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Abstract

Yellowtail kingfish (Seriola lalandi) are angled throughout their global distribution and released in large numbers under the unsubstantiatedassumption of few impacts. The validity of this supposition was tested for southeastern Australian stocks. In all, 54 fishwere angled and released into cages with 36 controls and monitored for 5 d. Of the angled fish, 15% died, mostly as a consequenceof gill-hooking and the associated physiological and mechanical damage. A biotelemetry experiment was then performed to determineif cutting the line on gill-hooked fish could improve their post-release fate. The attachment of transmitters was validated in anaquarium experiment before 12 jaw- and 10 gill-hooked fish were tagged, released, and tracked. One gill-hooked fish was detectedmotionless within 10 min, and another was last detected 7 min after release; both presumed dead. No jaw-hooked fish died withinthe first 24 h. The remaining fish were last detected between 3 and 49 d after release and, apart from subtle differences in theirshort-term responses, maintained similar wide-ranging movements and accelerations. The results justify cutting the line on deephookedfish to minimize post-release mortality and illustrate the utility of combining confinement and biotelemetry studies toassess the fate of released fish.

Keywords

Using, multi, experimental, approach, assess, fate, angled, released, yellowtail, kingfish, Seriola, lalandi

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Using a multi-experimental approach to assess the fate of angled-and-released yellowtail kingfish (*Seriola lalandi*)

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Yellowtail kingfish (*Seriola lalandi*) are angled throughout their global distribution and released in large numbers under the unsubstantiated assumption of few impacts. The validity of this supposition was tested for southeastern Australian stocks. In all, 54 fish were angled and released into cages with 36 controls and monitored for 5 d. Of the angled fish, 15% died, mostly as a consequence of gill-hooking and the associated physiological and mechanical damage. A biotelemetry experiment was then performed to determine if cutting the line on gill-hooked fish could improve their post-release fate. The attachment of transmitters was validated in an aquarium experiment before 12 jaw- and 10 gill-hooked fish were tagged, released, and tracked. One gill-hooked fish was detected motionless within 10 min, and another was last detected 7 min after release; both presumed dead. No jaw-hooked fish died within the first 24 h. The remaining fish were last detected between 3 and 49 d after release and, apart from subtle differences in their short-term responses, maintained similar wide-ranging movements and accelerations. The results justify cutting the line on deep-hooked fish to minimize post-release mortality and illustrate the utility of combining confinement and biotelemetry studies to assess the fate of released fish.

Keywords: angling, gills, post-release mortality, *Seriola lalandi*, telemetry, yellowtail kingfish.

Introduction

The yellowtail kingfish (*Seriola lalandi*) is a pelagic, cosmopolitan species, distributed throughout subtropical and temperate coastal waters (Gillanders *et al.*, 2001; Poortenaar *et al.*, 2001). In Australia, they are found from southern Queensland to central Western Australia where, as in other parts of their distribution, they are targeted by anglers (Saul and Holdsworth, 1992; Stewart *et al.*, 2004). There are no recent formal estimates of the Australian recreational catches of yellowtail kingfish, although Henry and Lyle (2003) estimated a total catch of >255 000 *Seriola* spp., most of which were yellowtail kingfish. Owing mainly to size limits and/or personal quotas (45–65 mm total length, TL, and 2–10 fish d^{-1} for yellowtail kingfish), almost 55% of all *Seriola* spp. were released (Henry and Lyle, 2003).

Such proportionally large rates of release are typical among many other internationally and locally important recreational teleosts and have resulted in many studies aiming to quantify the associated lethal and sublethal impacts and to identify strategies by which these can be minimized (for reviews, see Muoneke and Childress, 1994; Cooke and Suski, 2005; Arlinghaus *et al.*, 2007). Despite their global distribution and popularity, there is no similar published information in the primary literature for yellowtail kingfish. This deficit needs to be addressed to ensure effective management and conservation of the stocks (Gillanders *et al.*, 2001; Stewart *et al.*, 2004).

Research done with other angled-and-released species has shown that their fate often is strongly affected by the cumulative impacts of many factors, including hook type, landing methods, handling during hook removal, and time out of water (Muoneke and Childress, 1994; Arlinghaus *et al.*, 2007). Of these factors, hook type is among the most important because it usually determines the depth of hooking (mouth or stomach), which has a consistent negative impact on welfare (Arlinghaus *et al.*, 2007). More specifically, for many species, there is a clear positive relationship between the depth of hooking and fatality that is further exacerbated by the removal of ingested hooks. Often simply addressing this last issue, e.g. by cutting the line and leaving the hook in place, can significantly improve the overall fate of angled-and-released fish (Broadhurst *et al.*, 2007; Butcher *et al.*, 2007).

Usually, the impacts of the above factors on post-release mortality have been identified through short-term (<10 d) field- or aquarium-based confinement studies (Bartholomew and Bohnsack, 2005; Arlinghaus *et al.*, 2007). This approach usually involves angling fish according to either conventional or predetermined treatments, releasing them into floating cages or tanks (often along with controls), then monitoring their progress. Although cost-effective and conducive to large sample sizes that are statistically robust, confinement studies can underestimate treatment effects, especially beyond the short term. Of major

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concern is that, unlike fish that are released back into the wild, confined individuals are protected from the consequences of impaired behaviour that might normally reduce their ability to acquire prey and/or increase their predation (Danylchuk *et al.*, 2007; Butcher *et al.*, 2010).

