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Post-release survival and physiology of angled luderick (*Girella tricuspidata*) after confinement in keeper nets in an Australian estuary

Paul A. Butcher[1]*, Matt K. Broadhurst[1], Karina C. Hall[1], and Steven J. Cooke[2]

[1]*Industry and Investment NSW, Fisheries Conservation Technology Unit, National Marine Science Centre, PO Box 4321, Coffs Harbour, NSW 2450, Australia*

[2]*Fish Ecology and Conservation Physiology Laboratory, Department of Biology and Institute of Environmental Science, Carleton University, Ottawa, Canada*

**Corresponding Author: tel: +61 2 6648 3910; fax: +61 2 6651 6580; e-mail: pbutcher@nmsc.edu.au*

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The study was initiated in response to concerns about the post-release welfare of angled luderick (*Girella tricuspidata*) after protracted confinement in keeper nets. In all, 111 fish were angled and confined for 2–250 min before being released into holding cages (with 87 controls) and monitored for 4 d. Blood was taken from fish angled and brought on board immediately ($n = 11$), angled and held in keeper nets ($n = 25$), and angled and held in monitoring cages for 4 d ($n = 12$). Blood was also taken from controls held in monitoring cages for 4 d ($n = 12$). No controls and only one angled fish died. Compared with immediately sampled angled fish, those confined in keeper nets had significantly elevated cortisol, glucose, lactate, chloride, sodium, and aspartate aminotransferase. Most of the variables returned to pre-stress levels in caged fish after 4 d. Despite this recovery, the short-term stress associated with capture and keeper-net confinement has welfare implications and justifies avoiding such a practice and/or reducing the personal daily angling quota of the species.

Keywords: angling, catch and release, fish welfare, *Girella tricuspidata*, luderick, physiology, post-release survival.

Introduction

Globally, recreational fisheries are managed by input controls such as gear restrictions and spatial or temporal closures and, more commonly, output controls that include legal sizes, personal quotas, and obligatory catch and release (Policansky, 2002). Input measures are designed to reduce the rates of exploitation, whereas output measures permit effort to be maintained through the assumption of few impacts to released fish. The need to validate this latter requirement on a species-specific basis (Cooke and Suski, 2005), combined with the popularity of such management measures, has resulted in an expanding field of relevant research, referred to as catch-and-release science (reviewed by Bartholomew and Bohnsack, 2005; Arlinghaus *et al.*, 2007).

For many species, the assumption of relatively few post-release mortalities has been satisfied, with estimates mostly <30% (Bartholomew and Bohnsack, 2005). However, it is also recognized that there are sublethal physiological impacts that can vary according to the specific capture-and-handling methods of a particular species (Cooke *et al.*, 2002; Wedemeyer and Wydoski, 2008). Such effects are important because they can progress to more chronic tertiary or whole-animal consequences that might include reduced reproductive output (Siepker *et al.*, 2007), delayed mortality from disease, predation, or an inability to acquire food (Cooke *et al.*, 2002).

Like most countries with a large recreational fishing effort, recognition in Australia of the need to assess the fate of released angler-caught fish has resulted in many recent studies on key species (e.g. Broadhurst *et al.*, 2007; de Lestang *et al.*, 2008; Hall *et al.*, 2009). In addition to estimating short-term mortality, some of these studies examined sublethal impacts and methods by which such impacts might be ameliorated. The issues tend to be species-specific, but have included the effects of angling on reproductive development during spawning for Australian bass (*Macquaria novemaculeata*; Hall *et al.*, 2009), long-term physiological change associated with hook ingestion by yellowfin bream (*Acanthopagrus australis*; Broadhurst *et al.*, 2007), and landing net induced physical damage to barramundi (*Lates calcarifer*; de Lestang *et al.*, 2008). The focus of attention for individual species has largely been dictated by perceived or intuitive issues associated with conventional catch-and-release practices.

One important Australian species for which angling post-release fate has not been assessed, but that could sustain mortalities and/or various sublethal impacts, is luderick (*Girella tricuspidata*). This species forms the basis of a specialized recreational fishery in New South Wales (NSW), Australia (Scandol *et al.*, 2008). Anglers target luderick throughout the year, but particularly during austral winter (June–August), when they aggregate at the mouths of estuaries to spawn (West and

Gordon, 1994). The total NSW annual catch has been estimated at almost one million individuals (Henry and Lyle, 2003), of which some 30% are released, either because they are smaller than the minimum legal total length (L_T – 27 cm) or as a consequence of size-specific grading in response to personal quotas (20 fish person^{-1} d^{-1}).

