water (total air exposure less than 1 minute) and (ii) the hook removed or (iii) the line cut. Each fish was categorised according to anatomical hook location (gut- or mouth-hooked) before being released into an appropriate floating cage. All "water-released" fish were brought close to the surface of the pool or tank, lifted in a 25 L container along with about 20 L of water and then transferred to an appropriate cage. None of the "water-released" fish were exposed to air. Appropriate numbers of control fish were placed into cages on the same day of angling.

ABOVE: Technician Matt Timmins caught this juvenile mulloway while testing different designs and sizes of hooks on his day off.

A mulloway being released into a sea cage.

All fish were fed prawns and monitored daily for up to seven days.

Table 1 summarises the survival of hooked-and-released mulloway according to their various treatments. Like for yellowfin bream and sand whiting, anatomical hook location appeared to have a significant effect on the short-term survival of released mulloway;

Researcher Paul Butcher catching mulloway from the pool.

especially if swallowed hooks were removed (e.g. survival less than 28 per cent). Cutting the line and leaving swallowed hooks in fish greatly increased their short-term survival, particularly if the fish were released underwater (e.g. survival less than 90 per cent).

While mouth-hooked fish generally have a much greater overall probability of surviving, this can be maximised via simple procedures such as landing the fish and removing the hook to prevent subsequent swallowing or, alternatively, cutting the line and releasing the fish underwater.

As part of ongoing research, we are examining the utility of different sizes and shapes of hooks for mitigating the swallowing of hooks by mulloway. In addition, a mulloway C&R fishing event has been planned for a NSW estuary during summer 2005/06 (TBA at a later date). Using recreational anglers, this research will help us to isolate other factors influencing the survival of released mulloway, as well as the utility of simple alterations to handling practices that increase their survival.

Percentage of mulloway surviving according to their treatments

No. of fish	Air exposure	Hook location	Hook removal	% surviving (7 days)
22	yes	gut	yes	27.3
25	yes	gut	no	84.0
19	yes	mouth	no	84.2
42	no (water release)	gut	no	90.5
31	no (water release)	mouth	no	93.5
24	yes	mouth	yes	95.8

Appendix 7: Reynolds, D., Butcher, P., and Broadhurst, M. 2006. Tough bream. Fishing World. June 2006.

Fishy Science

Tough BREAM!

NSW Fisheries research shows that mouth-hooked yellowfin bream can survive significant air exposure and playing time. By DARREN REYNOLDS, PAUL BUTCHER and MATT BROADHURST.

YELLOWFIN bream (*Acanthopagrus australis*) inhabit eastern coastal and estuarine waters between Townsville and the Gippsland Lakes and are popular among recreational anglers, with more than 13 million fish caught each year. Owing to minimum legal sizes (23, 25 and 26-28 cm total length – in QLD, NSW and Vic, respectively) and daily bag limits (no limit, 20 and 10 fish, respectively) up to 63 per cent of all angler-caught bream are released. Until very recently, there was no information available on the fate of these fish.

As part of a two-year research project entitled, "Using recreational anglers to estimate and maximise the survival of released line-caught fish", NSW Fisheries is quantifying the fate of key species released from capture by hook and line, and examining angling practices that improve survival. This work has already demonstrated that anatomical hooking location is one of the most important factors influencing the mortality of yellowfin bream, with typical survival rates greater than 96 per cent for mouth-hooked fish compared to between 53 and 80 per cent for hook-ingested fish. For the latter individuals, subtle differences in angling practices, such as cutting the line and immediately releasing the fish (with the hook) have significantly improved short-term survival. Also, different designs of hooks are being examined for their utility in minimising ingestion. It is hoped that by restricting hooking to the mouth or jaw whenever possible, released yellowfin bream will have a greater chance of survival.

While it's apparent that only a few released mouth-hooked yellowfin bream die, information is still required on the contributing factors, so that these can be mitigated via subtle changes to handling practices. Our aims were to address this issue by examining the influences of air exposure and extended playing time on the survival of mouth-hooked yellowfin bream.