Currently, the only methods available for comprehensively assessing the long-term fate of angled-and-released fish in the wild involve traditional mark–recapture (i.e. fish being tagged and recaptured) and, more recently, biotelemetry (i.e. fish being tagged with transmitters that archive or relay information to receivers; Cooke *et al.*, 2004; Donaldson *et al.*, 2008). Provided there are sufficient tag returns, mark–recapture studies can estimate mortality, although mostly without discrimination among the causal factors (i.e. natural or angler-induced; Davis, 2002). Another constraint of mark–recapture work is that it does not allow for the fine-scale assessment of temporal and spatial movements, and hence the behaviour of released fish (Pollock and Pine, 2007; Donaldson *et al.*, 2008).

By continuously monitoring individual fish, biotelemetry addresses most of the limitations listed above (Donaldson *et al.*, 2008). However, like confinement and mark–recapture approaches, biotelemetry has important experimental considerations, including the assumption of no effects on fish associated with attaching often relatively large transmitters (relative to body size), and the very high cost of the equipment (Cooke *et al.*, 2004; Pollock and Pine, 2007; Donaldson *et al.*, 2008). The potential for confounding effects of transmitters on fish can be investigated via appropriately controlled experiments, similar to tag-retention studies done as a prelude to mark–recapture work (e.g. Ward *et al.*, 2008). The price of equipment, and particularly transmitters, is of greater consequence and typically means that replication is relatively low, which can prevent the detailed assessment of fish beyond a restricted range of treatments.

One coherent multi-experimental approach to maximizing the benefits of biotelemetry within limited replication might involve first using confinement studies to obtain general information on the key factors influencing short-term mortality and to identify the upper and lower extremes in treatments (e.g. Butcher *et al.*, 2010). Fish could then be subjected to either treatment, tagged with transmitters, and monitored to provide a comparative assessment of their longer-term movements and behaviour. Such insight could contribute towards a better understanding of the range and duration of impacts to released fish in the wild. We sought to apply this approach in the present study, to assess the fate of angled-and-released yellowtail kingfish, and to identify methods by which negative impacts might be minimized.

Material and methods

The study was carried out in New South Wales (NSW), Australia, between November 2008 and July 2009, and it consisted of (i) a field-based, confinement experiment to assess the short-term (up to 7 d) mortality and key causal effects of conventionally angled-and-released yellowtail kingfish, (ii) an aquarium experiment to determine the most appropriate method of attaching biotelemetry tags, then based on the results from above, (iii) a biotelemetry experiment to monitor yellowtail kingfish (for up to 64 d) in the wild after being subjected to two identified extremes of angling-and-release treatments.

Up to 1 month before starting the first experiment, 130 yellowtail kingfish (450–800 mm TL) were caught by boat-based anglers fishing off Coffs Harbour (30°18′S 153°09′E). Any mouth-hooked fish in a good physical condition (i.e. no fin, scale, or hook damage other than a small lesion) were placed into oxygenated 360-l tanks and transported to the National Marine Science Centre (NMSC), where they were distributed among three aerated, flow-through (5 l min^{-1}) 3800 l tanks. All fish were fed pieces of Australian sardine (*Sardinops neopilchardus*) and monitored daily for mortality before being used in experiments 1 and 2 below.

Experiment 1: evaluating the short-term fate of yellowtail kingfish during conventional angling and release

The first experiment was performed over 8 d and involved 18 boat-based anglers and six cylindrical sea cages (2.3 m in diameter, 2.5 m deep, and sufficient to hold ~100 kg of fish; for more detail, see Butcher *et al.*, 2006) anchored in Chowder Bay (33°50′S 151°16′E) near the entrance to Port Jackson (Figure 1). **Q2** One month before the experiment, 36 yellowtail kingfish were transferred (as above) from the NMSC to the Cronulla Fisheries Research Centre (CFRC), where they were distributed between two 5000-l tanks (supplied with air and water as above). On the day before the fishing event, the same 36 fish were relocated (as above) to Chowder Bay, tagged with a numbered, 55-mm yellow t-bar tag (Hallprint Ltd, Adelaide, Australia) for identification as controls, then distributed among the cages ($n = 6$ fish cage^{-1}).

On the following day, anglers were asked to use conventional gear to target all sizes of yellowtail kingfish then immediately to place their fish into a covered water-filled 110-l polyvinyl chloride (PVC) bin and to complete a data sheet. The data requested included: line strength (kg); bait type; hook configuration (single or treble) and point (barbed or barbless); time of capture; approximate duration of playing time and air exposure (s); type of landing net (knotted or knotless), if used; anatomical hook location and whether or not the hook was removed; if the fish was dropped; how (bare hands, cloth, or pliers/jaw grips) and where (on the body) it was restrained; and if it bled from the hook wound (presence or absence of blood) or had any associated damage (around the eye, mouth, gills, or elsewhere).

Boat-based researchers travelled to the angler and collected their data. If possible, water temperature (°C), salinity (psu), and dissolved oxygen (mg l^{-1}) were recorded from the angler's holding bin and 50 cm below the water surface in Port Jackson using an Horiba U10 water-quality meter (Kyoto, Japan). The fish were then removed in a 1-m polyvinyl sling (for detail, see Butcher *et al.*, 2008a) filled with water, checked for scale loss and fin damage, and placed into a 380-l fibreglass holding tank without exposure to air. Each fish was transported to one of the monitoring cages, again placed in a water-filled polyvinyl sling, marked with a t-bar tag, then released. Researchers recorded the time each fish was collected from the angler and released into the monitoring cage, and its tag and cage number.