Size grading is common among some luderick anglers. Immediately after capture, fish are placed into a submerged mesh bag (termed a keeper net) attached to the side of the boat or a rock platform. Up to 20 luderick may be confined in a single keeper net (usually for 1–3 h), with the net repeatedly retrieved and deployed as fish are added or removed. The confinement of luderick in keeper nets at high density before release may be of concern, primarily because similarly handled species overseas have demonstrated a range of associated lethal and sublethal impacts (Pottinger, 1997; Raat *et al.*, 1997). Also, although not directly comparable, luderick caught, confined for extended periods, then discarded from commercial gillnets incur mortalities and severe sublethal physiological impacts among survivors (Ling and Wells, 1985; Broadhurst *et al.*, 2009).

It is well established that teleosts respond to the stressors of high-density confinement, poor water quality, exercise, or other stressors through a series of biochemical and physiological processes that manifest as measurable changes to their blood chemistry (Kieffer, 2000; Barton, 2002; Portz *et al.*, 2006). Rapid increases in plasma catecholamines result in elevated plasma cortisol and glucose (Sumpter, 1997). Plasma lactate may also increase with severe exercise or hypoxia, and other electrolytic disturbances can follow, including changes in plasma chloride and sodium and potassium concentrations (McDonald and Milligan, 1997; Portz *et al.*, 2006). Furthermore, permanent tissue or cell damage can be indicated by increased intracellular enzyme concentrations in the plasma, such as aspartate aminotransferase (AST; Morrissey *et al.*, 2005).

In any study that seeks to provide a comprehensive assessment of the fate of released fish, it is desirable that in addition to quantifying immediate and short-term mortalities, adequate measures of stress are recorded among survivors to assess the full extent of impacts that could result in delayed mortality, impaired welfare, or reduced fitness. Based on this logic, our aims in this study were to quantify the short-term (i) survival and (ii) temporal physiological response of luderick after being angled, held in keeper nets, and then released.

Material and methods

Collection of control fish

During March and April 2008, 120 luderick (21–40 cm L_T) were either seined or gillnetted in Boambee Creek, Coffs Harbour (30°20′S 153°05′E). Netted fish were placed immediately into 380-l tanks (stocking density <25 kg m^{-3}) containing seawater (~35 psu) at ambient temperature, then transferred to the National Marine Science Centre (NMSC), Coffs Harbour, where they were housed in three 3000-l flow-through (5 l min^{-1}), aerated holding tanks. The captive fish were monitored for mortality and fed school prawns (*Metapenaeus macleayi*) at a rate of 1% biomass per day.

Angling experiment

The experiment was done in the Clarence River (29°24′S 153°20′E) over 8 d, starting on 11 July 2008, and it involved ten volunteer anglers on five boats. All participants targeted luderick between 08:00 and 16:00 on the first day of the experiment, using conventional rods and reels equipped with 4–5 kg monofilament lines, quill floats, and similar J-hooks [absolute size (Ralston, 1990) of 96–133 mm^2], baited with filamentous green and/or black algae (*Enteromorpha* spp.).

After each fish was caught, anglers measured the L_T to the nearest 0.1 cm and noted any damage (see below). Anglers were asked to place undersize fish into individual 20-l cages made from 0.3 × 0.4 m polyvinyl chloride (PVC) buckets. Each 20-l cage had one top and three lateral 230-cm^2 openings covered by 6-mm PVC mesh. Any legal-size fish were placed into conventional rectangular keeper nets (made from 20 mm diamond-shaped, knotted polyamide mesh, and measuring 1.0 × 0.4 m). The 20-l cages and keeper nets were secured in the river on the upstream side of the boat (as per normal angling procedures). Anglers then completed a datasheet describing the capture of each fish (see below).

In addition to the luderick caged by anglers, 11 fish were immediately sampled for blood (3 ml) using 21-gauge needles attached to syringes pre-heparinised with 125 USP units of lithium heparin. Sampling followed the methods described by Haddy and Pankhurst (1999) and was within 30 s of capture, by a researcher aboard two boats selected randomly. Such an approach is generally accepted as the most appropriate for estimating the baseline physiological status of fish (Hanson *et al.*, 2009), and more so than the only alternative, which is to hold acclimatized wild-caught fish in aquaria and subject them to sensory deprivation (Suski *et al.*, 2003; Arlinghaus *et al.*, 2009).

