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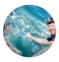

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Physical damage, behaviour and post-release mortality of *Argyrosomus japonicus* after barotrauma and treatment

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Two experiments were conducted to quantify the mortality of, and clinical signs of barotrauma to, *Argyrosomus japonicus* after retrieval from 20 m following either 'no treatment', 'venting' (a needle inserted into the swim bladder) or 'recompression' (released with a weighted line). In Experiment 1, 10 fish were hauled from 20 m and from 5 m (controls) and euthanised for assessment. The only effect on controls was a distended coelomic cavity, but all fish retrieved from 20 m had this symptom and a prolapsed cloaca, and many had haemorrhaging (81%), gastric herniation (70%), swimbladder rupture (50%) and affected buoyancy (66%). Another 20 fish were subjected to the treatments and, along with controls (from 5 m), were released into 'bathy-cages' (2.5 m × 20 m) for three days. Only two fish retrieved from 20 m died (total mortality of 3.3%). In Experiment 2, six fish retrieved from 20 m and three control fish were tagged with acoustic transmitters, released following the abovementioned treatments into the wild and monitored for 214 d. All fish with barotrauma remained at shallower depths than controls for the first 10 d, after which behaviour was similar among groups. Our findings are positive, but further research is required to explore the relationship between retrieval depth and the severity of barotrauma.

Keywords: angling, kob, mulloway, recreational fishing, telemetry, unaccounted fishing mortality

Introduction

Argyrosomus japonicus (commonly known as mulloway, meagre or dusky kob; Sciaenidae) is distributed across estuarine and nearshore waters of the Indo-West Pacific oceans surrounding Africa, Australia, China, India, Japan, Korea and Pakistan. In Australia, *A. japonicus* is common along the southern coast (<100 m) from central Queensland to the North-West Cape in Western Australia (Kailola et al. 1993), where it grows to 200 cm total length (TL) and 60 kg (Kailola et al. 1993).

On account of its large size and good eating qualities, *A. japonicus* is targeted extensively by recreational fishers but, owing to minimum legal sizes (45–75 cm TL) and personal or boat quotas (e.g. 2–10 fish d^{-1}), is released in large numbers. A creel survey conducted in Australia during 12 months in 2000/2001 estimated that up to 270 000 sciaenids (including *A. japonicus*, *Protonibea diacanthus* and *Atractoscion aequidens*), or 46% of the total catch, were released (Henry and Lyle 2003). Currently, there are concerns about the status of Australian *A. japonicus*, with south-eastern stocks classed as overfished (Silberschneider et al. 2009). Although the major threat is considered to be excessive harvesting (Silberschneider et al. 2009), over the past few years the potential for mortality from catch-and-release fishing has raised concerns (McLeay et al. 2002).

Three studies have assessed the fate of angled-and-released *A. japonicus*, with variable mortalities up to 73%, mostly attributed to hook ingestion and subsequent removal (mouth-hooked fish typically incurred zero mortality; Broadhurst and Barker 2000, Butcher et al. 2007, McGrath et al. 2011). Simply cutting the line on fish that ingested hooks reduced mortalities to <16% (Butcher et al. 2007), with some individuals eventually ejecting their hooks (up to 30% over 61 d; McGrath et al. 2011). Although such results have positive implications for sustainability, a limiting factor is that all of the studied *A. japonicus* were caught from <10 m. A remaining concern is the effect of barotrauma among individuals retrieved from deeper water.

Barotrauma can occur in many fish due to the associated pressure reduction causing gases to expand in their body cavities (Feathers and Knable 1983, Rummer and Bennett 2005, Jarvis and Lowe 2008, Kerwath et al. 2013). More than 70 different injuries can occur from gas expansion in the swimbladder (Rummer and Bennett 2005), although most clinical signs probably are reversible (Rummer and Bennett 2005, St John and Syers 2005). Clinical signs differ in range and severity but commonly include: compromised swimming; a distended coelomic cavity; gastric herniation; exophthalmia; prolapsed cloaca; haemorrhages in the liver, kidney and coelomic cavity; organ displacement; ruptured

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swimbladder; and the formation of gas bubbles under the skin, in the circulatory system, eyes, gills, heart or brain (Feathers and Knable 1983, Rummer and Bennett 2005, Jarvis and Lowe 2008, Kerwath et al. 2013).

Because *A. japonicus* has a physoclistous swimbladder, it is potentially susceptible to many of the abovementioned direct impacts, and some associated mortality. Further, the indirect consequences of such clinical signs are also of concern for fish welfare, because they can compromise immune function (Phelan 2008), reproduction (Hall et al. 2013), behaviour (Gitschlag and Renaud 1994) and buoyancy (Rummer and Bennett 2005).

Modified handling practices have been developed to alleviate the impacts of barotrauma in fish (Cooke and Suski 2005, Brown et al. 2010). Depending on species-specific vulnerabilities, some studies have shown that clinical signs and/or mortality can be reduced by either 'venting' (e.g. using a hypodermic needle to deflate the distended swimbladder; Sumpton et al. 2010, Roach et al. 2011) or by 'recompressing' fish using a weighted line or cage to return them to their capture depth (Brown et al. 2010, Roach et al. 2011). Alternatively, simply releasing fish untreated has benefits (Roach et al. 2011, Butcher et al. 2012). It is less clear whether the utility of these release practices extends beyond the short term, with most studies limited to monitoring fish for <10 d, either in field cages (Brown et al. 2010) or hyperbaric chambers in laboratories (Pribyl et al. 2009). At least some clinical signs of barotrauma and/or injuries sustained during release might have more delayed effects (e.g. buoyancy regulation), which could lead to further mortalities (Nichol and Chilton 2006).

One method for assessing the fate of released fish that has increased in popularity over the past decade is biotelemetry (Nichol and Chilton 2006, Gravel and Cooke 2008, Nguyen et al. 2009). Although not used to assess locally angled-and-released *A. japonicus*, conspecifics have been tagged with acoustic transmitters and tracked in a south-eastern Australian estuary to determine their key habitat and home ranges (Taylor et al. 2006). However, these fish were internally tagged, a method not appropriate when assessing individuals with barotrauma, owing to the confounding impacts of surgical procedures and the need to release fish immediately. External attachment methods, however, have been used to monitor the post-release movements and mortalities of other angled species (Butcher et al. 2010, Roberts et al. 2011), including those with barotrauma (e.g. *Gadus macrocephalus*, Nichol and Chilton 2006; *Micropterus dolomieu*, Nguyen et al. 2009; *Macquaria ambigua,* Hall et al. 2013).