All caged fish were fed Australian sardine daily and monitored for mortality over 5 d. Water quality (as above) was also checked daily. At the end of the experiment, all fish were measured (TL) and a 1-ml blood sample was taken from 12 randomly selected fish (six controls and six treatments) from three sea cages (4 fish cage^{-1}) according to the methods described by Broadhurst *et al.* (2005). A further six fish were angled on the same day, and a 1-ml blood sample was taken within 1 min of hooking. Blood samples were assessed for glucose (mmol l^{-1}) or lactate (mmol l^{-1}) by a hand-held glucose meter (Accutrend plus glucose and lactate meter; Roche Diagnostics, Australia). The hypothesis of no differences in the concentrations of these

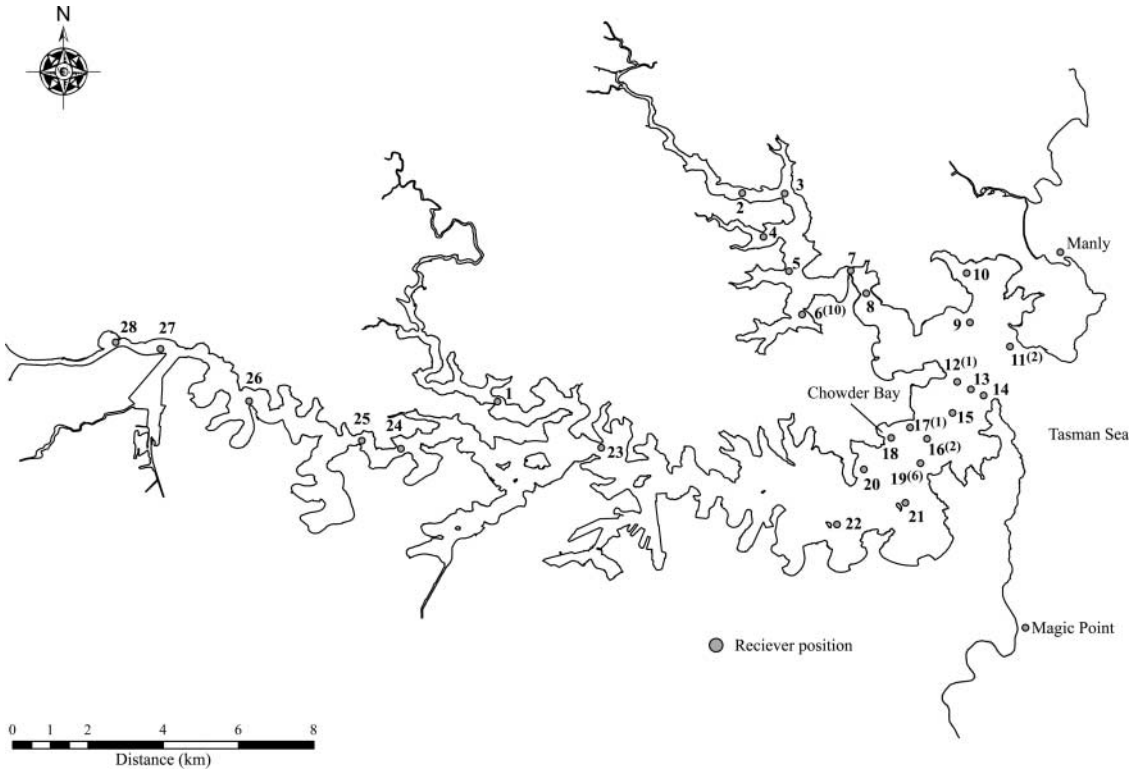

Figure 1. Locations of the monitoring site in Chowder Bay (experiment 1), 28 acoustic receivers throughout Port Jackson (experiment 3), and the additional receivers at Manly and Magic Point that detected tagged yellowtail kingfish, *S. lalandi*. The six release sites for the 22 tagged fish in experiment 3 are shown in parenthesis and indicate the number of fish released within 200 m of that receiver. Receivers 10, 11, and 13 were not recovered at the end of the experiment. **Q2**, **Q3**

factors within and between treatment and control fish as a result of being held in cages, or any differences between these groups and fish that were angled and immediately sampled from Port Jackson at the end of the experiment, was tested using one-factor analysis of variance (ANOVA). As variances could not be homogenized through data transformation, ANOVA was considered significant at $p = 0.01$.

The independence of the treatment of fish and the numbers surviving in the cages after 5 d was investigated using Fisher's exact test. All data describing the capture and handling of each angled fish were collated as either categorical or continuous factors. To investigate the influence of some of these factors on initial mortality, they were included with the random factors "days", "cages", and "anglers" in generalized linear mixed models (GLMMs) with a logit link and binomial error distribution. Models were fitted using the ASReml function within the R statistical package, with the random factors included in all models, even if not statistically significant (Butler *et al.*, 2007; R Development Core Team, 2008). The significance of fixed effects was assessed using Wald-type statistics.