To assess the combined physiological consequences of angling and retention, a further 25 fish confined in keeper nets by different anglers were similarly sampled for blood after being held for varying periods (between 19 and 170 min). To avoid any confounding effects on confined fish, the fish were only sampled when anglers either added or removed individuals from the keeper nets (as part of their normal fishing behaviour). Some of the blood-sampled, angled fish were immediately released back into the river, whereas others were placed into a 380-l water-filled tank and transferred to one of the six large floating cages (termed monitoring cages; 2.3 m in diameter and 2.5 m deep; see Butcher *et al.*, 2006, for details) that were moored behind a semi-submerged rock wall ~0.1–3 km upstream from the angling site, but in an area with similar water quality and low flow.

The remaining fish in the keeper nets were retained (as above) by the anglers until they caught either one undersize or 20 legal-size fish, or they stopped fishing. Researchers then travelled to the anglers and collected their datasheets. Any 20-l cages containing undersize luderick were lifted on board the research vessel along with ~15 l of water, and legal fish were removed individually from the keeper net (by the angler) and placed into the 380-l tank. The fish were then immediately transported and released into the monitoring cages (in groups of 16–23 fish cage^{-1}). Fish of similar size were released into separate cages or clipped on the right or the left pectoral fin, for identification.

One day (24 h) after angling had finished, 87 control fish were transported from the NMSC to the monitoring cages in two 380-l tanks supplied with oxygen. They were clipped on the lower caudal fin (for identification as controls), transferred by vessel as above, then distributed in groups of 10–17 among the cages so that, when combined with the angled fish, there were 33 fish cage^{-1}.

All caged luderick were monitored and offered school prawns, sea lettuce (*Ulva* spp.), and/or filamentous green and black algae daily. Four days (96 h) after the last luderick was angled, each monitoring cage was lifted and two angled fish (that had not previously been bled) removed (using a scoop net), and blood was taken within 3 min of initial disturbance. All fish sampled for blood were clipped on the upper caudal fin for identification at the end of the experiment. On the following day, the cages were again lifted and two controls sampled similarly (to provide the same relative monitoring period as the angled fish), before all fish were removed, measured (L_T), and assessed for scale or fin damage. All fish were then released back into the river.

Data collection and analyses

Daily replicates of dissolved oxygen (mg l^{-1}) and turbidity (NTU) were taken at the monitoring and angling sites using an Horiba U–10 water-quality meter. Air temperature (°C) was recorded with a digital thermometer. A Tyco EC 300 datalogger was attached to the base of one of the monitoring cages and used to record water temperature (°C) and salinity (psu) every 15 min over the duration of the experiment.

The data collected for each angled fish included: angler name; bait type; trace length (m); times of capture and release into the keeper nets or 20-l cages (to calculate air exposure duration); playing time (s); capture depth (m); landing method (net type or otherwise); whether it hit the boat or was dropped during hook removal, restraint method (e.g. hands or towel); anatomical hook location and any associated damage (including bleeding and scale or fin loss); whether or not the hook was removed; L_T; and the status (i.e. alive or dead). Researchers also recorded when each fish was collected, which was used to calculate the length of time fish were held in the keeper nets or 20-l cages before release. All data were collated as either continuous (mean $\pm$ s.d. or s.e.) or categorical (count) variables.

The blood samples were stored on wet ice for up to 3 h, centrifuged (at 839 g for 3 min), and the plasma transferred into a 2-ml vial and placed in a freezer (−18°C). To minimize the potential for changes in tissue biochemistry, all plasma samples were processed within 7 d (Barton, 2002) at IDEXX Laboratories (Brisbane, Australia) using an Olympus Autoanalyser (AU400, Olympus, Hamburg; all assays except cortisol) or Immulite Instrument (Immulite 2000, Siemens, USA; cortisol assay only). These assay methods are considered among the most precise in clinical medicine and veterinary applications (Lasnier *et al.*, 2000). Potassium (mmol l^{-1}), chloride (mmol l^{-1}), and sodium (mmol l^{-1}) were measured using the indirect standard electrode method. This technique was chosen because it was recently demonstrated to be strongly correlated with standard flame photometry for plasma samples collected from other teleosts (*Oncorhynchus* spp.; S. J. Cooke, unpublished data).

Glucose (mmol l^{-1}) and lactate (mmol l^{-1}) were both measured using the enzymatic approach, with the hexokinase and pyruvate methods, respectively. AST (enzyme number 2.6.1.1—IU l^{-1}) was measured using the kinetic UV test with the pyruvate/glutamate method. Cortisol (ng ml^{-1}) was measured using a solid-phase competitive chemiluminescent enzyme immunoassay.

