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Evaluating the consequences of catch-and-release recreational angling on golden dorado (*Salminus brasiliensis*) in Salta, Argentina

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ABSTRACT

Golden dorado (*Salminus brasiliensis*) is increasing in popularity as a target of recreational anglers practicing catch-and-release (C&R) in northern Argentina and bordering countries, however science-based best practices have yet to be developed for this iconic freshwater gamefish. We assessed the consequences of C&R on golden dorado captured by anglers on the Juramento River, in Salta, Argentina. Physical injury, physiological stress responses (blood glucose, lactate, pH), reflex impairment, and movement response post-release were compared among handling treatments for golden dorado. The 0 min and 2 min air exposure groups had significantly higher blood glucose and blood lactate concentrations relative to fish in the baseline group, while blood pH indicated evidence of acidosis in the 2 min air exposure treatment relative to baseline values. Golden dorado in the 2 min air exposure group also had significantly greater reflex impairment compared to fish without air exposure. An additional 24 golden dorado were affixed with radio tags to examine short-term (20 min) post-release behavior with air-exposure treatments of 0 min ($n = 11$) and 2 min ($n = 9$), as well as fish that were transported downstream in submerged recovery bags ($n = 4$). Subsequent relocations of tagged golden dorado were conducted every 1–2 days up to 8 weeks after capture. Upon immediate release, fish often exhibited fallback (-43 ± 49 m, $n = 20$), although post-release movement was not significantly different among treatment groups. Fallback distance was correlated with total reflex impairment scores. The translocated fish released downstream exhibited greater upstream movement immediately following release, with three fish returning to the location of capture within 4–12 days. No immediate mortality was observed for golden dorado in the physiology assessment, and limited evidence of short-term mortality was present for tracked fish (22 of 24 tagged fish movement detected >2 days post-tagging, ≤8% mortality). Our results indicate that minimizing air exposure should be advocated as part of guidelines for C&R for golden dorado. Our study also revealed that impairment of the equilibrium reflex is useful for anglers as an indicator for golden dorado vitality and potential need for monitoring recovery prior to release.

1. Introduction

Catch-and-release (C&R), whether to comply with regulations or because of conservation ethic, is a common strategy for the conservation and management of recreational fish stocks (Arlinghaus et al., 2007; Danylchuk and Cooke, 2011). The prevailing assumption of this strategy is that fish survive with negligible injuries or sub-lethal alterations in behavior or physiology (Cooke and Schramm, 2007; Cooke et al., 2012). Nevertheless, studies on a number of recreationally targeted species have shown wide-ranging responses to C&R angling including physical injury (Cooke and Suski, 2004; Skomal, 2007), prolonged physiological recovery periods (Suski et al., 2007; Cooke et al., 2013), reflex impairment (Davis, 2010; Brownscombe et al., 2013; Brownscombe et al., 2015), post-release predation (Cooke and Philipp, 2004; Campbell et al., 2010), delayed mortality (Diamond and Campbell, 2009), alterations in behavior (Rapp et al., 2012), and reduced spawning success (Richard et al., 2013). Individual recovery from C&R angling is context specific (Raby et al., 2015) and can vary according to species (Cooke and Suski, 2005), angling gear (Dotson, 1982),

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handling practices (Rapp et al., 2012), hook location (Meka, 2004), water temperature (Gale et al., 2013), duration of air exposure (Ferguson and Tufts, 1992; Suski et al., 2007), life history stage (Brobbel et al., 1996), body size (Lukacovic and Uphoff, 2002), and depth of capture (Jarvis and Lowe, 2008).

While C&R is often promoted as a conservation measure, it is frequently employed without an understanding of how elements of an angling event actually influence the fate of fish once released (Arlinghaus et al., 2007; Cooke and Schramm, 2007). Although a list of best practices can be applied across species and has shown promise at mitigating sub-lethal impacts and mortality (Cooke and Suski, 2005), such general guidelines can be vague or provide conflicting advice on best practices for capture and release in particular environments and certain species (Pelletier et al., 2007; Arlinghaus et al., 2010). Species-specific variation in response to C&R should be considered when developing guidelines for the use of this conservation tool (Cooke and Suski, 2005; Cooke and O'Connor, 2010). Context specific management is pertinent in recreational fisheries in emerging economies where there is limited capacity for management, increasing pressures for resource development, and limited basic knowledge of recreationally targeted and often imperiled species (Bower et al., 2014 Cooke et al., In Press).

Recreational angling is growing in popularity in emerging economies and remote locations around the world (Bower et al., 2014; Barnet et al. in Press), with C&R fishing often being presented as a non-destructive way to protect fish stocks while providing additional economic opportunities (Wood et al., 2013; Barnet et al. in Press; Cooke et al., In Press). Golden dorado (*Salminus brasiliensis*) in the Juramento River of Salta, Argentina, is an example of a growing remote C&R fishery in South America. The Juramento River has historically been a hook and line subsistence harvest fishery for bagre *Heptapterus mustelinus*, sábalo *Prochilodus lineatus*, pejerryes *Odonthethes bonariensis*, palometa *Serrasalmus* sp., and golden dorado (*Salminus brasiliensis*). Golden dorado in the Juramento River are piscivorous, egg laying, potadromous fish of the Characidae family (Aguilera et al., 2013). Golden dorado are also found in rivers of Bolivia, Brazil, Paraguay, and Uruguay (Hahn et al., 2011). Recently golden dorado in the Juramento River were placed under a C&R-only regulation by the provincial Environmental Ministry. To date, however, no study has been conducted to evaluate the consequences of C&R on golden dorado.

