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Mortality and physical damage of angled-and-released dusky flathead *Platycephalus fuscus*

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ABSTRACT: We completed 2 experiments to quantify the mortality and physical damage (fin, blood and scale loss) of angled dusky flathead *Platycephalus fuscus* during a live weigh-in tournament (Expt 1) and after being immediately released by anglers (Expt 2). In each experiment, 84 and 79 angled *P. fuscus* were placed into up to 6 replicate tanks and, along with appropriate numbers of controls, monitored for mortalities over 5 d. Five and 7 of the angled fish died within 12 h, providing mortalities of 3.6 and 8.9% in Expts 1 and 2, respectively. One control fish died, which was attributed to an incorrectly inserted tag. None of the continuous or categorical variables collected during angling and subsequent release, or the experimental design, could explain the few observed mortalities to treatment fish. However, knotted large-mesh landing nets caused significantly greater fin damage than knotless fine-mesh designs in both experiments ($p < 0.05$). Furthermore, although water quality had no measured impact on the confined fish, the samples taken from anglers' live wells (mostly for Expt 1) were significantly poorer than the environment from which the fish were caught ($p < 0.05$). These latter differences may have had a cumulative negative impact on fish that manifested as the observed deaths. Simple changes to the post-capture handling of *P. fuscus*, involving appropriate landing nets and live wells, should reduce some angling impacts on this species.

KEY WORDS: Dusky flathead · *Platycephalus fuscus* · Catch-and-release · Water quality · Live well · Handling method · Anglers

INTRODUCTION

The family Platycephalidae (commonly referred to as flatheads) comprises more than 65 species, most of which are typically confined to the Indo-Pacific (Nelson 2006). In Australia, several endemic species are targeted by anglers, with the majority of the recreational catch (estimated at 13 million individuals during 12 mo in 2000 and 2001, Henry & Lyle 2003) consisting of dusky *Platycephalus fuscus* and sand *P. bassensis* flathead. Both of these species are caught from estuarine and inshore waters along the eastern and southern coasts across a range of total lengths (TL), up to maximums of 1.2 and 0.46 m, respectively (Kailola et al. 1993).

Owing to bag limits, legal sizes and, more recently, a growing trend of non-consumptive angling, approximately 45% of all recreationally caught platycephalids are released (Henry & Lyle 2003). Recognition of the need to validate the inherent assumption that the majority of these individuals sustain few subsequent negative impacts has resulted in 2 preliminary studies to estimate mortality and the key contributing factors (Brown et al. 2006, Lyle et al. 2007). Both studies examined the fate of fish released immediately after conventional angling. As in studies of other local species targeted using similar gears (Broadhurst et al. 2005, 2007, Butcher et al. 2006, 2007), this work revealed few mortalities (<8%), most of which were caused by deep hooking.

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The observed correlation between mortality and anatomical hook location in released *Platycephalus fuscus* and *P. bassensis* means that simple modifications to angler practices, such as using different terminal rigs to reduce the frequency of deep hooking (Willis & Millar 2001) and/or cutting the line on ingested hooks (Butcher et al. 2007), should significantly improve their survival. However, notwithstanding the likely benefits of these practices, the available quantitative data on mortality and associated causes are still quite limited. The potential remains for additional cryptic mortality and/or sub-lethal impacts.

Relevant studies done with a range of different species indicate that, in addition to anatomical hook location, other causes of mortality can include, but are not limited to, air exposure, angling duration, handling methods (e.g. the use of landing nets and restraining devices), and the design and water quality of live wells (for reviews see Muoneke & Childress 1994, McLeay et al. 2002, Cooke & Suski 2004, Arlinghaus et al. 2007). These and other factors have been demonstrated to stress fish through fatigue, oxygen deprivation, scale, fin and blood loss, ammonia toxicity, and osmoregulatory and thermal shock. Further, there is potential for such sub-lethal stressors to affect fish through changes to their growth rate, general physiology, reproductive success, behaviour or immune responses (McLeay et al. 2002). It is possible that a combination of these sub-lethal stressors could eventually lead to mortality (Wedemeyer et al. 1990).