Size frequency distributions (1 cm L_T intervals) of all angled and control fish were compared using a two-sample Kolmogorov–Smirnov test. A two-tailed Fisher's exact test was used to determine the independence of the treatment of fish (angled or control) on their mortality. Linear regression analyses were used to investigate the relationships between L_T and the various physiological variables for four groups of fish. The groups included luderick that were: (i) angled and immediately sampled; (ii) angled and held in keeper nets for up to 170 min; (iii) angled, held in keeper nets, then transferred to monitoring cages for 4 d; and (iv) controls held in the monitoring cages for 4 d. The same analyses were used to investigate any temporal variation in blood chemistry among those luderick confined in keeper nets, i.e. group (ii) above.

Data for each physiological variable were tested for heteroscedasticity (Bartlett's test) and normality (Wilk–Shapiro) and $\log_{10}(x+1)$ transformed if required. Depending on the results of these preliminary tests, the hypothesis of no differences in the mean concentrations of the different physiological variables among the four groups above was tested using either one-factor parametric analyses of variance (ANOVA), or non-parametric Kruskal–Wallis ANOVA. Significant F-ratios or H-values were investigated further using the Tukey-type comparison of means (TCM) tests. All statistical analyses were done with JMP (version 7) software at the $p < 0.05$ significance level.

Results

Catch data and survival

Along with the 87 controls, 111 angled luderick were released into the monitoring cages. Both groups had similar size distributions

Table 1. Mean continuous ($\pm$ s.d. and range, minimum and maximum in parenthesis) and categorical variables collected for luderick.

Parameter	Mean or total number
Total length (cm)	
Angled	31.5 ± 2.7 (23.0–38.0)
Control	31.1 ± 3.9 (21.5–40.1)
Period in keeper net or 20-l cage (min)	80.1 ± 53.5 (2.0–250.0)
Trace length (cm)	31.9 ± 10.4 (20.0–50.0)
Capture depth (m)	1.6 ± 0.5 (0.6–2.4)
Angler	
1	37
2	27
3	23
4	11
5	8
6	5
7–10	0
Bait type	
Green filamentous algae	72
Black filamentous algae	39
Playing time (s)	
<10	60
11–30	42
31–60	8
>120	1
Fish landing method	
Knotless, fine-mesh net	70
Knotted, course-mesh net	2
No net	39
Fish restraining method	
Dry bare hand	69
Dry towel	42

Continued

Table 1. *Continued*

Parameter	Mean or total number
Air exposure (s)	
<10	3
11–30	88
31–60	15
>120	5
General hook location	
Ingested	5
Mouth	106
Specific hook location	
Upper jaw	57
Corner of mouth	33
Lower jaw	6
Roof of mouth	6
Ingested	5
Gill arch	1
Floor of mouth	0
Unknown	3
Fish contact with boat during capture	
Yes	2
No	109
Fish dropped after hook removal	
Yes	5
No	106
Hook removed	
Yes	109
No	2
Blood at mouth or gills	
Yes	6
No	105
Fin damage	
Yes	2
No	109
Scale damage	
Yes	1
No	110

(Kolmogorov–Smirnov $Z = 0.13$; $p > 0.05$; Table 1). Only three undersize fish (23.0, 26.0, and 26.5 cm L_T) were caught. Environmental conditions at the monitoring site remained similar within and among days with means ($\pm$s.d.) of 17.1 $\pm$ 3.7 and 18.2 $\pm$ 0.9°C for air and water temperature, 7.6 $\pm$ 0.4 mg l^{-1} for dissolved oxygen, 2.8 $\pm$ 1.6 NTU for turbidity, and 29.6 $\pm$ 4.3 psu for salinity.

No control fish died, either when held at the NMSC (after gill-netting and seining) or in the monitoring cages for 4 d during the experiment. Of the angled fish, only one died (within 30 min of release into a monitoring cage), providing a non-significant mortality of 0.9% (Fisher's exact test; $p > 0.05$). The dead fish initially appeared to be in good condition, but sustained a 10-mm lesion on its anterior cranium (penetrating 1–2 mm into the tissue above its brain) during confinement in the keeper net for 82 min and had minor blood clotting on the lamellae of its right gill arch.

