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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).

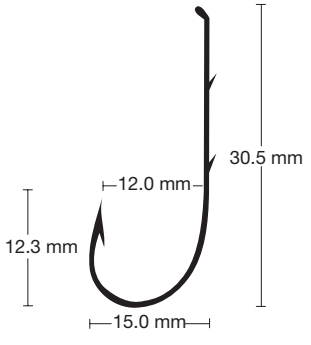

Fig. 1. Nominal dimensions of J-hooks used during this study

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.

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 finclipped 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 $7 \times 5 \times 2.5$ 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 finclipped 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)

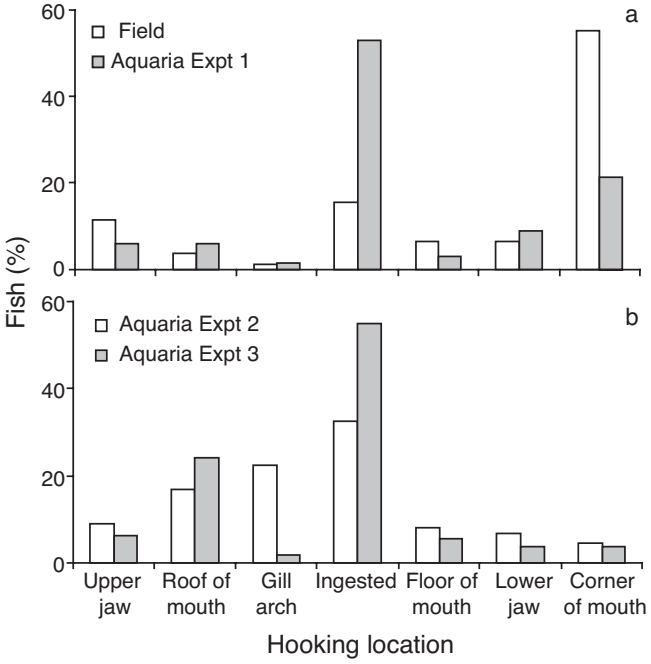

Fig. 2. *Acanthopagrus australis* and *Argyrosomus japonicus*. Anatomical hooking location of (a) *A. australis* and (b) *A. japonicus* during each experiment

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-*

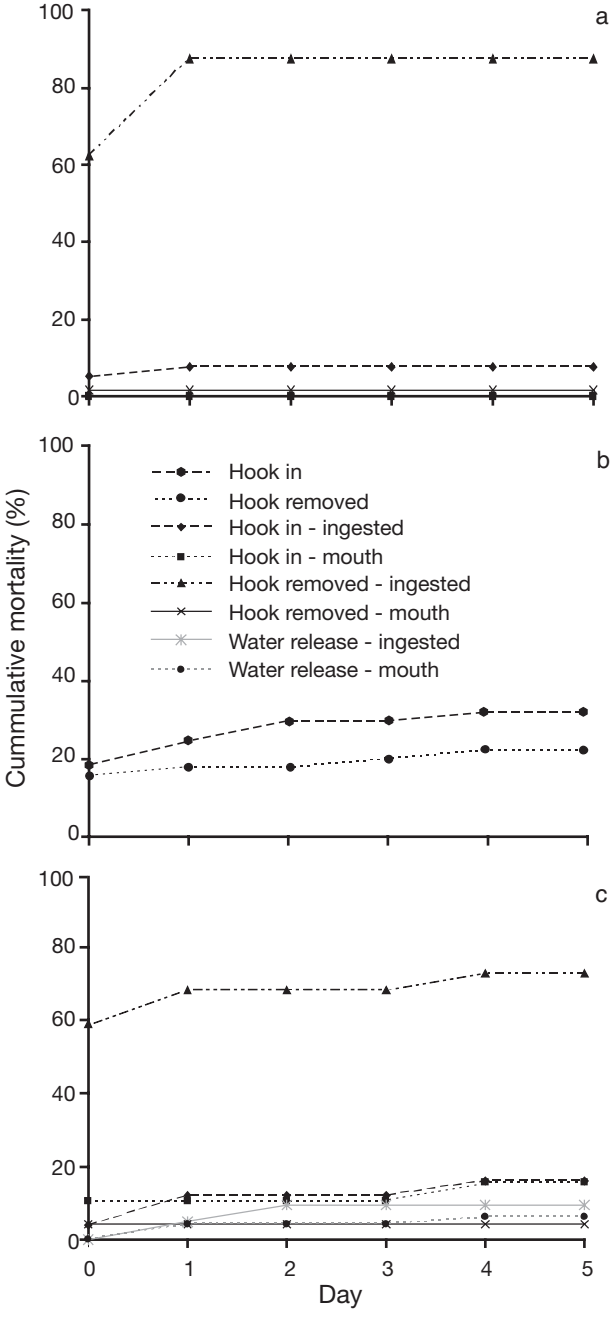

Fig. 3. *Acanthopagrus australis* and *Argyrosomus japonicus*. Daily cumulative mortality of *A. australis* during (a) Expts 1 and 2 (pooled results), and *A. japonicus* during (b) Expt 2 and (c) Expt 3

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)

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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