Because of their often large size and spiny morphology, platycephalids are typically lifted from the water in landing nets and then, irrespective of their anatomical hook location, physically restrained by a variety of methods (e.g. gloves, towels and pliers), while hooks are removed. The loss of fins, scales and mucus during this process may increase their susceptibility to pathogens and mortality (Cooke & Hogle 2000, Barthel et al. 2003). Furthermore, anglers regularly keep *Platycephalus fuscus* in live wells until catching a heavier fish, reaching the daily quota, or being required to present their catch for weighing at the end of designated fishing sessions during tournaments (typically 1 to 6 h). Unless appropriate live wells are used, the confinement of *P. fuscus* may render them susceptible to poor water quality (e.g. high water temperatures and ammonia concentrations, and low dissolved oxygen, Gilliland & Schramm 2002). For example, Brown et al. (2006) suggested that the time *P. fuscus* spent in live wells was directly related to mortality (due to declining water quality) and that fish should not be kept for longer than 60 min.

The potential for the above types of factors to affect the mortality and general health of angled-and-released platycephalids warrants further investigation. Our aims in this study were to quantify mortality (over 5 d) and physical damage for *Platycephalus fuscus* angled and released across a range of conventional practices (including immediate release and live weigh-in tournaments) typically used in southeastern Australia.

MATERIALS AND METHODS

We completed 2 experiments, in February and December 2006, each involving recreational anglers catching and releasing *Platycephalus fuscus* during 2 types of fishing events. The events comprised boat-based anglers holding fish in onboard live wells before either (1) presenting them at scheduled periods for weighing as part of an established catch-and-release tournament (Expt 1) or (2) releasing them due to legal size and/or bag limits and/or general non-consumptive angling (Expt 2). In both experiments, all fish were released and monitored in 6 land-based (within 50 m of the fishing area), 3000 l holding tanks supplied with flow-through seawater (5 l min^{-1}) at ambient temperature (20.3 to 25.1°C) and aerated with stone diffusers. The specific methods used in each experiment are described below.

Expt 1. Fate of *Platycephalus fuscus* after a catch-and-release tournament. The first experiment was done in Wallis Lake, New South Wales (NSW, 29° 24′ S, 153° 20′ E), over 6 d during February 2006 and involved 53 anglers (distributed among 23 boats) competing in an established catch-and-release tournament. On the day before the tournament, 42 captive *Platycephalus fuscus* (originally collected 3 to 6 mo earlier by hook and line) were removed from holding tanks at the National Marine Science Centre (NMSC) aquaria at Coffs Harbour and transported to Wallis Lake. The fish had their right pectoral fin clipped (for identification) and 24 were tagged (using t-bar anchor tags) before all fish were distributed in groups of 7 (comprising 4 tagged and 3 non-tagged individuals) among the six 3000 l holding tanks. These fish were used as experimental controls.

Before the start of fishing on the day of the tournament, the organisers briefed the anglers on the fishing rules. The 3 major restrictions were that (1) all boats had to be equipped with a live well (inboard or external), (2) all fish had to be caught on barbless hooks rigged with either hard-bodied lures, flies, jigs or soft plastic bait (natural bait and berley were not permitted), and (3) fish could be handled only with wet gloves. Fishing was divided into three 90 min sessions, starting at 07:30 h and ending with a 30 min weigh-in period. Anglers were permitted to present their fish for weighing during the fishing session, with only the largest fish counting towards their overall score. After catching a *Platycephalus fuscus*, an angler was required to place it into the live well and record relevant data (see below). At the end of each fishing session, all *P. fuscus* were removed from the live wells, placed into wet black synthetic bags and weighed by the tournament director. Researchers recorded relevant data on the live wells and any physical damage to fish (see below) and half of them were tagged with numbered, t-bar anchor tags before all were measured (to the nearest 1 mm TL) and released into one of the six 3000 l tanks.