This work was done during two

Removing a circle hook from a yellowfin bream after capture.

experiments at the Cronulla Fisheries Research Centre aquarium facility. In the first experiment, 205 yellowfin bream (between 18 and 28cm TL) were distributed among five 5000 litre fibreglass tanks positioned around a flow-through pool (30 x 14 x 2.5m) containing six cylindrical sea cages (2.3 x 2.5 m). Some 44 fish were hooked (using 1/0 Gamakatsu Nautilus circle hooks baited with prawns) and immediately removed from the holding tanks. Only mouth-hooked fish were used in the experiment. The hook was removed (see photo 1) and all fish were immediately placed into 100 litre plastic containers and exposed to air for either 2.5 or five minutes (22 fish for each exposure period) before being released into the appropriate sea cages (i.e. two cages for each exposure period) (see photo 2). Twenty-two control fish were removed from the 5000 litre holding tanks and placed into the remaining two sea cages. All fish were fed prawns and monitored twice daily for mortalities over 10 days.

In the second experiment, 31 fish were caught (using the same hooks as above) from about 400 individuals (between 17 and 32cm TL) distributed between two net pens (7 x 5 x 2.5m) located in the flow-through pool. All hooked fish were actively "played" for 30 seconds before being landed. The hooks were immediately removed and, like above, fish were exposed to air for either 2.5 (15 fish) or five (16 fish) minutes before being released into four of the sea cages. Sixteen control fish were transferred from the net pens to the remaining two sea cages. All fish were monitored and fed for five days.

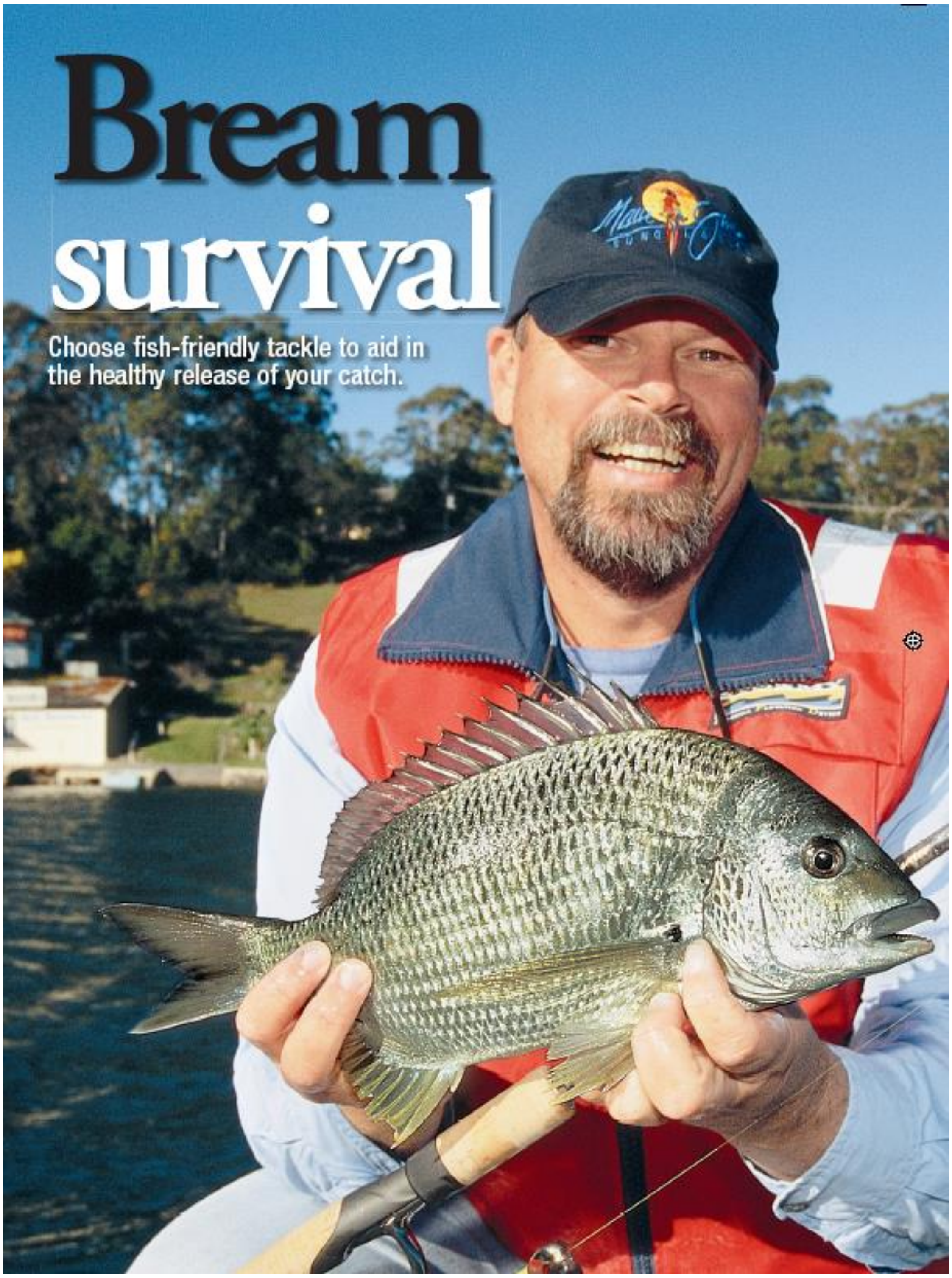
The majority of fish were hooked in either the right (40 per cent) or upper (30 per cent) parts of the mouth. All fish that were immediately landed and then exposed to air for 2.5 and five minutes in Experiment 1 survived. In contrast, two individuals that were played for 30 seconds and then exposed to air for 2.5 and five minutes respectively, died during experiment 2. This represents an overall survival rate of 97.3 per cent. Both fish that died did so within an hour of being released. During landing, these two individuals were observed to be bleeding from hook wounds in their mouth. The subsequent air exposure allowed the blood to clot around the gill filaments, and it is possible that this inhibited respiration after the fish were released.