Experiment 2: validating the retention of biotelemetry tags

This work was done to determine the most appropriate method of quickly attaching biotelemetry transmitters to yellowtail kingfish for eventual application during experiment 3. One oral and three external methods were explored using 50 small cylinders made from polyoxymethylene rod, identical in weight (3.3 and 6.3 g in water and air, respectively) and overall dimensions (46 and 9 mm in length and diameter, respectively) to the biotelemetry transmitters (model no. V9AP-2H, Vemco Ltd, NS, Canada; Figure 2). In all, 15 of these dummy transmitters were attached to a single, 80-mm plastic-tipped polyethylene dart tag (Hallprint Ltd) with epoxy resin and 12 mm black polytetrafluoroethylene tubing (termed single-dart tags; Figure 2a). Of the remaining 35 dummy transmitters, ten were similarly attached to two dart tags (one at either end and termed double-dart tags), and another ten were secured to a 5-mm self-locking plastic strap (termed tail tags); the remaining 15 were not attached to anything (termed stomach tags; Figure 2b and c).

The first part of the aquarium experiment was done to assess the fate of fish subjected to single-dart and stomach tagging, along with their appropriate controls. On the first day, 45 yellowtail kingfish were randomly scooped with a knotless net from three 3800-l tanks and measured for TL before being placed ventrally into a split foam block (0.7 × 0.3 × 0.3 m) and subjected to either tagging method or not being tagged at all (controls). The single-dart method involved using an applicator to insert the barb into muscle tissue ~20 mm below the fourth dorsal pterygiophore. Stomach tags were placed into a 300-mm flexible vinyl tube (12 mm diameter), which was then pushed into the stomach of the fish, through the mouth. A rod, 400 mm long and 10 mm diameter, was inserted into the vinyl tube to expel the tag (Bridger and Booth, 2003). After being tagged, the treatment fish were released along with the controls into three separate 3800-l tanks

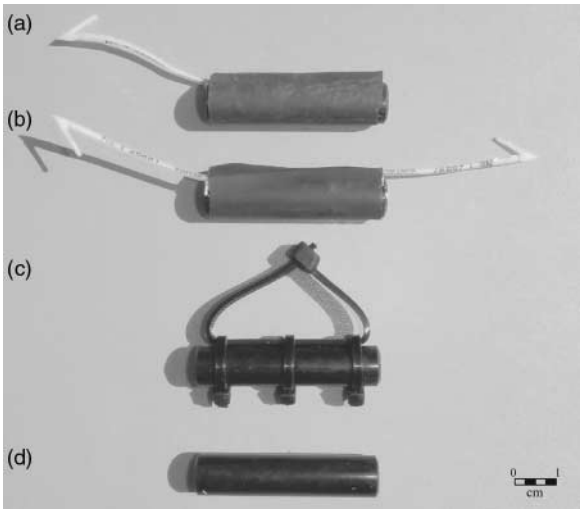

Figure 2. Dummy transmitter attachment methods used during experiment 2: (a) single-dart, (b) double-dart, (c) tail tag, and (d) stomach.

($n = 5$ fish per treatment and control group) and monitored over 23 d for mortality, presence or absence of feeding, loss of tag, and clear swimming impairment.

In addition to daily random observations during feeding, assessments of the last three factors were achieved during separate 8-h periods (08:00–16:00) using two Swann N3960 submersible cameras. The cameras were located 50 mm below the surface of each tank on alternate days, supported by 20-mm PVC pipe mounts which provided a recording field of view of 120°.

The second part of the experiment repeated the same methodology as above, but using ten replicates of the double-dart and tail tags and their controls. The anterior dart of the double-dart configuration was inserted at the same location as the single-dart tag, with the second dart located at the same distance below the backline towards the posterior of the fish, allowing the transmitter to lie laterally along the skin. The tail tags were positioned around the caudal peduncle with a 5-mm self-locking plastic strap. As above, a further ten fish were removed and used as controls ($n = 5$ fish group^{-1} tank^{-1}). All fish were monitored as above, but for 64 d and using three 8-h camera periods.

Experiment 3: using biotelemetry to monitor the fate of released jaw- and gill-hooked yellowtail kingfish

Two days before starting the work, 28 acoustic receivers (model VR2W, Vemco Ltd) were deployed throughout Port Jackson, with most placed at known aggregation sites of yellowtail kingfish (receivers 2–22; Figure 1). The receivers were secured at depths of 4–20 m by either attaching them directly to existing channel markers or pylons 4 m below the surface, or to a 10-mm diameter rope between a buoy 300 mm in diameter and a 53-kg iron bar on the seabed.

Over 4 d, yellowtail kingfish were targeted by anglers within 200 m of up to six receivers (Figure 1). In all, 22 transmitters were available for the work, and based on the aquarium experiment (see the "Results" section below), each was secured to two tags (i.e. double-tag method; Figure 2b). We aimed to tag approximately equal numbers of fish subjected to two treatments identified during the angling experiment as being the most benign (jaw-hooking) and deleterious (gill-hooking). Because most of the latter yellowtail kingfish died quickly (within 60 min) of their hooks being removed in experiment 1, these fish were released with their lines cut 5 cm from their mouth during experiment 3. Jaw-hooked fish had their hooks removed as per conventional fishing practice. All fish were angled using rods and reels equipped with 15 kg line and single J-hooks (840 mm^2 absolute size, i.e. length × width) baited with dead squid (*Uroteuthis* spp.) or live yellowtail scad (*Trachurus novaezelandiae*). Such bait was in common use among anglers during experiment 1. Each fish was measured for TL, before being double-tagged with an activated transmitter and released within 30 s.