The aims of this study were to quantify the physical response of *A. japonicus* and the mortality after retrieval from 20 m depth and subsequent handling by three conventional methods (venting, recompression or untreated). Short-term (3 d) and long-term (≤214 d) post-release assessments of *A. japonicus* were completed using 'bathy-cages' at 20 m depth (Experiment 1) and telemetry (Experiment 2) respectively.

Material and methods

Study site and fish collection

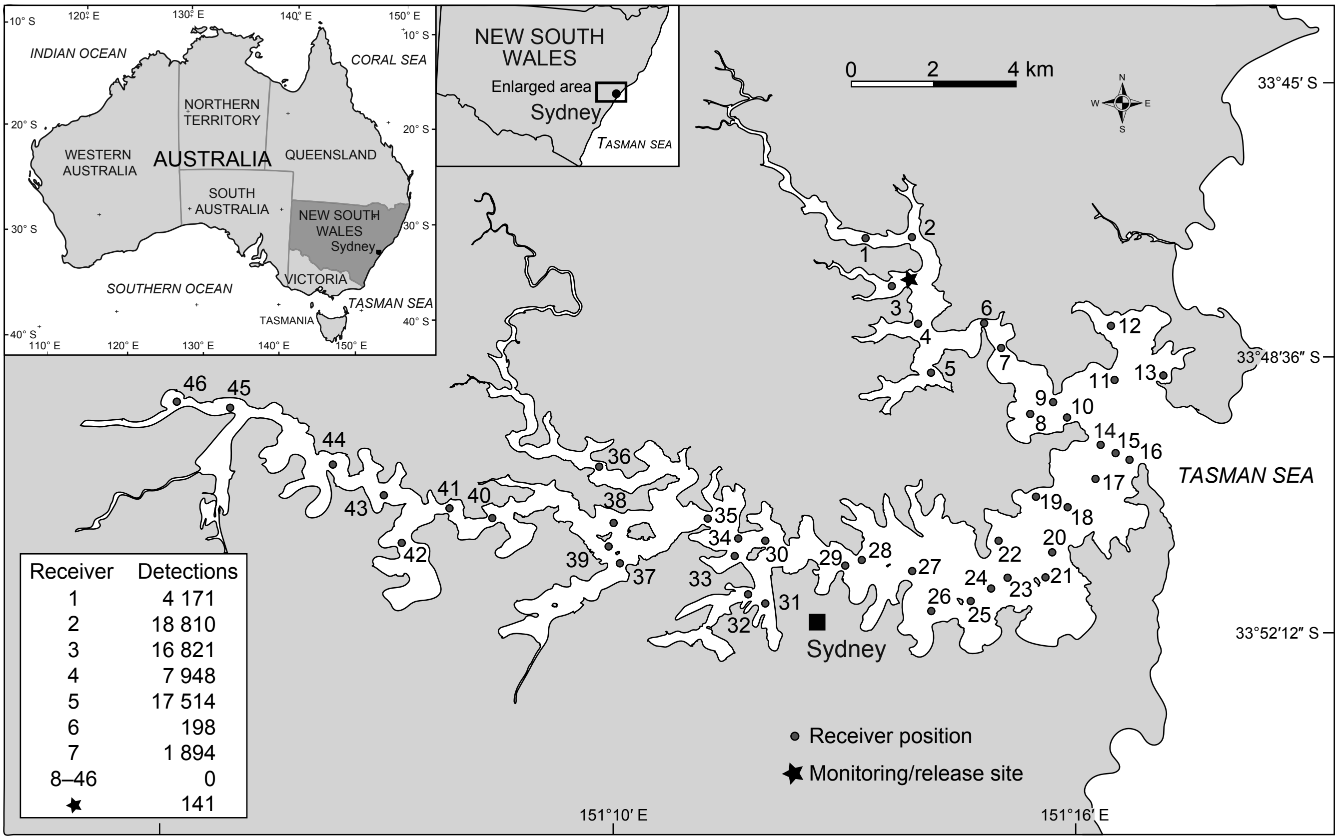
Two experiments were conducted between March and November 2011 in Port Jackson, Sydney, New South Wales (NSW), Australia (33°47′ S, 151°13′ E; Figure 1). Eight weeks before starting Experiment 1, 140 first-generation *A. japonicus* were collected from an aquaculture facility at Palmers Island (29°27′ S, 153°17′ E), placed into 380-litre tanks (stocking density of <15 kg fish m^{-3}) containing seawater at ambient temperature and transferred to the National Marine Science Centre, Coffs Harbour (30°16′ S, 151°08′ E), where they were evenly distributed between two aerated 4 000-litre holding tanks for quarantine. All fish handling, anaesthesia (25 mg l^{-1} of Aqui-S®) and husbandry procedures followed Barker et al. (2009). Each tank was supplied with seawater at a constant flow (5 l min^{-1}) and the fish were fed dead prawns *Metapenaeus macleayi* and sardine *Sardinops sagax* to satiation. Two weeks before the first experiment, the fish were transferred as above to the Cronulla Fisheries Research Centre (CFRC; 34°04′ S, 151°09′ E) where they were evenly distributed between two aerated and flow-though 5 000-litre holding tanks and monitored and fed daily, again as above.

Experiment 1: clinical signs of barotrauma and short-term mortality

On the first day of the experiment, two 98 000-litre cylindrical cages of 2.5 m diameter × 20 m depth (termed 'bathy-cages') and sixty 110-litre cylindrical cages (0.5 m diameter × 0.7 m depth; see Roach et al. 2011 for details), were anchored in a bay (>23 m depth — termed the 'monitoring site' — see Figure 1). The 110-litre cages were individually attached to 20 m retrieval lines (twisted polyethylene [PE], 8 mm diameter [ϕ]) deployed at 5 m intervals (termed 'positions') on a 300 m buoyed line (twisted 12 mm ϕ PE) anchored every 100 m.

Seventy fish were then removed from the CFRC holding tanks and transported to the monitoring site. To test the assumption of no existing clinical signs of barotrauma among the fish, 10 randomly selected individuals were externally assessed at the monitoring site for a distended coelomic cavity, gastric herniation into the buccal cavity, exophthalmia, ocular and subcutaneous gas bubbles, oculogyration reflex, haemorrhaging, prolapsed cloaca or affected (sideways/inverted) buoyancy before being euthanised in 100 mg l^{-1} of ethyl-p-amino benzoate (benzocaine) in seawater (Barker et al. 2009). These fish were then dissected and internally assessed for haemorrhages within the liver, kidney and coelomic cavity, organ displacement and/or ruptured swimbladder.