The purpose of our study was to evaluate the impacts of C&R on golden dorado in the emerging recreational fishery on the Juramento River. Specifically, we quantified physical injuries, physiological stress responses, reflex impairment, immediate and short-term mortality, and short-term movement patterns of golden dorado following capture and release. We predicted that golden dorado that experienced greater fight times and duration of air exposure would show elevated physiological stress indices, reflex impairment, and greater fallback distances following release.

2. Materials and methods

2.1. Study site and capture methods

Golden dorado were sampled from May 2, 2015 to June 29, 2015 on the Juramento River in the northern Argentinian province of Salta (Fig. 1). The river is fished on guided trips with anglers from the region. The river is also regularly fished without guides by local anglers. C&R fishing for golden dorado is mandated in the region by the local enforcement agency, although anecdotal reports of harvest of golden dorado still continues (pers. comm. 2015). The climate of the Neotropical Chaco region in Salta is characterized by distinct seasons, a cooler dry season from May through August, and a warmer wet season from September through March. The Juramento River is the upper reach of the Salado River, which drains into the Paraná River basin. The Juramento River is turbid with high sediment load and bank deposition from adjacent intensive agricultural land use runoff, and features substantial and often unregulated irrigation diversion canals. The reach of the river included in our study is regulated by a 5 Mw hydropower earthen dam without fish passage. The dam marked the upstream limit of our study site and the downstream study limit was the small settlement of El Quebrachal

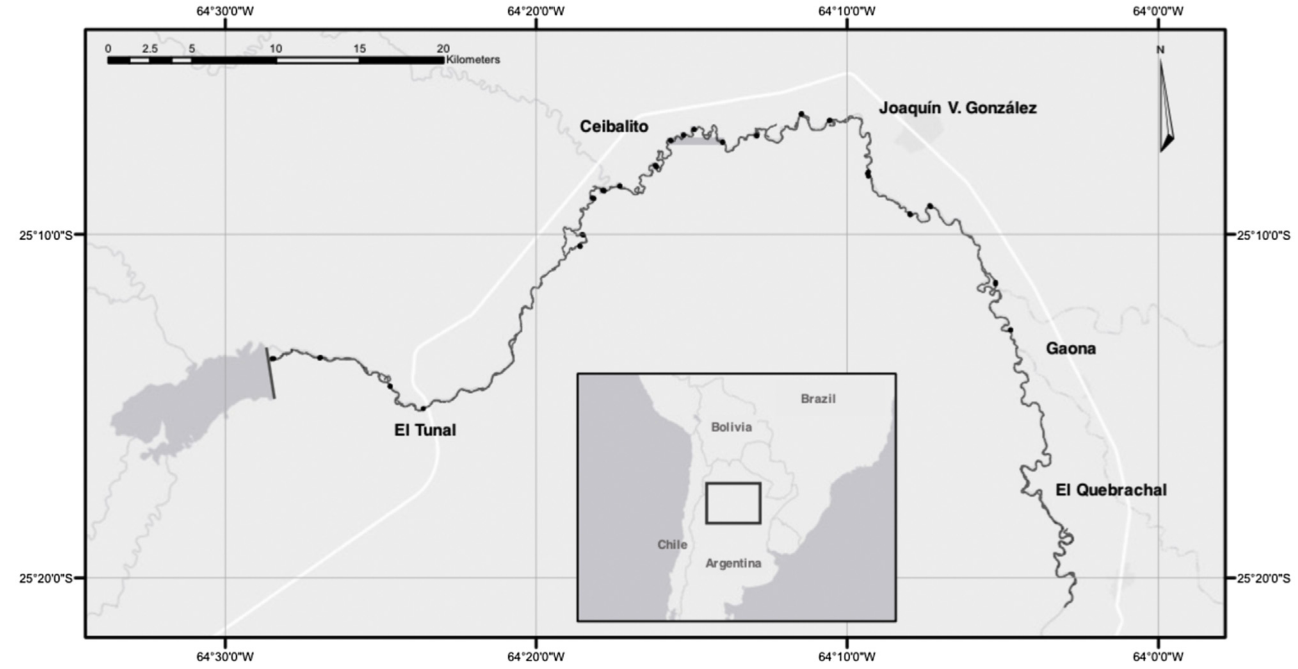

Fig. 1. Study area of the Juramento River in the Salta province of Northern Argentina. The river section in dark gray highlights the extent (~100 km) of the sampling area for the catch-and-release evaluation. The dark line at the reservoir west of El Tunal represents the 5 Mw hydropower dam marking the upstream delineation of the study site. Tagging locations are indicated by the black dots on the map.