Expt 2. Fate of *Platycephalus fuscus* after release during conventional angling. The second experiment was done in the Clarence River, NSW (32° 10′ S, 152° 30′ E), over 6 d during December 2006 with 33 recreational anglers on 18 boats and 7 researchers on 3 boats. On the day before the event, 84 control fish (caught by angling 6 to 12 mo earlier) were removed from tanks at the NMSC and transported to Iluka. These fish had their left pectoral fin clipped to facilitate their identification before being distributed evenly among the six 3000 l holding tanks.

All anglers were provided with a black 70 l (70 × 40 × 50 cm) live well (with a lid) and an aerator and asked to use any legal configuration of tackle to target *Platycephalus fuscus* during 2 fishing sessions (05:30 to 10:30 h and 14:00 to 18:30 h). Once an angler caught a fish, he/she placed it into the live well, recorded relevant data (see below) and immediately notified the researchers by raising a red flag. Because anglers normally release undersized individuals (<36 cm TL), these fish were always held individually in the live wells to avoid any confounding effects of multiple fish, including abrasion and/or poor water quality. However, as per normal fishing practices, anglers could hold multiple, legal-sized fish in their live wells before having them collected by the researchers. Some anglers had large live wells on board their boats, which were used to house any fish longer than 70 cm TL. All live wells were aerated and either had continuous flow-through systems or were provided with 10 l of fresh seawater by the anglers with a bucket every 15 min until their fish was collected.

Researchers travelled to the boats, confirmed the angler's data and recorded information on the live well (see below) before removing the fish (using a 30 l black synthetic catch bag filled with water) and placing it into a 200 l fish-holding tank on the research boat. Each fish was then measured for TL, checked for damage (see below) and transported to the holding tanks — all without exposure to air. To aid with the post-experiment identification of fish, similar-sized individuals were placed into separate tanks.

Data collection and analyses. The data recorded by the anglers during both events included the time of fish capture; line and trace strength; lure or bait type; whether the boat was drifting, trolling or anchored; amount of time the fish were played in the water and exposed to air during hook removal; landing method (type of net if used); depth fished; and anatomical hooking location. During Expt 2, anglers also recorded the manner in which fish were restrained after being landed and whether or not they were photographed. The researchers recorded the physical characteristics (type, volume, colour, aeration and water supply method) of the anglers' live wells and, in addition to the TL of all fish, the presence/absence of scale loss, fin damage and blood, the time of collection from the anglers and the daily survival.

Various environmental parameters were collected during the experiments. For Expt 1, the turbidity (nephelometer turbidity units, NTU), water temperature (°C), dissolved oxygen (mg l^{-1}), ammonia (ppm) and salinity (psu) were collected from the anglers' live wells, and daily at several locations in the adjacent river and from the land-based holding tanks. During Expt 2, these same parameters were recorded from the holding tanks and at several locations in the Clarence River where anglers were fishing (daily), but only water temperature, dissolved oxygen and ammonia were collected from the anglers' live wells.

All of the *Platycephalus fuscus* released into the holding tanks were fed live southern herring *Herklotsichthys castelnaui* and yabbies *Callianassa* spp. at a rate of 1% biomass d^{-1} and monitored every 12 h over 5 d. To maintain stocking densities, any dead individuals were removed and replaced with live fish (locally hooked and clipped on the bottom of the caudal fin to aid in identification). Following the procedures described by Broadhurst et al. (2005), blood was taken from up to 7 wild-caught individuals on the first and last day of the experiments, and then from the first 4 fish scooped with a landing net from each tank at the end of the 5 d monitoring periods. Blood plasma samples collected from angled and control fish were analysed for concentrations of cortisol (ng ml^{-1}) by radioimmunoassay (according to the methods of Pankhurst & Sharples 1992) and glucose (mmol l^{-1}) derived by means of colorimetric clinical kits (Roche Diagnostics) using an enzymatic spectrophotometric assay, which was done according to the manufacturer's instructions.