The results support previous estimates of the survival of released mouth-hooked yellowfin bream and indicate that this species can withstand prolonged air exposure. While mortality rates were low, it may nevertheless be possible to maximise survival by minimising playing period and subsequent exposure to air, especially if fish are bleeding. Quick release might prevent any blood from clotting in the gills and suffocating the released fish.

Because all of the research done so far indicates that released mouth hooked yellowfin bream have a very high probability of survival, further work in this area will be restricted to (i) examining the influences of different hook designs on anatomical hook location (to identify those hook types less likely to be ingested) and (ii) the longer-term fate of yellowfin bream that do swallow hooks and the rate of hook decay. It is anticipated that this information will greatly contribute to the sustainability of recreational fishing for yellowfin bream throughout their distribution.

Editor's note: *Fisho* will publish the results of the gut-hooked fish experiment in the July issue.

Appendix 8: Butcher, P., Broadhurst, M., Reynolds, D., and Cairns, S. 2007. Bream survival. Modern Fishing. March 2007**.**



A REPORT BY: Paul Butcher and Matt Broadhurst, NSW Department of Primary Industries, Fisheries Conservation Technology Unit; and Darren Reynolds and Stuart Cairns, School of Environmental Sciences and Natural Resources Management, University of New England, Armidale.

THE NSW DEPARTMENT of Primary Industries and the Recreational Fishing Trusts have funded a research project (using money from recreational fishing licences) to estimate and maximise the survival of key coastal fishes after being released by recreational anglers. Yellowfin bream have received the most attention because of their abundance and popularity, with several studies done to estimate their post-release survival and the key factors influencing mortalities. So far, this work has demonstrated that most released yellowfin bream survive, although anatomical hook location and subsequent handling have an important influence on their fate.

A 2004 recreational fishing event in Botany Bay, Sydney, recorded between 72 and 97 percent of yellowfin bream released into floating sea cages survived (over 10 days). The main cause of the few mortalities attributed to gut hooking.

Other experiments have been done to determine the short (five days) and long-term (105 days) post-release survival of mouth and gut-hooked yellowfin bream after having the line cut and the hook left in place; or the hook removed. This work revealed that only 13 percent of gut-hooked yellowfin bream survived being released after the hooks were physically removed by the angler. In contrast, irrespective of the release method, 98 percent of mouth-hooked fish survived. Similarly, between 85 and 92 percent of gut-hooked fish released with the line cut (and a nickel-plated J-hook left in the gut) also survived. Further, there were few long-term negative effects on the line-cut, gut-hooked fish, with more than 76 percent eventually shedding the hooks (after these had partly corroded).