Table 1

Summary of physiology and reflex assessments (mean ± SD) for golden dorado following catch-and-release. RAMP1 and RAMP2 indicates reflex score values (maximum score of 1 possible for RAMP total, and 0.2 for individual reflexes, i.e. equilibrium) taken immediately after the angling/handling period and after 1 h recovery bag period, respectively. Baseline RAMP and physiology values were assessed immediately upon landing prior to any handling.

Treatment	N	Fork length (mm)	Glucose (mg/dL)	Lactate (mg/dL)	pH	RAMP1 total	RAMP1 – equilibrium	RAMP2 total	RAMP2 – equilibrium
Baseline (Control)	14	492 ± 140	55 ± 12	50.1 ± 16.9	7.51 ± 0.14	0.03 ± 0.11	0.01 ± 0.05	n/a	n/a
Angling – 0 min air	12	552 ± 88	125 ± 25	169.9 ± 46.8	7.41 ± 0.17	0.20 ± 0.21	0.05 ± 0.09	0.08 ± 0.16	0 ± 0
Angling – 2 min air	10	560 ± 87	126 ± 23	176.7 ± 31.89	7.33 ± 0.13	0.38 ± 0.24	0.12 ± 0.10	0.12 ± 0.14	0.02 ± 0.07

(pop: 4500), covering a total distance was approximately 100 km (Fig. 1).

Angling was conducted from rafts that drifted with the current. Fish were caught by recreational anglers via fly fishing (6–8 wt rods, 9–14 kg leaders with 14 kg wire tippet, barbed size 3–4 flies on single J-hooks). When hooked, anglers fought and landed the golden dorado using practices common to the fishery. Fish were hooked and fought while the raft was rowed to a nearby shallow bank, after which the angler would step out of the raft and land the fish with the assistance of an additional angler or fishing guide. All research was conducted in accordance with the policies of the American Association for Laboratory Animal Science (IACUC protocol 2013-0031, University of Massachusetts Amherst, Amherst, MA, USA).

2.2. *Quantification of the angling event*

For each angling event, we quantified fight duration (sec), anatomical hooking location, difficulty of hook removal, presence of bleeding or tissue damage at the hook insertion point, water temperature, and fish size (fork length, mm). The duration of the fight was calculated to be the time from a hook set to the time the angler had secured and landed the fish in water. Hook removal difficulty was a 1–5 interval scoring system, 1 indicated that the hook was removed with no effort (i.e., hook fell out as soon as line tension was released) and 5 requiring considerable force with the use of pliers, typical of a deeply set, or entangled hook.

2.3. *Physiological assessment*

Fish were divided in to one of three treatment groups: baseline (n = 14, 492 ± 140 mm), no air exposure treatments (n = 12, 552 ± 90 mm), or 2 min air exposure treatments (n = 10, 560 ± 86 mm). The exposure time of 2 min was chosen since it emulated the average hook removal and admiration period observed in the fishery (pers. comm. 2015). Air exposure treatments were conducted by elevating fish held in recovery bags in order to simulate air exposure, while also minimizing variation in handling across experimental units. Immediately post-capture, fish in the baseline group had approximately ∼1.5 mL of blood drawn via a caudal venipuncture using a 21 g needle (BD, Franklin Lakes, NJ, 21 g, 38 mm, Ref: 305167) and 3 mL Vacutainer (BD, Franklin Lakes, NJ, 4.5 mL, 83 USP lithium heparin, Ref: 367962). Fish were held in the water and supported ventral side up in recovery bags (Dynamic Aqua Ltd., Vancouver, BC, 125 cm × 30 cm Hypalon with 0.5 cm mesh on both ends; see Donaldson et al., 2013 for description) for the blood sampling procedure. Fish in 0 min and 2 min treatment groups were placed into a recovery bag for 1 h prior to phlebotomy. The intention of the recovery bag use was two-fold; first, through the use of pre- and post-bag reflex evaluation, we were able to evaluate the potential for recovery bags to act as resuscitation and monitoring tools. Secondly, blood physiology stress for the indices recorded commonly peak approximately 1 h post-angling in most teleost fish (reviewed by Cooke et al., 2013). While some additional confinement stress was likely, the use of the recovery bag was the best field-based approach to retain and evaluate delayed stress response in angled fish. Fish held in the recovery bag period remained calm, often swimming slowly in to the direction of the current. Blood was immediately analyzed at the time of bleed using point-of-care field physiology meters (Cooke et al., 2008; Stoot et al., 2014) for blood-plasma lactate (mg/dL, Lactate Plus, Nova Biomedical Corporation, Waltham, MA, USA), glucose (mg/dL, Accu-Check Compact Plus, Roche Diagnostics, Basel, Switzerland) and pH (HI–99161 w/automated temperature compensation, Hanna Instruments, Woonsocket, Rhode Island, USA).