The transmitters emitted a unique acoustic sequence at a frequency of 69 kHz that was repeated after a random delay of 13–17 s for the first 7 d, then 150–300 s for the remaining battery life (64 d). The receivers detected the presence, depth (m), and acceleration (m s^{-2} on three axes; Vemco Ltd) of each transmitter and were retrieved by divers in June 2009. Transmission data were downloaded to the Vemco user-environment (VUE, Vemco Ltd) software package and into a database for analyses. The differences in the time until first detection between gill- and jaw-hooked fish were analysed using a one-factor ANOVA. A LMM using fish (random) and treatment (fixed) was used to test for any differences between the acceleration (m s^{-2}) of jaw- and gill-hooked fish during the initial detection period.

Results

Experiment 1: evaluating the short-term fate of yellowtail kingfish during conventional angling and release

In addition to the 36 controls (mean ± s.d., 593.4 ± 34.6 mm TL), 54 similar-sized, angled yellowtail kingfish (605.3 ± 74.8 mm TL) were released into the monitoring cages. They had been caught with rods and reels equipped with 22.1 ± 1.3 kg line containing primarily barbed J-hooks baited with live (63.0%) and dead (22.2%) squid. Only two fish were hooked using artificial lures. Most were hooked in the mouth (74.1%), generally in the corner (57.4%), and 20.4% were more deeply hooked in the gill arch. Very few fish ingested hooks (into the throat or stomach, 5.6%), but 33.3% bled and/or had damage (48.1%) at the hooking location. No fish had fin damage and only two lost scales. Most fish were played for <60 s, landed with a knotted net (53.7%) within 60 s (63.0%), restrained with bare hands (79.6%), and exposed to air for <60 s (77.7%). Fish were held in an upright position (55.5%) by either the head and caudal peduncle (31.5%) or the trunk and caudal peduncle (24.1%), and 37.0% were dropped into the boat during handling. Only two fish had the line cut and the hook left in place (both deep-hooked and both survived). Fish were confined in the angler holding bins for between 5 and 68 min (mean ± s.e., 24.18 ± 1.83 min) at water temperatures of 22.1–23.2°C (mean ± s.e., 22.7 ± 0.3°C). The water quality in the angler holding bins was similar to samples next to where the fish were caught (mean ± s.e., 22.7 ± 0.3 vs. 22.3 ± 0.3°C, dissolved oxygen 7.7 ± 0.1 vs. 7.4 ± 0.1 mg l^{-1}, salinity 33.7 ± 0.1 vs. 33.8 ± 0.3 psu).

None of the control and eight of the angled fish died, providing a significant mortality of 14.8% (Fisher's exact test; $p < 0.05$). Of the eight fatalities, seven were hooked in the gills, six of which were bleeding heavily at the hooking location. The fatalities to the seven gill-hooked fish (all of which had their hooks removed) were

within 60 min of capture. The remaining fatality was played for >5 min, then struggled to maintain equilibrium in the holding bin and monitoring cage before its death (which was 207 min after capture). GLMMs examining the potential effects of the various explanatory factors on mortality showed that only hook location was significant ($p < 0.05$; Table 1). All other factors remained non-significant ($p > 0.05$) in either the presence or the absence of hook location in the model, although the presence of hook damage and blood and the landing method had some effect on mortality ($p < 0.1$; Table 1).

At the end of the monitoring period, the treatment and control fish had significantly lower concentrations of glucose (mean ± s.e.; 1.1 ± 0.1 and 1.3 ± 0.1 mmol l^{-1}, respectively) and lactate (both 1.1 ± 0.1 mmol l^{-1}) than those found in angled fish sampled immediately (3.3 ± 0.9 and 3.2 ± 0.6 mmol l^{-1}, respectively; ANOVA, $F_{2,17} = 5.48$ and 10.49, respectively; $p < 0.01$). Although not part of the experimental design, 8 and 17% of the control and treatment fish released at the end of the experiment were subsequently caught and reported by anglers over the following 8 months. These recaptures included two controls (within 500 m of the cages) after <20 min of being released at the end of the experiment, one control and six treatment fish (between 0.5 and 9.2 km from the cages) up to 16 d post-release, and another two treatment fish (6.2 and 1.5 km from the cages) 226 and 242 d after release.

Experiment 2: validating the retention of biotelemetry tags

In all, 75 yellowtail kingfish (mean ± s.d.; 567.6 ± 40.2 mm TL) were used in this experiment, and none died. In the first part of the experiment, 87 and 93% of stomach and single-dart tags, respectively, were ejected over the 23-d monitoring period, 13 and 47% within the first 5 d. During the second part of the experiment, no double-dart tags were lost within the first 5 d, but this had accumulated to 60% by the 20th day. There were no subsequent losses for the remaining monitoring period (64 d). Although no tail tags were lost, they caused extensive physical damage around the caudal peduncle and were subsequently removed from each fish after 4 d.

All the stomach tags were ejected. The single-dart tags were mainly lost through the fish biting at the dummy transmitters as they swung free. The loss of double-dart tags was only a concern when the barb on the anterior dart was not properly inserted behind a pterygiophore, and the transmitter was free to move away from the skin. When inserted correctly, double-dart tags did not impede the ability of fish to swim or feed, nor were they subjected to predation, so they were chosen as the preferred method for marking yellowtail kingfish with biotelemetry transmitters during experiment 3.

Table 1. Summary of GLLMs examining the influence of the various selected continuous and categorical factors on short-term mortality of angled-and-released yellowtail kingfish, *S. lalandi*, with (model 1) and without (model 2) hook location.

	p-value	
Factor	**Model 1**	**Model 2**
Hook location	0.016	–
Damage from hook	0.052	0.781
Landing method	0.055	0.742
Blood at hooking location	0.091	0.370
Play time	0.123	0.279
Line cut and hook left in	0.331	0.938
Hook type	0.615	0.775
Dropped after capture	0.758	0.658
Air exposure	0.775	0.892
Bait type	0.789	0.968
Restraining method	0.854	0.924
Scale loss	0.922	0.896
TL	0.945	0.416
Position held during hook removal	0.964	0.980
Body part held by angler	0.998	0.996

p, probability.