The remaining 60 fish were photographed (ventral body surface) in air before their widths were measured with vernier callipers (to the nearest 1 mm) at the vertical intersection of the fifth dorsal spine and the top of the pectoral fin. The latter was done to quantify any changes in volume associated with swimbladder inflation after retrieval (see below). Each fish was then placed into a 110-litre cage and lowered at ~0.25 m s^{-1} to either 5 m (20 fish; termed 'controls') or 20 m (40 fish) for 48 h before being retrieved at 1.0 m s^{-1} (a velocity similar to that used by anglers) using a motorised line-hauler (3.7 kW) fixed to a 7 m vessel. The 5 m cages were also retrieved using 20 m ropes (but diagonally) to control for the effects of retrieving fish in their cages (Roach et al. 2011, Butcher et al. 2012).



Receiver	Detections
1	4 171
2	18 810
3	16 821
4	7 948
5	17 514
6	198
7	1 894
8–46	0
★	141

Figure 1: Location of the monitoring/release site and VR2W receivers in Port Jackson, Sydney, New South Wales, Australia. Inset: number of detections recorded on each receiver from tagged *Argyrosomus japonicus* during Experiment 2

Immediately after retrieval, the caged fish were assessed for external signs of barotrauma before being removed and measured (total length [TL] to the nearest 0.1 cm). Subsets of 10 fish from both depths were euthanised, photographed and examined for internal clinical signs of barotrauma. The photographs were used to quantify any changes in physical condition (e.g. prolapsed cloaca or haemorrhaging as a result of the treatment of the fish).

All remaining fish (i.e. 10 from 5 m and 30 from 20 m) were fin-clipped for identification (by either depth or eventual treatment). During fin-clipping, 10 *A. japonicus* retrieved from 20 m (comprising the first treatment group and termed vented fish) had their swimbladder punctured at the vertical intersection of the fifth dorsal spine and the top of the pectoral fin with a 12-gauge hypodermic needle. These and all other control and treatment fish were then individually placed into a 70-litre PVC live-well (0.7 m × 0.4 m × 0.4 m) and reassessed for affected buoyancy. All control and vented fish, as well as 10 fish retrieved from 20 m comprising the second treatment group ('untreated'), were released at the surface of each bathy-cage ($n = 5$ fish cage^{-1}). The remaining 10 fish in the third treatment group ('recompressed') were returned to 20 m inside the bathy-cages ($n = 5$ fish cage^{-1}) by attaching a weighted barbless hook (made from 2 mm ϕ wire and a 0.6 kg lead weight) with 20 m of line (twisted 2 mm ϕ PE) through the membrane of their lower jaw. All fish released at the surface were assessed to determine if they (1) swam away immediately and vigorously or (2) immediately and slowly, (3) swam at the surface but appeared disoriented or (4) did not move (based on the index developed by Patterson et al. 2000).

The bathy-cages were monitored twice daily, at the surface (down to ~5 m) over three days, for any mortalities. Temperature data-loggers (iBCod 22L; Thermodata®) were placed at the surface (1 m) and then at 3.5 m intervals adjacent to each cage, whereas two Greenspan ODO3000 data-loggers (Tyco Environmental Systems, Australia) were used to record water temperature (°C), dissolved oxygen (mg l^{-1}) and salinity at 20 m. These environmental data were collected hourly. The above variables were also taken twice daily with an Horiba U-10 meter (Horiba Ltd, Kyoto, Japan) across the same depths. Concurrently, air temperatures were measured with a digital thermometer. At the end of the monitoring period, the bathy-cages were retrieved and the fish removed and assessed for physical damage (i.e. at the venting and release-weight puncture sites). Subsequent monitoring was not possible because of the potential for repeat barotrauma during bathy-cage retrieval. The entire method (excluding the internal assessments) was then repeated, providing a total of 20 fish for each of the treatment and control groups.

Experiment 2: long-term assessment

After Experiment 1 was completed, nine *A. japonicus* were transported from the holding tanks at the CFRC, placed individually into the 110-litre cages, and lowered to either 5 m ($n = 3$ fish) or, in advance of the three release treatments as used in Experiment 1, to 20 m ($n = 2$ fish per treatment). After 48 h the fish were hauled to the surface as above. Each fish was then assessed externally for clinical signs of barotrauma, tagged (see below) and released according to their prescribed treatment (within 30 s; Table 1) for monitoring over 214 d (the battery life of the transmitters) by 46 permanent VR2W receivers (Vemco Ltd, Nova Scotia, Canada) in Port Jackson (Figure 1). An additional receiver was temporarily positioned at the monitoring site for 2–3 h following the release of each fish. The telemetry data were downloaded from the receivers to the Vemco User-Environment (VUE, Vemco Ltd, Nova Scotia, Canada) software package and then into a database for analysis.

All fish were tagged with V9P acoustic transmitters (Vemco Ltd, Nova Scotia, Canada). The transmitters weighed 2.9 and 6.2 g in water and air respectively and measured 46 and 9 mm in length and diameter. Each transmitter was secured at each end by a 80 mm plastic-tipped polyethylene dart tag (Hallprint Ltd, Adelaide) with epoxy resin and 12 mm black polytetrafluoroethylene tubing, following Roberts et al. (2011). The anterior dart was inserted into muscle tissue ~20 mm below the fourth dorsal pterygiophore, with the second dart located the same distance below the dorsal surface towards the tail, allowing the transmitter to lie laterally along the fish. Each transmitter emitted a unique sequence at a frequency of 69 kHz that repeated after a random delay of 90–210 s.

Data analyses

In Experiment 1, several experiment-specific hypotheses were tested concerning the effects of depth and the treatment of fish on the clinical signs of barotrauma using linear mixed (LMM) and generalised linear (GLM) models. The LMMs included the experimental design factors as random effects and TL as a fixed effect. The GLMs included all factors as fixed effects due to the limited sample size and the problems associated with the Hauck-Donner phenomenon (Hauck and Donner 1977). The p-values were obtained from (1) the asymptotic distribution of either the change in deviance using a χ^2 distribution if the residual mean deviance was <1 for the full model (i.e. the model including treatment) or (2) a pseudo F-statistic obtained as the ratio of the change in deviance from the full model. All analyses were done in ASReml-R (Butler et al. 2009).

The long-term telemetry data (Experiment 2) comprised an irregularly spaced time-series (range 30.4–213.1 d) and varying numbers of detections (range 2 423–17 810) for each of the nine fish. Initial scatterplots verified that formal modelling should be limited to observations within the first 10 d after release. This was done using a semi-parametric modelling approach on log(time), which allows cubic smoothing splines to be embedded within an LMM framework and facilitates modelling of both treatment and individual splines (Verbyla et al. 1999). Each model included an overall effect, as well as terms for both treatment effects (with four levels: control — 5 m; untreated — 20 m; vented — 20 m; and recompressed — 20 m) and individual splines for each fish. The tests of significance for spline components of variance were completed using ASReml-R likelihood-ratio tests, whereas Wald-type tests were used for examining the significance of the effect of treatment on the linear component of the splines.