2.4. *Reflex impairment*

Golden dorado were assessed for five reflex action mortality predictors (RAMP; Davis, 2010): tail grab, equilibrium, body flex, head complex, and vestibular-ocular reflex (VOR). These predictors were chosen because they were effective indicators of fish condition in other C&R studies (Brownscombe et al., 2013, 2014; Lennox et al., 2015). Reflex assessments (RAMP 1, Table 1) were conducted immediately post angling and air exposure treatment for all assessments (blood physiology, and short-term movement response). To evaluate the potential effectiveness of recovery bag and track recovery time courses, reflexes for each fish were also assessed a second time (RAMP 2, Table 1) after the 1 h holding period in the recovery bag. To test for tail grab reflex the fish's tail was hand held while in the water; the fish trying to escape the handler indicated a positive response. Rotating the fish ventral side up was used to assess equilibrium status; the fish righting itself within 3 s indicated a positive response. Lifting the fish into the air by center of the body assessed body flex; an active flex of the body indicated a positive response. Observing the fish's operculum tested head complex; consistent, rhythmic opercula movements indicated a positive response. Lastly, VOR was assessed by rolling the fish side to side in the water, with a positive response dictated by the fish's eye moving in response to remain level with the horizon. In the field, a passing response was scored as zero and a failed reflex response scored 1, reflex tests took approximately 20 s to complete. During analysis, the 0–5 cumulative scores were converted to 0–1 proportional values of impairment. These tests were used with the other assessments because they have shown promise in a number of studies to be rather effective measures of impairment in a range of teleost fish (Davis, 2010; Raby et al., 2012; Brownscombe et al., 2013, 2014).

2.5. *Short term post-release behavior*

Additional golden dorado were captured and released to measure post-release movements, with these fish either not exposed to air (n = 11, 605 ± 92 mm) or exposed to air for 2 min (n = 9, 601 ± 77 mm). Prior to release the five reflexes were assessed and then a radio tag (2 g in air, 13 × 6 × 18 mm, 110 mm antenna, ∼150 day battery life, 1.1–2.0 s pulse interval; Series F1900, Advanced Telemetry Systems, Isanti, MN, USA) was attached immediately ventral to the posterior end of the dorsal fin (following methods described by Cooke, 2003). Tagging involved supporting the fish in the water with the head upstream, dorsal side up, with two stainless 16 g surgical needles inserted into the dorsal musculature below the dorsal fin rays, to which 20 g coated stainless wire attached to the tag was inserted and the surgical needles removed. To protect the tissue, plastic backing plates were used prior to crimping the coated wire ends. All equipment was cleaned with an antiseptic solution of isopropyl alcohol. Mass of the transmitters were <2% of fish body mass, based on weight estimations from earlier length-weight relationships collected on the river (Aguilera et al., 2013). No anesthesia was used owing to the limited-invasive nature of the tagging, the ease of fish handling and control by the research team, and in order to minimize the confounding effects of the tagging process on post-release behavior associated with angling. The average tagging time from tag attachment to release was 5 min 9 s ± 2 min 49 s.

Fish were manually tracked using a radio telemetry receiver (Lotek Biotracker, Lotek Wireless, Ontario, Canada) with a 3-element yagi antenna. Range of detection and precision for relocating fixed tags suspended in 30 cm, 60 cm, and 120 cm of water in situ was approximately a 5 m radius within a range of 25 m (field calibration, June 2015). The average thalweg depth between El Tunal and Gaona was 1.15 ± 0.4 m with no significant differences between upstream and downstream reaches (randomized depth survey, 21–23 June 2015). Fish locations were obtained using successive gain reductions (zero-point tracking: (Gravel and Cooke, 2008). Fish tracking took place immediately after release for 20 min. The period of time to first stationary location was recorded, and the position at 20 min was recorded. Subsequent point relocations of tagged fish were conducted for the entire study period to obtain daily rates of movement. River line positions were recorded using a handheld GPS instrument (Garmin 65csx, Lenexa, KS, USA) set to Universal Transverse Mercator projection. In addition, site-specific variables such as surface water speed (m/s) and water temperature (C°) were measured and calculated using a float timed traversing downstream a fixed distance (3 m) and handheld digital thermometer respectively (Taylor Precision Digital Thermometer, #9847, Taylor USA, Oak Brook, IL, USA).

2.6. Translocation tagging events

Given that the recreational fishery in the Juramento River operates out of rafts and anglers continue to fish as the raft floats downstream (i.e. fishing location is rarely static) fish held in recovery bags would be translocated prior to release. To investigate the impact of this practice on golden dorado recovery and movement, four fish (665 ± 72 mm) were angled, handled, placed in to a recovery bag and drifted downstream behind the raft for 1 h. Fish were then tagged, released and tracked. Short-term movement of these fish was monitored for 20 min in congruence with the methods used to track other tagged fish, and subsequently all tagged fish in our study (0 min air exposure, 2 min air exposure, translocated) were monitored daily for point relocations.