There was little variation among luderick in how they were caught and handled (Table 1). Six of the ten anglers caught all the fish, and most used green filamentous algae (65%) as bait fished at depths <2.4 m (Table 1). Most (92%) fish were played for <30 s, then exposed to air for <30 s (82%) during hook removal and measurement. Many (625) were lifted with a landing net before being handled with dry bare hands (63%) or a dry towel (37%; Table 1). Most fish were either hooked in the upper jaw (51%) or corner (30%) of the mouth, with only five ingesting their hooks (Table 1). The line was cut and the hook left in place for two of the hook-ingested individuals. Very few fish hit the boat during landing, were dropped after their hook was removed, bled, or had fin or scale damage (Table 1). Before release into the monitoring cages, fish were kept in the keeper nets or 20-l cages for a mean ($\pm$s.d.) of 80.1 $\pm$ 53.5 min (Table 1).

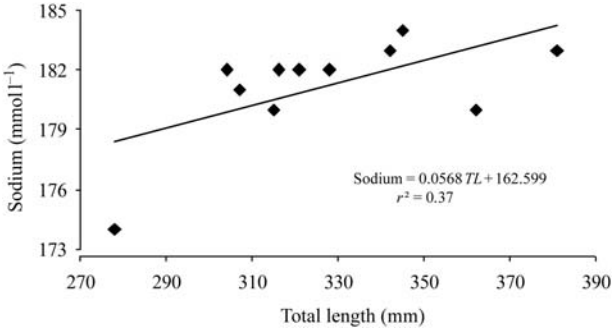

Figure 1. Significant linear regression ($p < 0.05$) between total length (mm) and plasma sodium concentrations (mmol l^{-1}) for luderick angled and immediately sampled.

Physiology

There were no significant relationships between L_T and the various physiological variables for any of the four assessed groups of fish, except for sodium which exhibited a positive relationship with size for fish angled and immediately released ($r^2 = 0.37$, $p < 0.05$; Figure 1). Significant positive linear relationships were detected between the time fish were held in keeper nets and their concentrations of plasma glucose ($r^2 = 0.33$, $p < 0.01$), potassium ($r^2 = 0.41$, $p < 0.01$), and lactate ($r^2 = 0.16$, $p < 0.05$; Figure 2). In contrast, there were no temporal effects on the concentrations of plasma cortisol, chloride, sodium, or AST in the luderick fish confined in keeper nets ($p > 0.05$).

All biochemical variables varied significantly among the four groups of fish (ANOVA, $p < 0.001$; Table 2). Compared with angled fish that were sampled immediately, those held for up to 170 min in the keeper nets had significantly elevated (by up to nine times) concentrations of all biochemical variables examined (TCM, $p < 0.05$), except for potassium (TCM, $p > 0.05$; Table 2). The potassium concentrations in control and angled fish held in the monitoring cages for 4 d were similar and significantly greater than the concentrations in angled fish held in the keeper nets (TCM, $p < 0.05$; Table 2). There was no significant difference in potassium concentrations between angled and immediately sampled fish and control fish (TCM, $p > 0.05$; Table 2). Conversely, compared with fish angled and sampled immediately and those held in keeper nets for up to 170 min, all fish in the monitoring cages had significantly lower concentrations of lactate and sodium (TCM, $p < 0.05$; Table 2). For cortisol, glucose, chloride, and AST, angled fish held in the keeper nets had significantly greater concentrations than angled and immediately sampled fish and those angled and control fish held in monitoring cages (TCM, $p < 0.05$; Table 2).

Discussion

The lack of any immediate deaths and only one short-term fatality among the angled and released luderick in this study can be attributed to the optimal environmental conditions, relatively mild