All data were analysed separately within each experiment. Appropriate 3-factor ('tagging', 'treatment of fish' and 'tanks,' Expt 1) and 2-factor ('treatment of fish' and 'tanks,' Expt 2) ANOVAs were used to test for differences in the mean concentrations of cortisol (ng ml^{-1}) and glucose (mmol l^{-1}) between tagged and untagged treatment and control fish in Expt 1 and only treatment and control fish in Expt 2. Tanks were included as a random nested (Expt 1) or orthogonal (Expt 2) factor. Where there were no significant effects of the treatment of fish or tagging, cortisol and glucose concentrations from tank-held *Platycephalus fuscus* were compared against samples taken from fish angled from the river or lake at the same time (considered baseline estimates) using a 1-factor ANOVA. Where variances were heterogeneous (Cochran's test), data were $\ln(x + 1)$-transformed.

Size-frequency distributions (1 cm TL intervals) of (1) treatment and control fish, and (2) those subjected to different landing and restraining methods were compared using 2-sample Kolmogorov-Smirnov tests. Two-tailed Fisher's exact tests were used to determine the independence of the treatment of fish on mortality at the end of the experiments. All variables describing the capture and holding of *Platycephalus fuscus* were collated as either categorical or continuous variables. Logistic regression models incorporating these explanatory variables were fitted separately to the survival data for each experiment (Agresti 1996). In addition, logistic regressions were also fitted to assess the effect of the different types of landing methods and fish restraining methods in relation to fin damage or scale and blood loss in Expt 2. In Expt 1, because only a single type of handling method (gloved hand) was used, only the effect of landing method on fin damage and scale or blood loss (presence/absence) was assessed. Because the mortalities and numbers of fish suffering fin damage or scale and blood loss were low in both experiments (see 'Results'), the logistic regressions were fitted using the method of conditional maximum likelihood (Agresti 1996) with the LogXact 8 software package (Cytel Software 2007). Two-sample *t*-tests were used to test for differences in water quality (temperature, turbidity, ammonia and dissolved oxygen) between anglers' live wells and the rivers on the day of angling in each experiment.

RESULTS

A total of 84 (mean ± SE of 43.6 ± 0.7 cm TL) and 79 (37.7 ± 1.6 cm TL) *Platycephalus fuscus* were angled and released into the holding tanks during Expts 1 and 2, respectively. Kolmogorov-Smirnov tests detected significant differences between the size-frequency distributions of angled and control fish in Expt 1 ($p < 0.01$, with the latter individuals comparatively smaller), but not in Expt 2 ($p > 0.05$, Table 1).

The anglers primarily caught their fish using lures while drifting (both experiments) or anchored (Expt 2) in shallow water (typically <2 m) (Table 2). Average play time (after hooking) was longer in Expt 1 (mostly 11 to 60 s) than in Expt 2 (mostly <30 s, Table 2). The majority of fish were exposed to air for less than 60 s in both experiments (Table 2). Knotless fine-mesh landing nets (67%) were primarily used in Expt 1, while 51.9% of fish were landed with no net in Expt 2 and restrained using either a towel (34.2%) or bare hands (31.7%, Table 2). The anatomical hooking location was mainly limited to the upper jaw (44.0 and 46.8%) or corner of the mouth (25.0 and 26.6%) in Expts 1 and 2, respectively (Table 2). Only 1 fish ingested a hook (Expt 1, Table 2). Very few fish were photographed (3.8%) in Expt 2 or had blood at their mouth or gills (5.8 and 8.9%), or fin (19.0 and 6.3%) and scale (1.2 and 7.6%) damage in Expts 1 and 2, respectively, before being released (Table 2). The mean ± SE time that fish were held in live wells after capture was longer in Expt 1 (58.1 ± 4.0 min) than in Expt 2 (14.9 ± 2.0 min, Table 1).

In Expt 1, 5 angled (1 non-tagged and 4 tagged) and 1 control (tagged) fish died, providing an adjusted non-significant mortality rate of 3.6% (Fisher's exact test, $p > 0.05$). There were no significant differences in mortality detected between tagged and non-tagged angled and control fish (Fisher's exact test, $p > 0.05$). In Expt 2, 7 angled and no control fish died, providing a significant mortality rate of 8.9% (Fisher's exact test, $p < 0.05$).