Results

Experiment 1: clinical signs of barotrauma and short-term mortality

A mean salinity of 31.6 (SD 0.2) and mean dissolved oxygen of 8.4 mg l^{-1} (SD 0.4) remained fairly constant over depth and time. Air and water temperatures varied temporally, with warmer temperatures occurring in the afternoon (Figure 2). There were small differences in water temperature among depths, with the largest daily fluctuations consistently occurring at 1 and 3.5 m below the surface (Figure 2).

None of the 10 *A. japonicus* (mean 55.0 cm TL; SD 2.3) euthanised on the first day of the experiment had clinical signs of barotrauma. Similarly, none of the controls ($n = 30$; 54.7 mm TL; SD 2.1) or fish at 20 m ($n = 70$; 54.4 cm TL; SD 2.6) had exophthalmia, negative oculogyration reflex or

Table 1: Summary of detections recorded on the VR2W receivers (see Figure 1) over 214 d for *Argyrosomus japonicus* retrieved from 5 m (control fish) or 20 m and released into Port Jackson, Sydney, Australia, during Experiment 2. After retrieval, each fish was tagged with an acoustic transmitter and then two of each were either: (1) released immediately at the surface untreated, (2) lowered to 20 m using a weighted line and recompressed or (3) vented with a hypodermic needle prior to release at the surface.

Fish	Depth (m)	Treatment	Number of detections	Receiver				Depth (m)		Last detection	
				Day 1	Days 2–5	Days 6–20	Days 20+	Mean ± SD	Range	Day	Receiver
1	5	Untreated	2 423	MS, 3	3	1–5	1–4	18.1 ± 4.0	3.7–29.5	40	4
2	5	Untreated	8 143	MS, 3	4	1–4	1–5	20.1 ± 3.8	4.8–31.0	75	4
3	5	Untreated	8 217	MS, 3	3	1–4	3–4	14.1 ± 5.2	2.4–30.6	31	4
4	20	Untreated	3 734	MS, 4	4	ND	2–7	17.4 ± 4.8	1.1–31.4	101	6
5	20	Untreated	3 497	MS, 1–2	ND	1–4	1–5	16.0 ± 3.6	3.1–27.7	53	3
6	20	Vented	13 790	MS, 4–5	5	5	5	15.2 ± 1.6	4.2–20.4	43	5
7	20	Vented	4 212	MS	4	ND	2–5	20.1 ± 5.9	0.2–31.7	75	4
8	20	Recompressed	5 677	MS, 3	3	3	1–3	17.9 ± 3.4	4.4–27.5	64	2
9	20	Recompressed	17 810	MS	1–2	1–4	1–7	17.6 ± 5.0	1.5–31.2	214	4

MS = temporary receiver located at the monitoring/release site for 2–3 h after release

ND = no detections. Acoustic transmitters emitted a signal every 90–210 s for 214 d corneal and subcutaneous gas bubbles, and none of the 20 necropsied fish (n = 10 from each depth) had displaced organs or haemorrhaging of the liver, kidney or coelomic cavity.

Irrespective of depth, all fish had a distended coelomic cavity, but those retrieved from 20 m had significantly greater body width increases than the control fish (predicted means of 0.2 vs 0.1 cm; p(deviance) < 0.001). In addition, all fish retrieved from 20 m had a prolapsed cloaca, 81% had subcutaneous congestion and haemorrhages along the ventrum between the gills and anus, 70% had gastric herniation into the buccal cavity and 50% had swimbladder ruptures, which ranged from 1.2–4.0 cm (mean 2.2 cm; SD 0.5) in length (Figure 3e, f). These clinical signs occurred at a significantly greater rate than among control fish (0%) (p(deviance) < 0.001).

Upon retrieval, none of the control fish from 5 m and 65.7% of the fish from 20 m displayed altered buoyancy (i.e. swimming sideways or inverted; p(deviance) < 0.001). Venting the fish from 20 m effectively removed buoyancy complications for most individuals (88%) (i.e. similar to controls; p(deviance) < 0.001). Although not formally quantified, immediately after retrieval all controls appeared more active (i.e. swimming around their 110-litre cage and live-well during observations) and were more difficult to handle during measuring and condition assessment than those from 20 m.

Immediately after being placed into the bathy-cages, all but one fish (untreated) released at the surface swam down slowly (i.e. >5 m within 5 s). The untreated fish remained in lateral recumbency and motionless on the surface for 180 s, before slowly regaining their righting reflex and swimming down vertically. The same fish and another untreated individual were found dead and floating on the surface within 6 h of release into cage 1 (replicate 1), providing non-significant total mortalities of 3.3% for fish