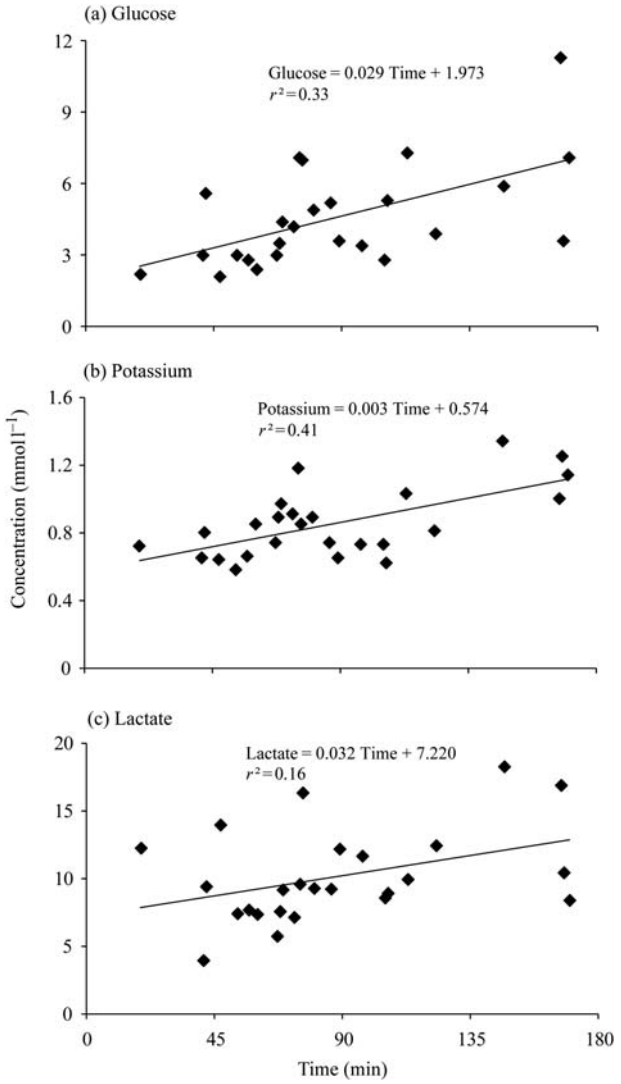

Figure 2. Significant linear regressions ($p < 0.05$) between the time luderick were held in the keeper nets and the concentrations (mmol l^{-1}) of plasma (a) glucose, (b) potassium, and (c) lactate.

catching procedures, and the apparent physical resilience of the species. More specifically, all fish were collected during winter and most were angled in shallow water, hooked in the upper jaw or corner of the mouth (with minimal blood loss), played and exposed to air for <30 s, and securely held during hook removal. Previous studies have shown that such treatments rarely evoke sufficient trauma to result in wide-scale immediate mortality (for reviews, see Bartholomew and Bohnsack, 2005; Arlinghaus *et al.*, 2007). Further, although the subsequent confinement of nearly all angled luderick in keeper nets at high densities would have undoubtedly caused extensive physical interactions, this resulted in minimal associated scale or fin damage. The physical robustness of the species is also supported by the lack of any deaths among the few fish that had their ingested hooks removed, a procedure that typically causes considerable trauma and short-term fatality among most species (Arlinghaus *et al.*, 2007).

Despite their apparent ability to withstand the immediate physical consequences of angling, luderick experienced significant physiological alterations during their subsequent handling, most of which can be attributed to keeper-net confinement, because they were well beyond the levels routinely expected for fish after mouth-hooking and <30 s play and air exposure periods (Meka and McCormick, 2005). However, a lack of information on the response of the species and its congenerics to normal daily stressors means that any interpretations of the physiological data are mostly limited to relative comparisons among the four groups of fish and within their limited size range (220–381 cm L_T). Nevertheless, by considering the known dynamics of the various measured parameters in other species, and their observed temporal variation in luderick, it is possible to discuss the potential severity of impacts and longer-term consequences.

It is likely that angling luderick evokes a rapid and acute response to stress, but for the fish immediately sampled, insufficient time had elapsed for the associated stimuli to register as major changes in their blood chemistry (Barton, 2002). In our study, concentrations of plasma cortisol and glucose remained low and were comparable with previous estimates for similarly treated luderick (Broadhurst *et al.*, 2009) and within the ranges of baseline estimates for other species (Barton, 2002). Of these two variables, cortisol is perhaps the more commonly used

Table 2. Means (± s.e.) of blood-chemistry variables for luderick exposed to three angling-and-retention treatments and controls held in cages for 4 d.

	Angled and sampled immediately		Angled and held in keeper nets for up to 170 min		Angled and held in cages for 4 d		Control and held in cages for 4 d		
Blood variable	***n***	**Mean (s.e.)**	***n***	**Mean (s.e.)**	***n***	**Mean (s.e.)**	***n***	**Mean (s.e.)**	***F*- or *H*-value**
Cortisol (ng ml^{-1})	11	11.9^{a} (2.4)	25	92.8^{b} (13.9)	12	15.1^{a} (2.2)	12	20.9^{a} (5.0)	$F = 16.02^{***}$
Glucose (mmol l^{-1})	11	1.1^{a} (0.2)	25	4.6^{b} (0.4)	12	2.7^{a} (0.1)	12	2.5^{a} (0.1)	$H = 38.08^{***}$
Lactate (mmol l^{-1})	11	2.4^{b} (0.2)	25	10.1^{c} (0.7)	12	0.7^{a} (0.1)	12	0.7^{a} (0.1)	$F = 232.86^{***}$
Chloride (mmol l^{-1})	11	154.4^{a} (0.9)	25	167.4^{b} (1.5)	12	155.8^{a} (1.2)	12	150.2^{a} (1.7)	$F = 28.16^{***}$
Sodium (mmol l^{-1})	11	181.2^{b} (0.8)	25	206.1^{c} (1.7)	12	173.3^{a} (1.5)	12	169.5^{a} (2.1)	$F = 113.30^{***}$
Potassium (mmol l^{-1})	11	0.9^{ab} (0.1)	25	0.9^{a} (0.1)	12	2.6^{c} (0.4)	12	2.2^{bc} (0.3)	$H = 26.17^{***}$
AST (IU l^{-1})	11	3.3^{a} (1.0)	25	22.3^{b} (2.3)	12	11.0^{a} (3.0)	12	6.6^{a} (1.4)	$F = 20.48^{***}$