While the above results suggest that cutting the line is an appropriate strategy for improving the survival of released gut-hooked yellowfin bream, it's also apparent that mortalities can be reduced if hooking is restricted to the mouth and jaw. Overseas studies indicate that one way of reducing the rate of gut hooking in some fish is to use different sizes and designs of hooks—in particular 'circle' or modified 'J' hooks.

Our aims in this study were to investigate the rates at which these different types of hooks were swallowed by yellowfin bream. This work was undertaken with field and cage experiments using 50 designs and sizes of commonly-configured circle and J-hooks, and a modification to a small J-hook that we termed the 'stop swallow'.

The field experiment was conducted between December 2004 and May 2006 and involved 75 anglers targeting yellowfin bream throughout NSW. All the anglers were given different designs and sizes of circle and J-hooks and asked to record gear and catch information, including the terminal rig configuration and the type of bait used, along with the total length (TL) and anatomical hook location of each fish that was landed.

The cage experiment involved hooking yellowfin bream from net cages at the Cronulla Fisheries Research Centre (CFRC), and from a commercial fish farm in Botany Bay. At the CFRC, approximately 600 fish (15-30 cm TL) were distributed in two large net cages in a flow-through pool, while in Botany Bay, 800 fish (15-41 cm TL) were located in a sea cage. Fish were fed pellets daily and allowed to acclimatise for up to four weeks before the experiment. All fish were hooked (and then released) using similar configurations of fishing gear to those used by anglers in the field experiment.

Data was collected for 1,059 (average TL of 25 cm) and 976 (average TL of 22 cm) yellowfin bream during the field and cage experiments, respectively. The results showed that, overall and irrespective of the experiment and rig configuration, considerably fewer fish were hooked in the gut (13 percent of the total) than in the mouth (85 percent). Given that our earlier studies showed that nearly all released mouth-hooked yellowfin bream survived, this result has obvious positive consequences for stocks of this species throughout NSW.

For those fish that were hooked in the gut, we identified five significant contributing factors, including the type and size of hooks, the size of fish and the bait and rig type. In both experiments, a greater percentage of conventional J-hooks were swallowed (16 percent) than circle hooks (10 percent) and the modified J-hook with the stop swallow (two percent). But, irrespective of hook design, the rate of gut hooking also decreased with larger hook sizes and smaller fish sizes. During the cage experiment, considerably more fish (30 percent) swallowed hooks with soft baits (such as chicken gut, octopus and squid) than those rigged with hard baits (seven percent—crustacean, fish or artificial).

The effects of bait were not as clear in the field experiment, although compared to crustaceans (prawns, yabbies and shrimp), fewer hooks were swallowed when they were baited with artificial bait (dough, bread, pellets). Rig type also had an effect on gut hooking in the field experiment, with proportionally fewer hooks swallowed when they were attached to floats (0 percent) or short traces (11 percent), compared to no trace (13 percent), paternoster and split shot (17 percent) or long trace (24 percent).

The 'stop swallow' modified hook reduced gut hooking but also reduced the efficiency of the J-hook.

Various hook patterns were used during the experiment.

The above results, combined with those from our other research, support some general strategies for maximising the survival of yellowfin bream following release from capture by hook and line. In particular, it would seem appropriate to encourage the use of circle hooks for this species, although, given that very few fish ingested the stop swallow (two percent), simple modifications to conventional J-hooks may be a viable alternative. The stop swallow does require some refinement—anglers suggested it reduced the efficiency of the conventional J-hook. One option might be to reduce the length of the horizontal bar. Such design modifications should be encouraged, mainly because the utility of this type of concept could potentially extend beyond J-hooks to all types and sizes of hooks.

Regardless of the hook design, it would also seem appropriate to use the largest size possible to target legal-sized bream. The likelihood of hooks being swallowed might then be further reduced by using floats or short traces and hard baits. Lastly, because our other research showed that many line cut, gut-hooked yellowfin bream eventually passed their hooks, these should be made from materials that quickly corrode.

According to our research, following the above simple protocols should result in most of the released yellowfin bream surviving.

Ongoing work is being undertaken to examine the main factors influencing the post-release survival of other key species targeted in NSW and whether or not strategies such as those recommended here will have similar benefits. Ultimately, this information should contribute towards the sustainability of recreational fishing in Australia.

Circle hooks can reduce the amount of gut-hooked fish.

These net cages at the Cronulla Fisheries Research Centre were used during the experiment.

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