Experiment 3: using biotelemetry to monitor the fate of released jaw- and gill-hooked yellowtail kingfish

Ten gill- and 12 jaw-hooked individuals were angled then tagged and released at six angling locations over 4 d (Figure 1; Table 2). All fish were played for <60 s and lifted with a knotless landing net. None of the jaw-hooked fish bled, but all the gill-hooked individuals had blood and damage at their gills. Both groups of fish were handled with bare hands, had no scale or fin damage, were successfully tagged with double-dart configurations (with no visible bleeding), and released with their hooks removed and lines cut, respectively, all within 30 s of being taken from the water. The sizes of the gill- and jaw-hooked fish were similar (mean ± s.d.; 586.6 ± 28.3 vs. 573.9 ± 27.8 mm TL).

At the end of the experiment (after 64 d), all but three of the receivers (10, 11, and 13; Figure 1) were recovered and provided 43 085 and 67 761 detections for gill- and jaw-hooked fish, respectively (Table 2). These detections are separated temporally to quantify initial (mostly within 60 min) and longer-term (up to 49 d) movements below.

Eight and ten of the gill- and jaw-hooked individuals, respectively, were first detected at the same receiver at which they were released, and across similar times (mean ± s.e.; 219 ± 78 and 451 ± 126 s, respectively; ANOVA, $F_{1,17} = 2.16$, $p > 0.05$). The two remaining gill-hooked fish were released at one of the missing receivers (receiver 11) and were therefore removed from any subsequent analyses of time to initial detection. The two remaining jaw-hooked fish (fish 13 and 17) travelled from their release sites (receivers 19 and 6) ~1.2 and 1.4 km to receivers 20 and 5 and were not detected for 29 min and 4 h, respectively (Table 2). Only one fish (gill-hooked; fish 3) remained in the immediate vicinity of the receiver at which it was released (detected after 23 s; Table 2); all others swam outside the range of detection at their release site (and were not detected at other receivers) before returning within range.

The eight gill- and ten jaw-hooked fish that were first detected within the range of their release sites either swam in midwater or within 1 m of the seabed and with similar rates of acceleration (mean ± s.e.; 1.35 ± 0.13 vs. 1.26 ± 0.13 m s^{-2}; LMM, $p > 0.05$). These rates of acceleration were significantly greater than those observed for both groups during the rest of the experiment (mean ± s.e.; 0.81 ± 0.004 vs. 0.79 ± 0.003 m s^{-2}; LMM, $p > 0.05$). Irrespective of their anatomical hook location, those fish that were first detected at their release site in midwater appeared to assume standard movement patterns immediately (i.e. variation in depth and acceleration throughout the water column identified from observed behaviour over the monitoring period). In contrast, those that were first detected at depth tended to swim just above

Table 2. Summary of detections for gill- and jaw-hooked yellowtail kingfish, *S. lalandi*, tagged and released in Port Jackson.

				First detection		Receivers visited				Last detection	
Fish	Group type	Number of detections	Release location	Time (h:m:s)	Receiver	Day 0	1–5 d	6–15 d	>15 d	Receiver	Day
1	Gill	100	19	0:04:38	19	19	19	19	–	19	7
2[a]	Gill	9	6	0:01:24	6	6	–	–	–	6	0^{10min}
3	Gill	1 638	6	0:00:23	6	2–6	2–8, 12, 21, 22	–	–	22	5
4[a]	Gill	2 107	16	0:02:40	16	16, 19, 20, 23	–	12, 16, 17, 23, MP	MP	MP	23
5[a]	Gill	25 941	16	0:03:46	16	15–17, 19	16, 17, 19	16, 17, 21	15–17, 19, 21	16	19
6[a]	Gill	12 589	6	0:01:13	6	6	6	6, 7	7–9	9	19
7[a]	Gill	154	11	291:00:48	9	–	–	9	–	9	14
8[a]	Gill	534	19	0:12:00	19	19	19	16, 17, 19, 21	–	16	12
9	Gill	7	11	98:08:05	16	–	16	–	16	16	49
10	Gill	6	6	0:03:05	6	6	–	–	–	6	0^{7min}
11[a]	Jaw	30 444	19	0:06:10	19	16, 19	12, 16, 19	12, 15–17, 19	–	16	15
12	Jaw	672	19	0:06:34	19	19, 23	–	23, M	M, MP	MP	22
13	Jaw	1 746	19	0:28:45	20	20	18, 20	20	–	20	9
14[a]	Jaw	381	19	0:04:36	19	9, 12, 19	5, 7–9	–	–	5	3
15[a]	Jaw	23 903	12	0:06:12	12	12	12	12, 15, 23	–	15	15
16	Jaw	33	6	0:11:35	6	6	–	–	7, 8	8	18
17[a]	Jaw	4 890	6	4:15:04	5	5	5	–	–	5	3
18[a]	Jaw	177	6	0:01:17	6	5, 6	–	4, 5	–	4	12
19	Jaw	2 465	17	0:05:22	17	15–17	15	15–17, MP	–	MP	13
20	Jaw	2 017	6	0:05:23	6	6	6	6–8	–	8	14
21[a]	Jaw	893	6	0:24:54	6	6	5, 6	2–5	–	4	8
22	Jaw	140	6	0:03:04	6	6	5, 6	–	16	16	30

The time to last detection is indicated for fish 2 and 10. Receivers outside Port Jackson are represented by M (Manly) and MP (Magic Point). –, no data collected.
[a]Motionless tag within the range of a receiver.

the seabed for between 1 and 7 min before following the same standard movement patterns as the other fish.