One-way parametric or non-parametric (Kruskal–Wallis) ANOVA was carried out on each blood variable. Dissimilar superscript letters are used to separate significantly different treatments identified by the Tukey multiple comparisons of means tests ($p < 0.05$). AST, aspartate aminotransferase; n = number of specimens sampled. Glucose and potassium were $\log_{10}(x + 1)$-transformed.
$^{***}p < 0.001$.

indicator of acute stress; for most species, its concentrations are typically elevated within a few minutes of disturbance (Barton, 2002).

Despite the low levels of cortisol and glucose in fish sampled immediately, sodium was significantly elevated (compared with the levels in angled fish held in monitoring cages for 4 d) and, more importantly, was positively correlated with the limited range of sampled total lengths. Perhaps the latter relationship was attributable to size-specific differences in playing times, with larger fish taking slightly longer to land and hence incurring greater stress (Cooke and Philipp, 2004; Meka and McCormick, 2005). However, the regression was largely driven by one low value of sodium for the smallest fish, the removal of which returned a non-significant F-ratio ($p > 0.05$). Additional data across a greater range of sizes of luderick would be required to facilitate more definitive conclusions about any associated effects on sodium concentrations immediately after angling.

The potential for size-specific variation among physiological responses did not extend to fish that were held in the keeper nets for 19–170 min following angling, with all fish demonstrating similar and significant elevations in most of their blood constituents relative to fish sampled immediately after angling. These elevated concentrations were comparable with those observed for other fish after exposure to severe angling stressors (Suski *et al.*, 2004; Meka and McCormick, 2005). In particular, plasma lactate and glucose in luderick were 3–4 times greater after confinement than at the time of capture and, along with potassium, had a significant positive relationship with the time spent in keeper nets (ranging from 19 to 170 min). Cortisol was also considerably elevated (by nine times) in fish confined in keeper nets, and for some approached the levels (mean $\pm$ s.e. of 128.8 ± 29.2 ng ml^{-1}) observed by Broadhurst *et al.* (2009) for luderick entangled in gillnets for up to 13 h.

Further support for a strong physiological disturbance in luderick confined in keeper nets was provided by the elevation of chloride and sodium to levels ~10% greater than fish sampled immediately after angling (Barton, 2002). Plasma AST, an indicator of tissue damage (Morrissey *et al.*, 2005), was also significantly elevated (seven times), but compared with other species, the recorded concentrations of AST in luderick were comparatively low and probably caused by capture and handling rather than confinement (e.g. Morrissey *et al.*, 2005; Thompson *et al.*, 2008).

Previous research on many species indicates that most blood-chemistry variables, including glucose, lactate, cortisol, chloride, and sodium, typically recover to near baseline values within ~120 min after angling and handling (Suski *et al.*, 2007). Only when technical or environmental conditions are extreme (e.g. long play times or warm water temperatures) would recovery be protracted (Cooke and Suski, 2005). The observed elevation of nearly all blood-chemistry variables in luderick held for up to 170 min in the keeper nets suggests that either this species has (i) a comparatively slower rate of recovery from capture-induced stressors or, more likely, (ii) that their confinement was stressful. This latter hypothesis is supported by the positive relationships between confinement period and plasma lactate and glucose, which extended across 170 min. In the absence of any other stressors, lactate and glucose in marine fish would typically peak by 30 and 20 min, respectively, after initial disturbance, and not continue to rise (as observed here for luderick; Frisch and Anderson, 2000; Begg and Pankhurst, 2004; Milston *et al.*, 2006; Cooke *et al.*, 2008). Hypotheses (i) and (ii) are also partially supported by the only other study done to assess the protracted physiological response of luderick to capture and handling (Ling and Wells, 1985). During the earlier work, luderick were caught in gillnets (for between 45 and 90 min) before being released into tanks and then, along with controls, repeatedly sampled for blood via a cannula over 12 h. Whole blood nucleoside triphosphate (a likely indicator of lactate metabolism) increased among the gilled-and-released fish and remained elevated across the sample time, and although lactate eventually decreased from 12 to 3 mmol^{-1}, the response was similarly protracted (Ling and Wells, 1985). Such a response might be expected because, by restricting the operculum and compromising ventilation, gillnetting typically evokes a high metabolic cost in fish (Broadhurst *et al.*, 2009). The comparable levels of lactate observed in gilled-and-released luderick by Ling and Wells (1985) and those angled and held in keeper nets in the present study reinforces the severity of the latter treatment.