2.7. Data analysis

Golden dorado fork lengths and fight times were compared among treatments with one-way ANOVAs. To distinguish factors that were best predictors of reflex response, physiological, and movement response, generalized linear models were developed for blood glucose, lactate, pH, reflex impairment, and linear river movement from full candidate models. Blood lactate, glucose, pH, and reflex impairment models were generated containing: hook removal difficulty, fight time, water temperature, and air exposure treatment. Full candidate models were selected for parsimony using second-order Akaike Information Criterion (AICc) and the R package *glmulti* (*glmulti* package in R, Calcagno, 2013). After model selection was performed on full models, we ensured assumptions were met by examining plots of standardized residuals verses theoretical quartiles (q–q plots), plots of residual verses fitted values, variance inflation, checking the variance of residuals, and examined outliers with Cook's distance calculation. Data are presented as mean ± SD unless otherwise noted, and level of significance for statistical tests was $p \leq 0.05$. All analyses were conducted using RStudio (v. 0.97.314, R Core Team, Boston, MA, USA).

For linear movement values, fish locations were plotted along an up to date river line layer (collected June 2015) and plotted in a Geographic Information System (GIS). Individual fish location points were snapped to the nearest point on the river line, and individual distances from release site were calculated using network analyst tools in ArcMap (ESRI 2014. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute). Model selection was run using the R package *glmulti* (*glmulti* package in R, Calcagno, 2013) for the full candidate model of linear movement distance relative to release site (fallback/upstream distance) including the predictors of reflex impairment total score, fight time, air exposure treatment, and hook removal difficulty. There was no significant difference of water flow between the two air exposure treatments ($F_{1,10} = 1.91$ $p = 0.197$), thus it was eliminated from the model development and selection.

3. Results

Across all treatments, 60 fish (561 ± 108 mm FL) were landed out of 184 hook strikes during 869 individual fishing hours. Discharge at the upstream dam during the study period averaged 33.3 ± 2.6 cubic meters per second with water temperatures averaging 19.1 ± 1.7 °C with a range of 16.3–22.7 °C.

3.1. Physical injury

For all fish captured (n = 60), mean hook removal difficulty was 2.6 ± 1.2, with 2% of hooking events resulting in bleeding. Hooking locations were predominantly in the corner of the jaw (75%). Hooking in the tongue (12%) and front lip (8%) were infrequent and 5% were classed as deep-hooked (i.e. either in the esophagus or gill arch area). Fight time ranged from 30 to 554 s (170 ± 106 s), and fight times and were positively correlated with fish size ($r = 0.71$, $p < 0.05$).

3.2. Physiological response and reflex impairment

Fish used in the physiological component of the study were of similar size (i.e., fork length) in the three treatments (baseline, 0 min air, 2 min air; $F_{2,33} = 1.41$ $p = 0.26$). Mean physiological responses for baseline fish were: blood glucose, 55.3 ± 12.3 mg/dL, blood lactate, 125.1 ± 68.8 mg/dL and blood pH, 7.5 ± 0.1. After 1 h of holding, mean glucose was 125.5 ± 23.7 mg/dL, mean lactate was 173.0 ± 39.6 mg/dL, and mean pH was 7.37 ± 0.16. While not significant, mean blood lactate was higher on average for air exposed fish than 0 min air exposed fish (Fig. 2 and Table 1). Mean blood pH was significantly different between baseline and air exposed treatment groups (Fig. 2; $p = 0.05$, post-hoc Tukey-Kramer HSD), with pH being lowest for the 2 min air exposure treatment.

The mean reflex impairment score was greater for the 2 min air exposure treatment (Table 3) (mean = 0.38) relative to the 0 min air exposure treatment mean = 0.23 ($t = -1.5$, $df = 18.71$, $p = 0.16$, Welch two sample t-test). Body flex, tail grab, and equilibrium were the most prevalent reflexes impaired independent of treatment, with a higher proportion of impairment within air exposure groups (Fig. 3). Although not significant ($p = 0.131$, post-hoc Tukey-Kramer HSD), golden dorado exposed to air tended to have increased incidences of equilibrium loss (Fig. 3 and Table 1). Though as the physiological and reflex impairment results are not equivocal in their findings, the efficacy of these diagnostic tools used need to

Table 2
Generalized linear model outputs for fallback/upstream movement (20 min post angling), blood glucose, lactate, and pH concentrations (1 h post) angling and handling events. Predictive parameters considered in the model development and selection were: fight time, air exposure treatment, water temperature, hook removal difficulty, and RAMP score.