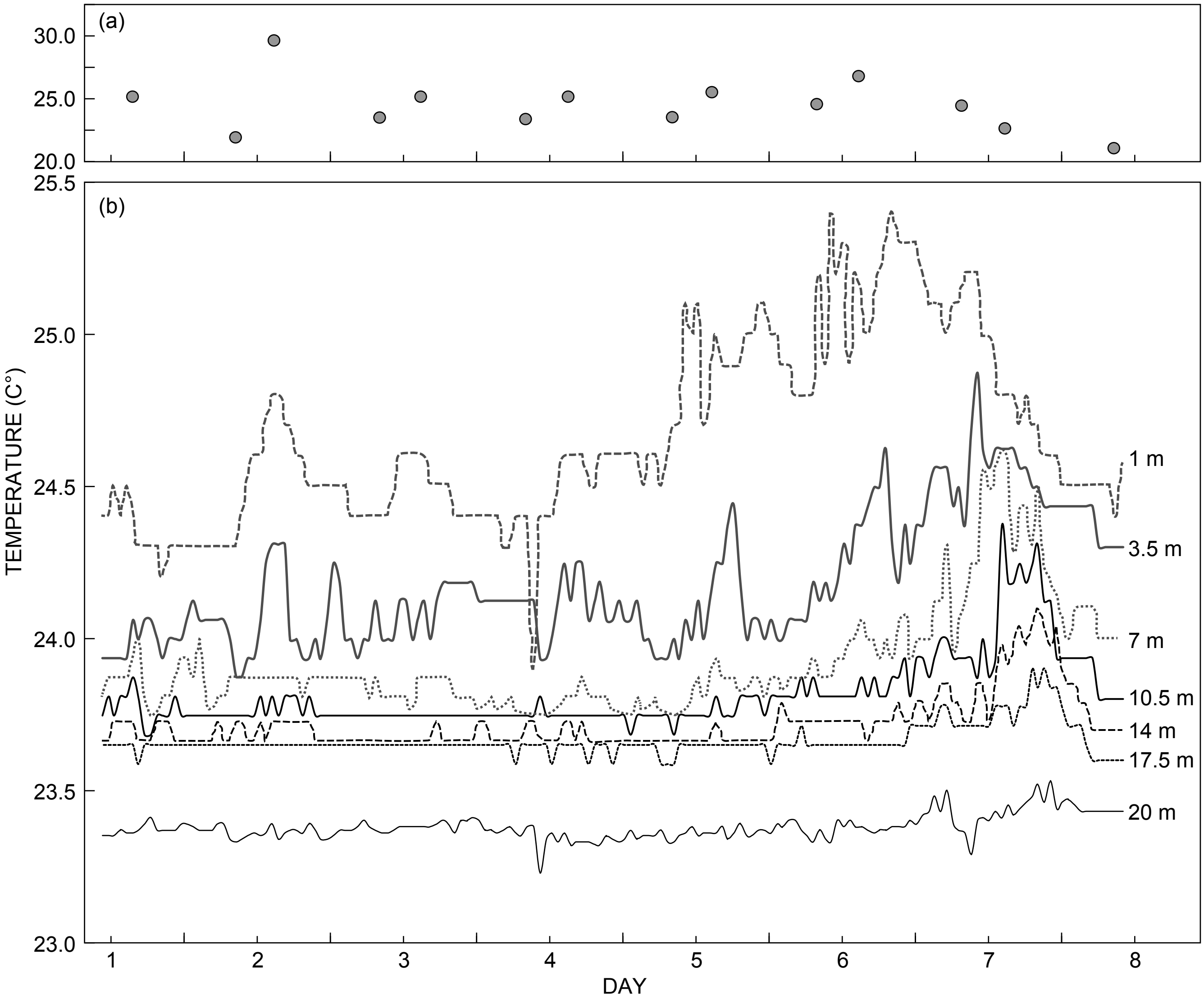


Figure 2: Variations in (a) air and (b) water temperatures during Experiment 1. Air temperatures were recorded daily at 09:00 and 15:00 and water temperatures hourly at 1.0, 3.5, 7.0, 10.5, 14.0, 17.5 and 20.0 m

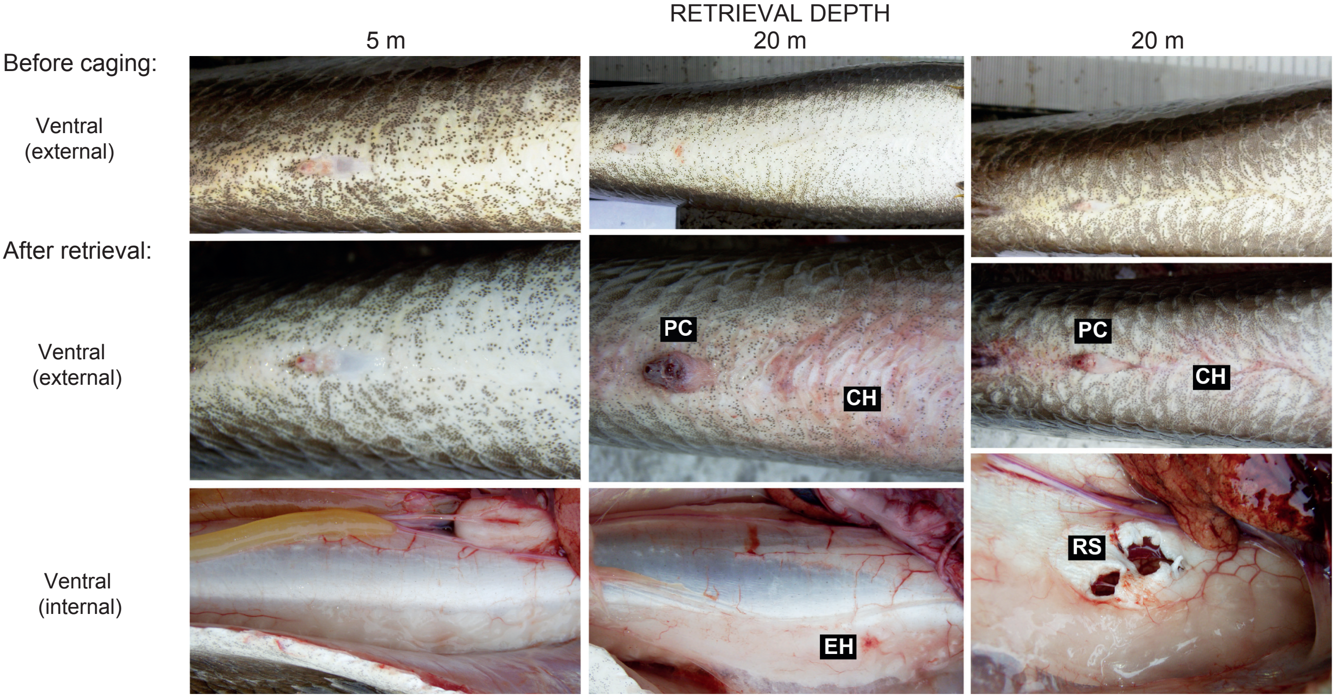


Figure 3: Ventral view of *Argyrosomus japonicus* before caging and after retrieval from 5 and 20 m. Note the associated prolapsed cloaca (PC) and cutaneous haemorrhages (CH), ruptured swimbladder (RS) and echymotic haemorrhages (EH) into the swimbladder wall in fish retrieved from 20 m

hauled from 20 m and 10.0% for those that were released untreated (Fisher's exact test, $p > 0.05$ for both). Both dead fish had a distended coelomic cavity (as evidenced by increases of 0.2–0.3 cm in their body width after retrieval), a prolapsed cloaca, cutaneous haemorrhages and a ruptured swimbladder (2.0 and 3.0 cm long respectively). At the end of the experiment, all vented and recompressed fish had very small lesions (that seemed to be healing) at the puncture sites.

Experiment 2: long-term assessment

After retrieval, none of the three control fish (mean 54.2 cm TL; SD 2.5) showed any external clinical signs of barotrauma. But, as in Experiment 1, all six fish hauled from 20 m (54.3 cm TL; SD 2.0) had a prolapsed cloaca and widespread congestion and/or petechial to echymotic haemorrhages along the ventrum between the gills and anus, and four fish (66.6 %) had moderate gastric herniation into the buccal cavity. Compared with all control fish, those retrieved from 20 m also had significantly wider bodies (predicted means of 0.1 vs 0.3 cm; p(deviance) < 0.001).