Given the above, and the positive regressions between the time spent in keeper nets and the concentrations of plasma glucose, potassium, and lactate in angled luderick, it is likely that stress levels remained elevated (or even increased) after fish were released into the monitoring cages. However, it is clear that all fish recovered within 4 d. In fact, the concentrations of plasma lactate and sodium in caged fish were less than those in angled fish sampled immediately, suggesting that caged individuals were expending little energy. Although the concentrations of glucose and cortisol in caged fish were also not significantly different from those in fish angled and sampled immediately, the means were slightly greater. The results of other studies suggest that such minor elevations of cortisol and glucose typically reflect a low level of chronic stress when wild fish are confined, even in large monitoring cages (Mommsen *et al.*, 1999; Barton, 2002; Butcher *et al.*, 2007).

Like cortisol and glucose, plasma potassium levels in the caged angled and control fish were also elevated (by some three times) above fish sampled immediately after angling or after being retained for up to 170 min in keeper nets. Normally, such a result might also support chronic stress associated with confinement, but sodium was not elevated and it actually decreased. Both of these ions have similar dynamics, increasing in response to anaerobic exercise and an associated ionic/osmotic disturbance (Gonzalez and McDonald, 1992). Perhaps, the observed divergent trend simply reflects insufficient data and/or normal diurnal variation, particularly given that the observed mean concentrations (2.2 and 2.6 mmol l^{-1}) were well within the range (0.1–8.4 mmol l^{-1}) typically observed for other, unstressed species (Folmar *et al.*, 1992; Martem'yanov, 2001). More data are required to explore the significance of this trend.

Despite some evidence of stress associated with their confinement in the monitoring cages, it is apparent that the luderick generally recovered from the physiological disturbance associated with being caught and held in keeper nets. However, such recovery does not preclude the potential for tertiary welfare impacts. Many of the blood-chemistry variables were elevated to levels that have previously been demonstrated to have tractable negative impacts on other species, which could ultimately extend to luderick (Pickering and Pottinger, 1989; Pankhurst and Sharples, 1992; Kieffer *et al.*, 1995; Haddy and Pankhurst, 1999; Cooke and Philipp, 2004).

Irrespective of the potential for sublethal impacts, the severe changes observed in blood physiology raise welfare issues about causing unnecessary stress in fish (Davie and Kopf, 2006). Such concerns have resulted in keeper nets being prohibited in some countries (e.g. Netherlands and Germany; Raat *et al.*, 1997). Based on the results from this study, a similar approach might be warranted in Australia, with any unwanted fish immediately released, or if they are to be consumed, immediately euthanized. Alternatively, reducing the daily personal quota for luderick (currently 20 fish in NSW) would ultimately translate to fewer fish being subjected to the stressors associated with being angled then held in keeper nets and/or reduce their confinement times (with fish being more rapidly graded according to size).

Although the results of this study have quantified the immediate and short-term fate of luderick after being angled and released, it is important to remember that the results are limited to boat-based anglers targeting aggregations of mostly adult spawning fish in winter. There are few data available on the effects of angling and release on juveniles (<25 cm L_T) which, based on the observed size-specific effect on sodium, might be more susceptible to stressors. Also, we did not assess the fate of luderick caught and released by anglers on rock platforms. Conceivably, fish retrieved across rocks might suffer greater physical injury (and possibly stress), especially in areas with the movement of large volumes of water (i.e. by tide or waves). In addition, there is no information on the fate of fish released into predator-rich waters or those caught and released during warm air and water temperatures (when physiological responses are often more extreme; Broadhurst *et al.*, 2009). Acquiring the above additional information would facilitate a more comprehensive assessment of the post-release survival of angled luderick. In the interim, the results from our study provide sufficient justification to encourage anglers to avoid using keeper nets, a recommendation consistent with similar previous studies on a range of other teleosts (e.g. Pottinger, 1997; Raat *et al.*, 1997).

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