Model Variable	Parameter	Coefficient	S.E.	DF	t-value	p-value
Glucose						
	Intercept	125.45	5.05	21	24.83	<0.01
Lactate						
	Intercept	172.97	8.47	21	20.3	<0.01
pH						
	Intercept	8.13	0.35	20	23.29	<0.01
	Water temperature	−0.04	0.02	20	−2.51	0.02
	Air exposure	−0.05	0.03	20	−1.73	0.1
	Hook removal difficulty	0.07	0.03	20	2.68	0.02
Fallback/upstream distance						
	Intercept	−2.46	24.57	18	−0.1	0.92
	RAMP total score	−107.7	58.6	18	−1.84	0.08

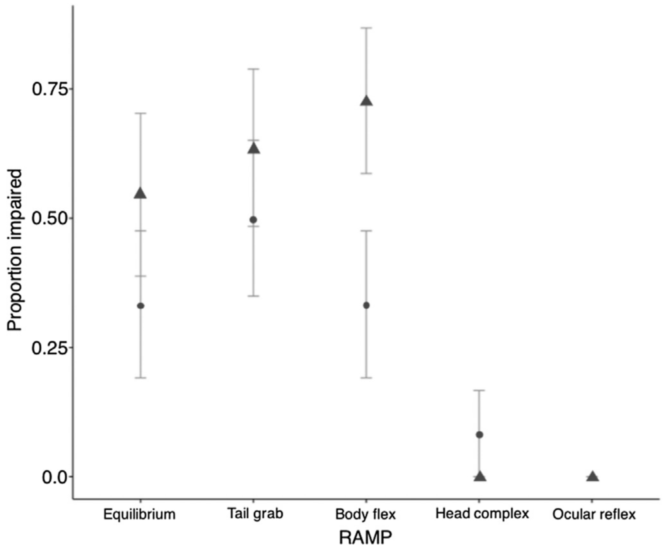

Fig. 2. Proportion of reflexes impaired (reflex action mortality predictors; RAMP) in golden dorado after angling, handling, and air exposure treatments (0 min exposure = circle, 2 min air exposure = triangle). Error bars shown represent standard error around the mean proportion.

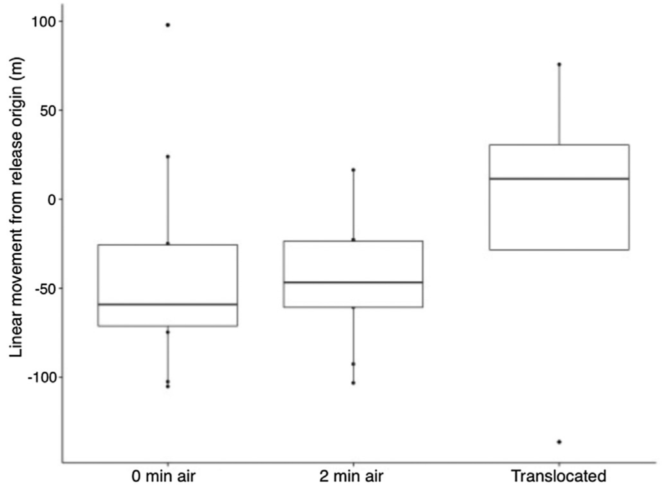

Fig. 3. Short-term tracking linear movement box plots between tagging treatment groups. 0 min air and 2 min air labels represent angling events where fish were immediately landed, tagged, and released with an air exposure (0 or 2 min) treatment. The translocated fish were captured drifted in recovery bags downstream ~45 min (2800 ± 909 m), tagged, released, and tracked for 20 min.

be critiqued further in future studies. Lastly, no fish experienced immediate mortality when landed or at time of release.

3.3. *Short-term behavior*

Twenty fish were tagged to assess short-term behavioral responses to C&R, 11 with 0 min air exposure, and 9 with 2 min of air exposure. Fish in both treatments were of similar size (i.e., fork length; $F_{1,18} = 0.73$ $p = 0.40$). There was no significant difference in the fallback distance between fish in the 0 min air exposure (−40.1 ± 58.8 m, *negative distance values represent downstream movement*) and 2 min air exposure groups (−47.4 ± 37.8 m; t = 0.3, df = 17.1, p = 0.7, Welch two sample t-test; Fig. 4). Independent of treatment, 58% of fish reached a stationary position (no movement for >2 min) within 5 min following release, and 95% of fish reached a stationary position within 10 min.

Although there was no significant difference in mean fallback distances between treatments, total reflex impairment score was the best predictor based on AICc (Fig. 5 and Table 2). A total of 22 of 24 total radio tagged golden dorado were relocated for the entirety of the tracking period (42 days), and their movements suggest that low mortality occurred for these fish. If we presume that the two fish that were not relocated died, post-release mortality for this study was 8%. For relocations, 62% of tagged fish were found along the outer bank of a river bend, 2% were located along the inside bank, and 36% were located along a straight run bank.

3.4. *Translocation and prolonged tracking*

Mean distance of translocation (~45 min–1 h downstream) was 2800 ± 909 m. Recovery bag retention and translocation resulted in a mean fallback of −9 ± 90 m within the first 20 min relative to the immediate capture and release mean fallback of −43 ± 49 m. Rates of movement (m/day) were significantly greater for translocated golden dorado (189 ± 275 m/day) when compared to golden dorado immediately released following tagging (43 ± 78 m/day; Fig. 6; t = 2.22, df = 18, p = 0.04, Welch t-test). Three of four translocated fish returned upstream within 750 m of the capture site within 4–12 days of release, while the one remaining fish remained >2 km downstream from the capture site.