Depth affected the buoyancy of fish after retrieval, with all controls orientated upright, but three fish (50%) from 20 m remained on their sides. These three disorientated fish were then tagged and either released untreated (fish 4), vented (fish 7) or recompressed (fish 9). The untreated fish spent one minute at the surface before swimming away slowly, whereas the vented individual regained normal orientation and swam away, but not towards the bottom (see below), and the recompressed fish was released successfully (i.e. displayed normal behaviour). The remaining two individuals (fish 5 and 6) released at the surface swam away slowly and generally towards the bottom, and the other recompressed fish (fish 8) was released successfully.

A total of 67 503 detections from all nine fish were recorded on receivers 1–7 over the 214 d study period (Table 1; Figures 1, 4, 5). During this period, the mean (17.1 m; SD 2.0) and range (0.2–31.4 m) of depths detected were similar among fish, but varied daily (Figures 4, 5). Scatterplots of the first 12 h suggest that most fish orientated at a distinct depth within 2–4 h of release (Figure 4a). Two controls (fish 1 and 2) initially swam at depths of between 12 and 24 m and the other (fish 3) was detected at 12 m before returning to 4.0–7.0 m for the first 90 min after release (Figure 4). The untreated fish retrieved from 20 m occupied various depths, with fish 4 detected at between 3.0 and 12.0 m and at 23.3 m, 90 min later, before returning to shallower depths (Figure 4b). The other untreated fish (fish 5) was detected at between 14.0 and 22.0 m at the release site and at between 11.0 and 22.9 m at receiver 1, just 4 h later (Table 1; Figure 4b).

The vented fish remained at much shallower depths than the untreated fish immediately after release (Figure 4c). Specifically, fish 6 swam at between 0.2 and 2.4 m below the surface before moving away from the release site after 15 min and was not detected again until day 2 at receiver 4, where it remained for the next 43 d across a constant depth range until its last detection (Table 1; Figures 4c, 5f). The other vented fish (fish 7) remained at between 5.5 and 6.5 m for 17 min before being recorded on receivers 4 (1.5 km downstream) and 5 (3 km downstream) after 60 and 100 min respectively (Table 1, Figures 4c, 5g). The two recompressed fish released at 20 m immediately returned

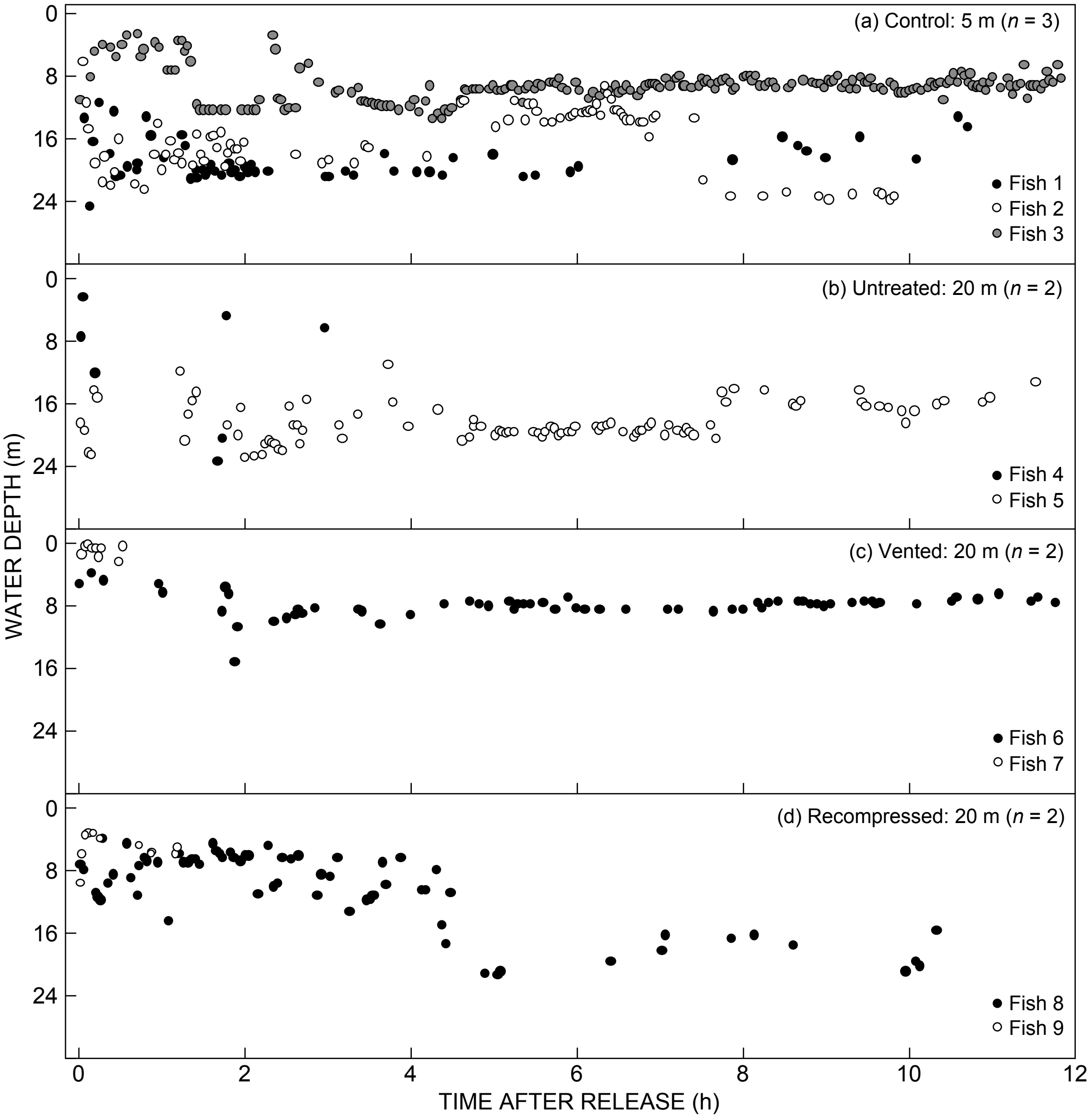


Figure 4: Depth patterns of nine *Argyrosomus japonicus* during the first 12 h after being retrieved from (a) 5 m ($n = 3$ termed 'controls') or (b–d) 20 m ($n = 6$), tagged with an acoustic transmitter and released into Port Jackson either: (1) immediately at the surface untreated (all controls — (a) and two fish retrieved from 20 m — (b)); (2) vented with a hypodermic needle prior to release at the surface (two fish retrieved from 20 m — (c)); or (3) lowered to 20 m using a weighted line and recompressed (two fish retrieved from 20 m — (d)). The acoustic transmitters emitted a signal every 90–210 s for 214 d. The different shaded circles on each graph indicate individual fish (see Table 1)

to shallower depths (3.0–16.0 m) for up to 4 h post release (Figure 4d). One individual (fish 9) spent the first 50 min at the release site and was not detected again until day 5 at receivers 2 (1 km upstream) and 1 (3 km upstream) (Figures 4d, 5i).