Although there were few apparent differences in the initial movements of both groups of yellowtail kingfish, two of the gill-hooked individuals subsequently had unexplained short-term disappearances. Specifically, 10 min after being released and within 8 min of first detection at its release receiver, one gill-hooked fish (fish 2) was detected motionless at receiver 6 and another gill-hooked fish (fish 10) was last detected 7 min after release (after being tracked for 4 min) then not subsequently detected (Table 2). After their initial reactions, but still within 24 h of release, 12 fish (five gill- and seven jaw-hooked) remained within the range of the receiver at their release site and the other eight fish (three gill- and five jaw-hooked) visited two or more receivers. Two of the latter gill-hooked yellowtail kingfish (fish 4 and 12) travelled between ~8 and 9 km from their release sites to receiver 23 (Table 2).

Over the longer term (up to 49 d), five gill- and five jaw-hooked fish remained within a 2.5-km radius of their release site inside Port Jackson (Table 2). Three fish were detected outside Port Jackson, the tag from one of which was recovered by scuba divers on the seabed at Magic Point on day 23 (Table 2, Figure 1); it had some physical damage, perhaps indicative of predation. The other 12 fish moved up to 10.5 km away from their respective release locations (Table 2, Figure 1). The furthest daily movement was exhibited by a gill-hooked fish (fish 3; up to ~26.2 km on day 4), with averages of ~6.5 and 21.7 km d^{-1} over days 0–1 and 2–4, respectively. The most westerly movements were to receiver 23 (~10 km from the entrance to Port Jackson, Figure 1) by one gill- (fish 4) and two jaw-hooked (fish 12 and 15) fish (Table 2). In total by day 23, six tags from each group remained motionless within the range of a receiver (Table 2). The other 10 fish disappeared between days 5 and 49 (Table 2).

Discussion

The few short-term mortalities (15%) to yellowtail kingfish released during conventional angling in experiment 1, and their strong dependence on anatomical hook location, support previous observations for species taken from shallow water and released quickly (Muoneke and Childress, 1994; Cooke and Suski, 2005; Arlinghaus *et al.*, 2007). However, unlike most other species in which hooks typically are ingested into the digestive tract, causing temporally variable mortality that is most often explained by the immediate or delayed (i.e. up to 48 d) perforation of vital organs (Butcher *et al.*, 2007; Margenau, 2007; Hall *et al.*, 2009), all but one of the fatalities to yellowtail kingfish were attributable to their being hooked in the gills, and all these took place within 60 min of release.

The mechanisms contributing to such rapid death may have been mechanical and/or physiological, both of which are supported by other non-significant, but nevertheless important, explanatory factors, including damage from the hook ($p = 0.052$), landing method ($p = 0.055$), and the presence of blood ($p = 0.091$). For example, any gill filaments and lamellae that were torn or damaged by hooks would have directly affected overall gas exchange and respiration (Ferguson and Tufts, 1992). Such damage may have been exacerbated by the use of landing nets. For example, as fish struggled during removal from the water, the terminal gear or any protruding gill filaments may have contacted the sides of the net. Further, unlike fish that were immediately secured by hand, those that were landed in nets were typically

placed (confined and struggling) on the floor of the boat, so could have sustained further injury before being secured.

In addition to mechanically damaged gills, some of the observed blood (which was more profuse after hook removal) may have clotted during air exposure and subsequently blocked undamaged filaments and lamellae, further inhibiting respiration. The impacts of even minor damage or restrictions to gills could be quite substantial for yellowtail kingfish because they have a high aerobic metabolic rate and a cardiac output that would have approached near maximum capacity at the observed water temperatures (Clark and Seymour, 2006). Failure to meet the associated oxygen demand would quickly cause irreversible physiological damage in such fish (Cooke *et al.*, 2001).

Although there is undoubtedly considerable intra- and interspecific variability in the actual cause of anatomical-hooking mortality, it is well established that for many species such fatality can be mitigated via simple changes to either (i) terminal rigs and fishing practices (Arlinghaus *et al.*, 2008; Butcher *et al.*, 2008b) or (ii) post-capture handling (Broadhurst *et al.*, 2007; Fobert *et al.*, 2009). For example, owing to their shape and size, circle hooks and large artificial lures can reduce the frequency of deep-hooking among several species, especially when they are fished actively (Arlinghaus *et al.*, 2008; Butcher *et al.*, 2008b). A lack of data precluded the assessment of any relationship between terminal rigs and anatomical hook location in this study, but given the above, future research would benefit from a closer examination of this issue.

Notwithstanding the possibility of limiting mortalities through the terminal rig design, unless their gills are severely damaged, an alternative, appropriate strategy for yellowtail kingfish involves simply changing the way they are handled, including securely restraining fish during the entire catch-and-release process, and especially cutting the line on all deep-hooked individuals. Preliminary support for the latter approach was provided in experiment 1 by the short-term survival of two fish that ingested hooks and had their lines cut. More definitive evidence was presented in the biotelemetry experiment, with similar temporal and spatial movements and comparable recoveries observed between the jaw-hooked and line-cut gill-hooked fish.