4. Discussion

C&R fishing for golden dorado represents an increasingly popular fishery in Northern Argentina, and as pressure and interest grows, so does the potential cumulative impact of increased catch-and-release fishing pressure (Cooke and Suski, 2005). Better understanding species-specific best practices and assessment

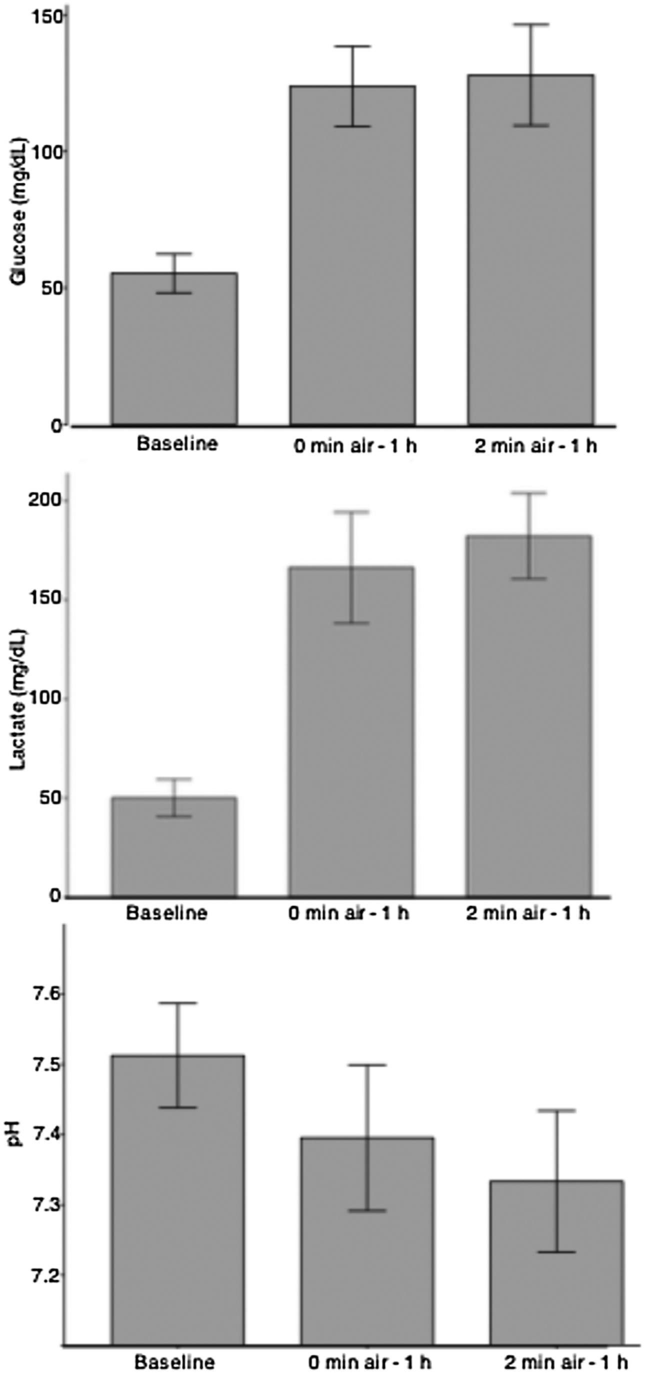

Fig. 4. Mean blood glucose, lactate, and pH concentrations for golden dorado. Error bars represent 95% confidence intervals around the mean. Baseline values represent blood physiology values obtained immediately upon landing and the 0 min air – 1 h and 2 min air – 1 h labels represent blood physiology values after angling and handling treatments with a one hour holding period to obtain peak physiology readings.

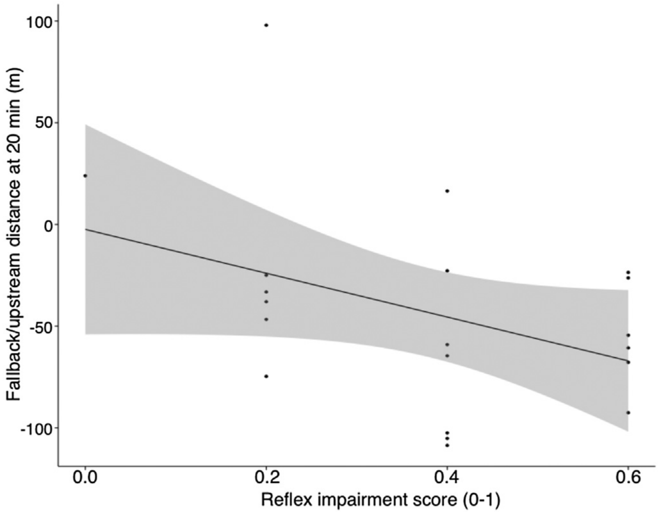

Fig. 5. Linear relationship between post-release fallback distance and total reflex impairment score. The black line represents fitted linear model with 95% confidence bands displayed.