Table 1. *Platycephalus fuscus.* Mean (±SE) continuous parameters for the numbers of live and dead angled-and-released fish used in the logistic regression analyses for Expts 1 and 2. NA: not applicable

Parameter	Expt 1			Expt 2		
	$\bar{x}$ (±SE)	Alive	Dead	$\bar{x}$ (±SE)	Alive	Dead
Total length (cm)						
Angled	43.6 ± 7.3	43.3 ± 0.8	48.0 ± 3.0	37.7 ± 1.6	37.9 ± 0.8	35.4 ± 3.0
Control	33.9 ± 1.5	33.7 ± 1.5	39.2 ± 0.0	37.8 ± 1.0	37.8 ± 1.0	NA
Period in live well (min)	58.1 ± 4.0	58.7 ± 4.1	48.2 ± 15.7	14.9 ± 2.0	15.1 ± 2.1	13.3 ± 5.3
Line strength (kg)	3.5 ± 0.2	3.5 ± 0.2	4.4 ± 1.0	5.1 ± 0.4	5.2 ± 0.4	3.9 ± 0.4
Trace strength (kg)	6.4 ± 0.4	6.3 ± 0.4	7.6 ± 2.1	6.9 ± 0.6	7.1 ± 0.7	5.1 ± 0.4
Water depth (m)	2.1 ± 0.1	2.1 ± 0.1	1.6 ± 0.6	2.2 ± 0.2	2.2 ± 0.2	1.7 ± 0.5
Live-well capacity (l)	56.4 ± 2.5	56.2 ± 2.6	60.0 ± 6.3	73.2 ± 2.5	72.5 ± 2.6	80.0 ± 10.0

Table 2. *Platycephalus fuscus.* Pooled categorical parameters collected at the end of Expts 1 and 2 for the total numbers of live and dead, angled-and-released fish used in the logistic regression analyses. NA: not applicable

Parameter	Expt 1 Alive	Expt 1 Dead	Expt 2 Alive	Expt 2 Dead
Hook location				
Upper jaw	35	2	33	4
Corner of mouth	20	1	21	0
Lower jaw	8	0	7	1
Roof of mouth	7	1	10	1
Gill arch	4	0	0	1
Floor of mouth	4	1	0	0
Ingested	1	0	0	0
Body	1	0	1	0
Play time (s)				
<10	2	0	36	3
11–30	28	1	29	2
31–60	32	2	4	2
>60	17	2	3	0
Exposure to air (s)				
<30	31	2	45	6
30–60	34	3	21	0
61–120	14	0	5	1
121–300	0	0	1	0
Fin damage				
Yes	15	1	5	0
No	64	4	67	7
Scale loss				
Yes	1	0	6	0
No	78	5	66	7
Blood at mouth or gills				
Yes	9	1	2	0
No	70	4	70	7
Fish landing method				
Knotless, fine-mesh net	53	4	17	4
Knotted, large-mesh net	12	0	16	1
No net	14	1	39	2
Fishing method				
Drifting	71	4	34	3
Anchored	7	1	32	4
Trolling	1	0	4	0
Fish restraining method				
Towel	NA	NA	26	1
Bare hand	NA	NA	24	1
Gloved hand	79	5	7	3
Not restrained	NA	NA	10	2
Pliers	NA	NA	5	0
Bait				
Lure	79	5	43	6
Whitebait	NA	NA	12	0
Pilchard	NA	NA	8	1
Live herring	NA	NA	6	0
Prawn	NA	NA	3	0
Photograph taken by angler				
Yes	NA	NA	3	0
No	NA	NA	69	7

In both experiments, most deaths occurred within 12 h of the fish being released into the tanks, with the only tagged control mortality occurring on Day 4 of Expt 1. This fish had been tagged incorrectly so that the tag punctured the peritoneal cavity. Visual inspections of the 5 dead angled fish from Expt 1 revealed that all but one had either some physical damage to their bodies, which included frayed fins and bruising in the mouth where the hook had penetrated or, in the case of 1 fish, an old injury (ulcer) between the nape and gill plate. Furthermore, of the 7 fish that died during Expt 2, one was hooked in the gill arch and another had been exposed to air for 1–2 min before being placed into a live well containing high concentrations of ammonia (>1.0 ppm).