When considered collectively within treatments over the first 10 d, there was a significant main effect of the treatment of fish on their vertical distribution (i.e. intercept at log(time) = 0; LMM, p(deviance) < 0.01; Figure 6). Specifically, controls occupied greater depths (predicted mean 26.9 m; SE 1.6) than either vented (17.9 m; SE 5.2), recompressed (17.3 m; SE 0.2) or untreated (12.2 m; SE 4.2) fish (Figure 6).

Despite the abovementioned differences, the obvious external signs of barotrauma and the likelihood of internal damage to fish retrieved from 20 m (i.e. ruptured swimbladders), all tagged individuals survived over the medium term (Table 1, Figure 5). The time from release until the last detection for each fish varied between 30.4 and 213.1 d (mean 77.3 d, SD 18.5; Table 1; Figure 5). Despite the close proximity of the receivers, only one fish (recompressed — fish 9) was detected regularly throughout the study period; all others were detected for fewer than 101 d (Figure 5). One untreated fish retrieved from 20 m (fish 4) was caught and retained by an angler at receiver 6, 101 d after being released (Table 1; Figure 5d).

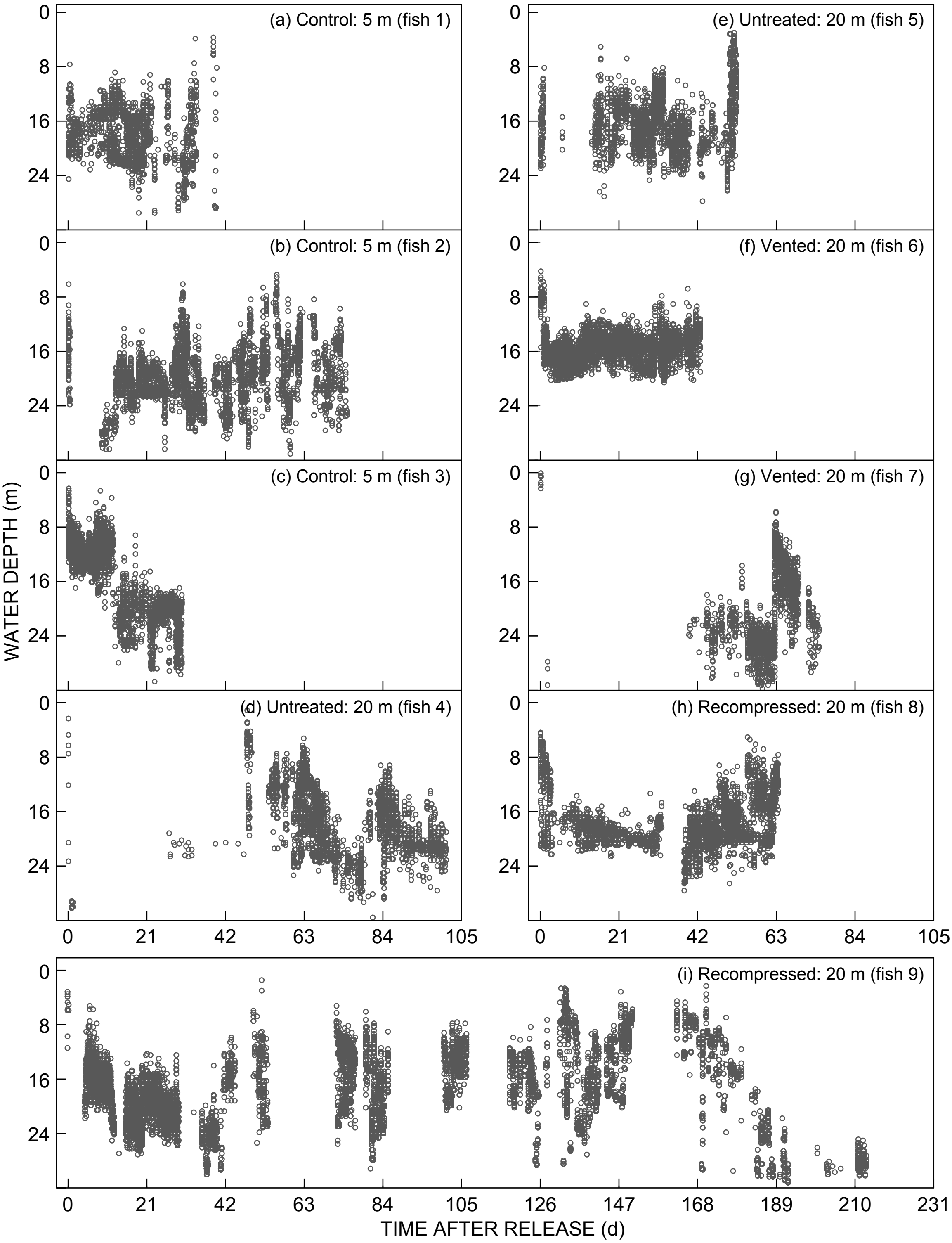


Figure 5: Depth (m) patterns and time to last detection of nine *Argyrosomus japonicus* after being retrieved from (a–c) 5 m (termed 'controls', *n* = 3) and (d–i) 20 m (*n* = 6) and released into Port Jackson either: (1) immediately at the surface untreated (controls and two fish retrieved from 20 m — (d) and (e)); (2) vented with a hypodermic needle prior to release at the surface (two fish retrieved from 20 m — (f) and (g)); or (3) lowered to 20 m using a weighted line and recompressed (two fish retrieved from 20 m — (h) and (i)). The transmitters emitted a signal every 90–210 s for 214 d. Individual fish histories are provided in Table 1

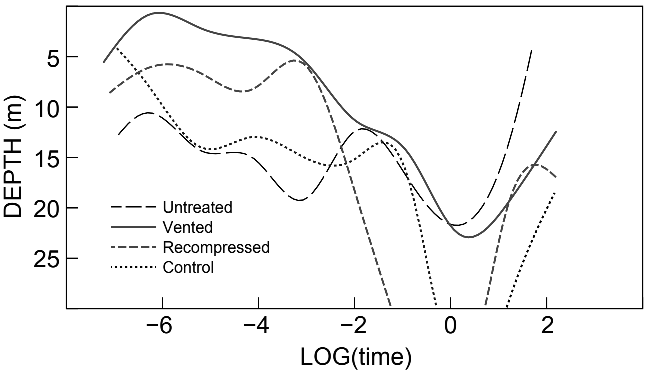


Figure 6: Predicted mean depths of control (5 m), and vented, recompressed or untreated *Argyrosomus japonicus* (20 m) over the first 10 d after release