The only exceptions were the unexplained disappearances of two gill-hooked fish within 18 min of release. Given the results of the tag-retention work in experiment 2, it is unlikely that these missing transmitters were shed. Rather, they probably represent mortalities either as a direct consequence of angling and release (e.g. damaged gills) or perhaps more indirectly through predation (Pepperell and Davis, 1999), possibly by pelagic sharks (*Carcharhinus* spp.), because signals from two tagged bull sharks (*Carcharhinus leucas*) were detected on some of the receivers in Port Jackson during the monitoring period.

Excluding the damaged tag recovered from Magic Point, which may also reflect predation or simply shedding, the fates of all remaining longer-term disappearances remain unknown, although these can be postulated based on the available evidence. For example, the timings of most disappearances (>15 d) mean that they were probably not directly related to their initial catch and release unless some gill-hooked fish subsequently ingested their hooks and, as with observations made for other species (e.g. mulloway, *Argyrosomus japonicus*; Butcher *et al.*, 2007), died as a consequence of associated organ damage. It is also possible that some fish may have been caught again by anglers, although all were under the minimum legal size in NSW (<65 cm TL), so should have been released. The more likely explanation for the missing fish was that they moved well offshore (outside the range of the receivers). This hypothesis is supported by movements recorded during previous tagging studies (Baxter, 1960; Gillanders *et al.*, 2001) and also the lack of any detections at more than 130 receivers located primarily inshore (<5 km) along the NSW coast.

Assuming that most of the longer-term disappearances were not attributable to fatality, and except for the short-term susceptibility of yellowtail kingfish to the trauma associated with gill-hooking (which usually can be addressed by modified handling), the results from all three experiments support the results of previous studies that indicate a general physiological resilience by this species to anthropogenic and environmental disturbance (Gillanders *et al.*, 2001; Moran *et al.*, 2008). For example, (i) all yellowtail kingfish fed quickly (within 24 h) after capture and confinement in experiment 1 and all methods of tagging in experiment 2, (ii) there were no significant differences in blood chemistry between captive and immediately sampled angled fish at the end of experiment 1, (iii) two controls were caught by anglers within 20 min of release at the end of experiment 1, and another seven fish were caught within 16 d, and (iv) during experiment 3, all fish appeared to return to normal behaviour quickly, irrespective of their initial treatment.

Although the lack of biotelemetry controls, i.e. fish that were not angled and immediately released, precludes accurate assessment of when the effects of angling dissipated, i.e. (iv) above, or indeed the quantification of normal behaviour, this can be inferred by considering the temporal variability in movement. In particular, there were consistent initial responses after catch and release that may reflect a fairly common dispersal reaction for most fish, irrespective of the differences in their handling (Pepperell and Davis, 1999; Arlinghaus *et al.*, 2008; Butcher *et al.*, 2010). For example, as did the recaught tagged fish at the end of experiment 1, most biotelemetered individuals fled their release area rapidly, but quickly (mostly within 7 min) recovered from any capture stress and trauma and returned, probably to rejoin their schools.

There were slight variations in behaviour within the general initial response above, but these might simply reflect subtle, intraspecific reactions to the imposed stressors. For example, the observed return of some fish to their release site along the seabed could be indicative of relatively greater stress (than those that returned midwater) and a need to seek protective habitat (Rose, 2007). Such behaviour was independent of the hooking treatment and could reflect the cumulative impacts of a range of other biological or technical factors known to influence the behaviour of released fish (Muoneke and Childress, 1994; Cooke and Suski, 2005; Arlinghaus *et al.*, 2007).

Given the evidence to suggest that yellowtail kingfish quickly recovered from their handling, the observed longer-term movements were probably typical behaviour and, based on their known high metabolic rate (Clark and Seymour, 2006), reflected attempts at locating suitable prey, such as small schooling teleosts and cephalopods (Kailola *et al.*, 1993). The importance of nutrition for yellowtail kingfish is supported by the almost immediate recapture of released tagged fish during experiment 1 and the consumption of offered food by fish soon after being collected or caught in all experiments, and being tagged by what could be considered quite severe treatments, e.g. stomach tags, in experiment 2.

As for estimates of longer-term mortality, the low replication of transmitters and receivers, combined with some loss of both (and

especially 12 transmitters by the 23rd day), precludes more-detailed discussion of the general movements and behaviour of yellowtail kingfish. Notwithstanding these limitations, the data collected during the biotelemetry experiment and the confinement study were sufficient to provide comprehensive information on the immediate and short-term fate of released fish, illustrating the utility of such an approach for future catch-and-release studies and providing support for recommendations to reduce the unaccounted fishing mortality of the species.

Specifically, anglers targeting yellowtail kingfish should be encouraged to explore techniques previously demonstrated to promote jaw-hooking (e.g. large baits, lures, and circle hooks; Arlinghaus *et al.*, 2008; Butcher *et al.*, 2008b) and to handle their fish carefully (including securing fish during all stages of the catch-and-release process). Any yellowtail kingfish that are hooked deeper than the jaw should be released quickly by having their lines cut. If the rates of gill-hooking (~20%) and associated handling methods, i.e. hook removal before release, observed during experiment 1 are representative of conventional angling for this species in Australia, then based on the estimated released catches by Henry and Lyle (2003), cutting the line could translate to an additional short-term survival of > 12 300 fish year^{-1}. Such an estimate might be substantially increased across the global distribution of the species.

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