Logistic regression models failed to detect any significant interactions or main effects of the various continuous or categorical factors on mortality (Tables 1 to 4, $p > 0.05$). However, in terms of physical damage (blood, scale and/or fin loss) caused by the different landing and handling methods, the logistic regression analysis identified a significant main effect of landing method (but not handling method or an interaction between the 2) on fin damage, but not scale or blood loss in each experiment. More specifically, knotted large-mesh landing nets were responsible for more damage (58.3 and 29.4% of fish) than knotless fine-mesh nets (10.5 and 0.0%) or not using a net at all

Table 3. *Platycephalus fuscus.* Pooled categorical live-well parameters collected at the end of Expts 1 and 2 for the total numbers of live and dead angled-and-released fish used in the logistic regression analyses. NA: not applicable

Live-well parameter	Expt 1 Alive	Expt 1 Dead	Expt 2 Alive	Expt 2 Dead
Type				
Plastic tub with lid	37	2	54	6
Inboard	19	3	12	0
Insulated tub with lid	23	0	6	1
Water level (%)				
50	41	1	12	0
75	18	3	54	6
100	20	1	6	1
Water flow				
Continuous	30	4	12	0
Water changes every 15 min	49	1	60	7
Aeration				
Yes	51	5	72	7
No	28	0	NA	NA
Internal colour				
White	41	3	18	1
Clear	31	0	NA	NA
Dark blue	1	1	NA	NA
Black	6	1	54	6

Table 4. Mean (±SE) continuous water quality parameters collected from anglers' live wells and river samples during Expts 1 and 2. The numbers of live and dead *Platycephalus fuscus* in the anglers' live wells were used in the logistic regression analyses. NTU: nephelometer turbidity units. NA: not applicable

Parameter	Expt 1			Expt 2		
	$\bar{x}$ (±SE)	Alive	Dead	$\bar{x}$ (±SE)	Alive	Dead
Angler live well						
Water temperature (°C)	24.6 ± 0.2	24.6 ± 0.2	24.6 ± 0.5	22.8 ± 0.2	22.8 ± 0.2	23.4 ± 0.4
Dissolved oxygen (mg l^{-1})	5.5 ± 0.2	5.4 ± 0.4	6.0 ± 0.2	6.5 ± 0.1	6.5 ± 0.1	6.6 ± 0.3
Ammonia (ppm)	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Turbidity (NTU)	7.2 ± 0.7	7.3 ± 0.7	6.0 ± 0.7	NA	NA	NA
Salinity (psu)	35.6 ± 0.3	35.6 ± 0.3	36.2 ± 0.1	NA	NA	NA
River samples						
Water temperature (°C)	22.6 ± 0.3	NA	NA	22.1 ± 0.4	NA	NA
Dissolved oxygen (mg l^{-1})	6.5 ± 0.2	NA	NA	5.8 ± 0.1	NA	NA
Ammonia (ppm)	0.0 ± 0.0	NA	NA	0.0 ± 0.0	NA	NA
Turbidity (NTU)	1.0 ± 0.4	NA	NA	10.1 ± 1.6	NA	NA
Salinity (psu)	36.7 ± 0.0	NA	NA	34.9 ± 0.1	NA	NA

(20.0 and 0.0%) during Expts 1 and 2, respectively. There were no significant differences among the size-frequency distributions of fish landed or restrained according to the different handling treatments in each experiment (Kolmogorov-Smirnov test, $p > 0.05$).