Discussion

The physical impacts of barotrauma on *A. japonicus* were similar to those recently observed for a congeneric (*A. inodorus*; Kerwath et al. 2013), but relatively mild compared to those for other teleosts retrieved across similar depths, including another Australian sciaenid, *Protonibea diacanthus* (Phelan 2008). Specifically, only one internal and four external clinical signs were recorded for *A. japonicus* from 20 m, whereas other affected teleosts often have more than 10 signs, including compressed, displaced or everted organs, gas embolisms and exophthalmia (Feathers and Knable 1983, Rummer and Bennett 2005, Jarvis and Lowe 2008, Phelan 2008). These differences might suggest that, at a broad level, *A. japonicus* is relatively robust, but as for many species (e.g. Rummer and Bennett 2005, Rogers et al. 2008, Kerwath et al. 2013), most of the clinical signs were clearly depth-related and so it is possible that impacts would be exacerbated among individuals retrieved from deeper water.

It is also important to consider that, whereas most of the clinical signs were temporary and reversible, some still could indirectly contribute towards additional mortality (Butcher et al. 2010). For example, fish with buoyancy complications (often lasting up to 16–24 h) are vulnerable to predation, injury from moving boats and/or sun exposure (Feathers and Knable 1983, Gravel and Cooke 2008). Although all fish released at the surface in both experiments swam away slowly, one untreated individual remained buoyant and on its side for 3 min after release into the cages. Several pelicans *Pelecanus conspicillatus* subsequently attempted to pursue the fish, but were prevented from doing so by the cages. Similar behavioural problems were observed for the two untreated fish from 20 m in Experiment 2, both of which were unable to control their buoyancy for the first 2–4 h after release, before being detected at varying depths. These latter fish also remained at significantly shallower depths than their vented and recompressed conspecifics. Conceivably, any such fish could be vulnerable to large avian predators, including cormorants *Phalacrocorax carbo*, which frequently are observed close to boats and can dive to 20 m (White et al. 2008). Sharks and dolphins might pose a similar predation threat.

Considering that two untreated fish died in Experiment 1, the above results might support the preferential release of fish via venting and recompression, but these methods were not without complications. Specifically, although venting and recompression techniques both removed immediate buoyancy complications, all fish were detected at or near the surface soon after release (and shallower than controls), possibly as a consequence of perforated swimbladders and associated buoyancy complications. Both of the tagged, vented fish swam away slowly, but could be seen just below the surface. Further, although not observed in our study, venting can cause mortality if the appropriate procedure is not used (Rummer and Bennett 2005, Jarvis and Lowe 2008, Roach et al. 2011), and even when done correctly, fish may still not achieve gas homeostasis (Butcher et al. 2012).

Notwithstanding the abovementioned short-term impacts, after 10 d fish appeared to return to their normal behaviour, with similar vertical movements (i.e. residing mostly in deep water, but with shallower forays) to those recorded for both hatchery-reared and hooked wild-caught conspecifics during a study evaluating key habitats and home ranges in the Georges River (located 30 km south of the current study site; Taylor et al. 2006). In our study, such movements might be consistent with the resolution of barotrauma, including a repaired swimbladder. Such temporal repair is within the variable range reported for several other species of between one day (e.g. cod *Gadus macrocephalus*, Nichol and Chilton 2006) and eight weeks (*Lota lota*, Bruesewitz et al. 1993), but more often less than two weeks [e.g. rainbow trout *Oncorhychus mykiss* (Bellgraph et al. 2008), perch *Macquaria ambigua* (Hall et al. 2013) and the seabream *Pachymetopon blochii* (Kerwath et al. 2013)].

The relatively short horizontal movements of fish (all detections were recorded between receivers 1 and 7, i.e. within 6 km of the release site) also support the notion that normal behaviour was rapidly resumed in the fish under study. Although tagged *A. japonicus* can travel up to 400 km after release, the site fidelity observed in our study is more characteristic of this species (Griffiths 1996, Griffiths and Attwood 2005, Taylor et al. 2006). For example, Taylor et al. (2006) reported that 12 tracked *A. japonicus* (38–73 cm TL) had relatively small home ranges of between 3 260 and 9 200 m^2, but that there was a distinct positive correlation between fish TL and distance travelled. These fish utilised up to three core areas and generally returned to the same hole each day. Similarly, Griffiths and Attwood (2005) found that most (71% of 73 individuals) *A. japonicus* were recaptured within 3 km of their tagging site off the south-west coast of South Africa.

Whereas this study has provided important information about the fate of released *A. japonicus* after incurring barotrauma, there are at least three important caveats. First, the work was limited to assessing isolated impacts from a uniform depth. Beyond the potential for some positive correlation between depth and impacts discussed above, under conventional angling, other unassessed factors and especially the anatomical hook location, surface interval and variable environmental conditions could exacerbate the observed clinical signs and behavioural responses

(Butcher et al. 2007, Phelan 2008, Hall et al. 2013, Kerwath et al. 2013). Second, like many other studies incorporating biotelemetry, large costs precluded extensive replication (Voegeli et al. 2001, Cooke et al. 2004). We attempted to address this issue by first using a replicated confinement study to examine broad short-term impacts and then longer-term consequences using the more expensive biotelemetry (following Brown et al. 2010, Butcher et al. 2010, Roberts et al. 2011). Third, to achieve sufficient replication in the first experiment, we used hatchery-reared fish and experimentally induced barotrauma with the assumption of few differences in physiological and/or behavioural responses compared to angled fish in the wild (Taylor et al. 2006). However, given that adequate controls were used, such a caveat may not be of particular importance in terms of comparing the relative utility of different handling methods designed to alleviate barotrauma (Hall et al. 2013).

Despite the abovementioned assumptions, and although the relationship between depth and the extent of barotrauma in *A. japonicus*, as well as subsequent effects, remain unknown, optimum handling methods can be specifically proposed (Butcher et al. 2012, Hall et al. 2013). Fish that have obvious barotrauma (as evidenced by a prolapsed cloaca) should be left untreated and immediately released (provided there are no predators known to be present). In the presence of predators, or if fish remain floating on the surface, recompression by returning to depth with a release weight would be appropriate. Venting should be used only as a last option, because of the potential for negative effects (Rummer and Bennett 2005, Jarvis and Lowe 2008).

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