The live-well configurations used by anglers to hold fish during Expt 1 varied considerably (Tables 1 & 3). Nearly half (47.8%) held fish in external plastic containers, which were, on average, 57.5 l (±1.4), white (47.8%) or clear (34.8%) in colour, had water provided via a flow-through system (56.5%) and had some type of aeration (78.3%) (Tables 1 & 3). Live wells in Expt 1 had significantly higher water temperatures (24.6 ± 0.2°C; $t_{11} = 5.8$, $p < 0.05$), ammonia concentrations (0.3 ± 0.4 ppm; $t_{73} = 9.7$, $9 < 0.05$) and turbidity levels (7.2 ± 0.7 NTU; $t_{93} = 9.2$, $p < 0.05$) and lower dissolved oxygen concentrations (5.5 ± 0.2 mg l^{-1}; $t_{23} = 5.1$, $p < 0.05$) than river samples taken during angling (Table 4). During Expt 2, most anglers (88.9%) held fish in 70 l, black, aerated live wells (Table 3). The water temperatures in these live wells were similar to those in the river, but dissolved oxygen (6.5 ± 0.2 mg l^{-1}; $t_{106} = 4.5$, $p < 0.05$) and ammonia (0.1 ± 0.0 ppm; $t_{77} = 5.7$, $p < 0.05$) concentrations were significantly greater (Table 4). There were no differences in water quality between the river and those live wells used to hold undersize *Platycephalus fuscus*, thereby minimizing the potential for any confounding effects ($p > 0.05$).

A 3-factor ('tagging', 'treatment of fish' and 'tanks') ANOVA detected a significant main effect of tanks on the mean (±SE) cortisol concentrations [ln(x + 1)-transformed] of tagged fish in Expt 1 ($p < 0.05$). There were no significant differences in the mean glucose concentrations [ln(x + 1)-transformed] between tagged and untagged or treatment and control fish within and among tanks in Expt 1 or cortisol and glucose concentrations between treatment and control fish within and among tanks in Expt 2 ($p > 0.05$). Significant differences were also detected in the concentrations of plasma cortisol [ln(x + 1)-transformed] between wild-caught (9.7 ± 3.3 ng ml^{-1}) and tank-held (101.2 ± 7.3 ng ml^{-1}) fish in Expt 1 ($F_{1,21} = 43.9$, $p < 0.01$). Similarly, significant differences were found in cortisol concentrations between wild-caught (4.6 ± 0.5 ng ml^{-1}) and tank-held (65.2 ± 12.9 ng ml^{-1}) fish in Expt 2 ($F_{1,27} = 55.3$, $p < 0.01$). There were no significant differences in the mean glucose concentrations between wild-caught and tank-held fish in Expt 1 (1.1 ± 0.1 and 1.2 ± 0.4 mmol l^{-1}, respectively; $p > 0.05$) or Expt 2 (1.1 ± 0.1 and 1.11 ± 0.0 mmol l^{-1}, respectively; $p > 0.05$).

DISCUSSION

The mortality rates (3.6 and 8.9%) of *Platycephalus fuscus* observed in this study were similar to those recorded for this species in Queensland (6.9%, Brown et al. 2006) and *P. bassensis* in Tasmania (7.6%, Lyle et al. 2007), but the underlying causes were apparently different. Similar to numerous other local (Diggles & Ernst 1997, Broadhurst et al. 2005, Butcher et al. 2007) and overseas (Warner 1976, Schill 1996, Aalbers et al. 2004) species, both of the previous studies demonstrated a positive correlation between deep hooking and the number of deaths. A comparatively lower rate of ingestion (<1%) by *P. fuscus* in this study precluded the examination of any associated impacts on mortality. Most of the fish were caught with lures, which typically were superficially located in their anterior mouth and upper jaw and easily removed, with little obvious damage.

Numerous studies have demonstrated that mouth hooking by lures causes few negative impacts to released fish (e.g. Van der Walt et al. 2005, Brown et al. 2006) and so, although most of the dead *Platycephalus fuscus* were caught by this method, it is unlikely to have had any major influence on their fate. This result, combined with the lack of any detectable cause of the observed deaths may indicate the influence of multiple stressors during the handling of fish after they were hooked. Relevant reviews suggest that combinations of abiotic and biotic factors often have a cumulative negative impact on the wellbeing of angled-and-released fish, eventually leading to mortality (Wedemeyer et al. 1990, McLeay et al. 2002). These factors are not limited to catch-and-release mechanisms, but can also include the experimental design, particularly the methods of confining and monitoring fish (Broadhurst et al. 2005).

It is unlikely that the experimental methodology in this study had any confounding effects on the observed mortalities. Although 1 control fish died (after 4 d), this was attributed to an incorrectly inserted tag. All angled fish were quickly transported by researchers under optimal conditions and carefully released into the tanks with no exposure to air. The lack of any chronic response to their subsequent confinement is demonstrated by the similar plasma glucose concentrations between tank-held and wild-caught individuals after 5 d in both experiments. There was evidence of a significant, acute stress response in tank-held individuals that manifested as elevated plasma cortisol levels, compared to those in the wild, but this may be explained by the sampling process. To facilitate access to fish at the end of the experiments, the water levels in each tank were lowered to approximately 50%. Similar disturbances have caused comparable elevations in cortisol in other fish (Broadhurst et al. 2007, Butcher et al. 2007).

Although not isolated as a significant predictor of mortality, the methods of landing *Platycephalus fuscus* did significantly affect fin damage, which supports the idea of cumulative negative impacts of post-capture handling procedures. Specifically, fish held in knotted, large-mesh landing nets lost a greater proportion of their fins than those held in knotless, fine-mesh designs. Knotted large-mesh nets allowed fins to pass through meshes, causing them to tear. Similar observations have been made for other species. For example, studies with barramundi *Lates calcarifer* in Australia (Lestang et al. 2004) and bluegill *Lepomis macrochirus* in Canada (Barthel et al. 2003) showed that compared to knotless landing nets or not using any net at all, knotted designs were more likely to cause physical damage, which in some cases led to infection and death.

Another parameter that may have contributed towards some negative impacts on *Platycephalus fuscus* in both experiments was the water quality in the anglers' live wells. During Expt 1, live wells had, on average, higher temperatures, turbidity and ammonia concentrations and were lower in dissolved oxygen than the lake samples taken on the same day. The poor water quality in many of these live wells was most likely due to insufficient water exchange and aeration. Water quality in the live wells during Expt 2 was mostly similar to the river, primarily because fish were held for much shorter periods (average of 15 min) than in Expt 1 (58 min) and anglers also used some form of aeration. Concentrations of ammonia were significantly elevated in some live wells in Expt 1, although the levels were below those typically considered harmful to some species (Rowland 1995, Gilliland & Schramm 2002). Simple modifications, such as flow-through systems or regular replacement of the water with a bucket might mitigate these live well water quality issues. Other worthwhile strategies could involve aeration, ice to cool water, or chemical conditioners (Plumb et al. 1988, Gilliland & Schramm 2002), although the utility of these would need to be assessed on a species-specific basis, given that Suski et al. (2006) observed retarded recovery in angler-caught largemouth bass *Micropterus salmoides* held in live wells that were cooled and hyper-oxygenated.

While this study has identified few short-term angling impacts on *Platycephalus fuscus*, the results are restricted to the conditions examined. An important limitation of this work is that although the method of holding fish in tanks enabled immediate and short-term (<5 d) mortalities to be accurately estimated, these individuals might not have experienced all of the factors that contribute towards longer-term mortality and/or negative physiological impacts under normal conditions. Unlike tank-held fish, those that are hooked and then immediately released into the wild may suffer short- or long-term behavioural impairment or a protracted recovery from stress that could (1) reduce their ability to feed (Siepker et al. 2006), (2) increase their susceptibly to predation and infection (Barthel et al. 2003) and/or (3) affect their reproductive output (Ostrand et al. 2004). The latter impacts are of particular concern, as *P. fuscus* are often targeted during their spawning season (Kailola et al. 1993).

Ultimately, to provide an accurate and comprehensive assessment of the fate of *Platycephalus fuscus* released by anglers in southeastern Australia, the above effects which have not been accounted for need to be determined and quantified. In the meantime, the available data indicate that anglers can reduce unnecessary impacts by avoiding hook ingestion, using knotless fine-mesh landing nets, releasing fish quickly and/or using appropriate live wells.

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