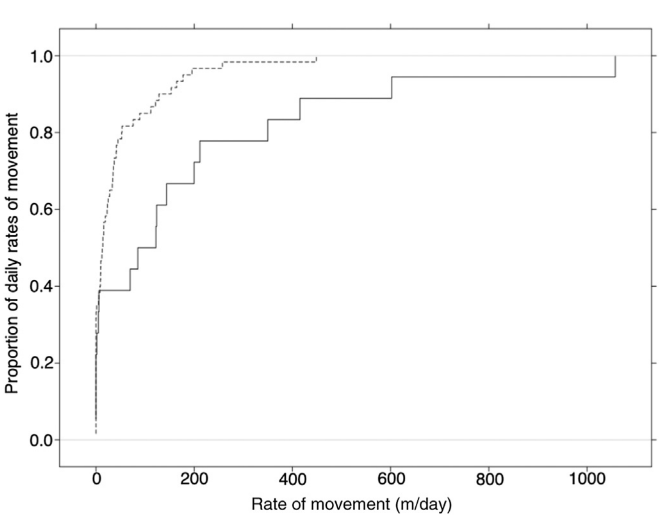

Fig. 6. Empirical Cumulative Distribution plot of daily rates of movement for immediate tag and release fish (dashed line) relative to translocated fish (solid line). Daily rates of movement are defined as individual river line distances between previous point of relocation divided by the time between last location.

methodology offers the chance to help contribute to the sustainability of this industry (Granek et al., 2008; Barnett et al., In Press). As demonstrated by our study, C&R angling can induce stress and impair reflexes of golden dorado, however, hooking injury beyond simple insertion were low. Additionally, 22 of 24 tag relocations suggested that short-term post-release mortality was relatively low (8% maximum). Our study acts as the foundation for best practices for the C&R of golden dorado in Northern Argentina, and throughout the range of this species where they are targeted by anglers practicing C&R. Coupled with education and engagement, best practice development based on our results may reduce potential impacts of capture and handling in emerging golden dorado recreational fisheries.

Excessive tissue damage from hooking often represents a clear negative impact in recreational fisheries (Cooke and Suski, 2004; Meka, 2004). Physical injury was rarely observed in our study, with hooking seldom resulting in the presence of blood or hooking in critical areas (e.g. gills). Limited hooking injury observed in our study may be due to flies being actively fished (they are moved through the water to provoke a strike) and that there is only a single hook being used (i.e., no treble hooks). Studies have shown that passive fishing can result higher rates of deep hooking (Alós, 2009). This could be tested with golden dorado by comparing hooking injury when flies are actively fished to passively fished gear with single hooks and bait. In our study we also observed that anglers inadvertently removed golden dorado from the water when hook removal was difficult. Barbless hooks were not evaluated in this

Table 3
Linear model outputs for RAMP values immediately and 1 h after handling and angling events. RAMP scores interval of 1–3: RAMP: low score (1) = 0, Med (2) = 0.2–0.4, High (3) = 0.6+.

Model Variable	Parameter	Coefficient	S.E.	DF	t-value	p-value
RAMP 1 – Total						
	Intercept	1.67	0.21	20	8.058	<0.01
	Air exposure	0.53	0.31	20	1.739	0.1
RAMP 2 – Total						
	Intercept	1.36	0.11	21	12.99	<0.01

assessment, but could assist in reducing air exposure during hook removal (Meka, 2004; Cooke and Suski, 2005).

Consistent with other assessments of C&R, our study indicated that capture via hook and line induces a physiological stress response for golden dorado. Specifically, the physiological assays showed a significant increase in blood glucose and lactate 1 h after angling in comparison to the baseline blood physiology values. Lactate is primarily produced when fish respire anaerobically during angling and utilize white muscle for high intensity locomotor activity, in turn, producing lactate from the metabolism of glycogen (Milligan and Wood, 1986 Wood, 1991). Lactate values were elevated for golden dorado exposed to air, suggesting that air exposure had an incremental negative effect on fish (Ferguson and Tufts, 1992; Cook et al., 2015). As a compounding factor, this is often attributed to the anaerobic respiration post-release when gill lamellar efficiency is affected by air exposure and resulting adhesion and collapse (Ferguson and Tufts, 1992). The production of lactate and the exchange of lactate to glycogen after exhaustive muscle use is energy intensive and can prolong recovery in fish (Wood, 1991). Lastly it should be mentioned that while a degree of captivity stress was likely present in our study, it was moderately uniform across treatments allowing us to compare relative differences among air exposure groups–a common caveat of many catch-and-release studies (Cooke et al., 2013).

Golden dorado showed a secondary hyperglycemic response when exposed to angling (Barton, 2002). Glucose has been used as a generalized measure of stress in activities such as C&R fishing, often related to angling time (Wedemeyer and Wydoski, 2008; Cooke et al., 2013; Brownscombe et al., 2015). It is generally considered important to reduce angling times to minimize physiological stress associated with capture (Cooke and Suski, 2005). However, in some species fight times are not predictors of fish stress when typical gear of the fishery is used (Brownscombe et al., 2014); this was true in our study as fight time was not identified as a key predictor of glucose levels in the model selection (Table 2).

Blood acidosis is a response often experienced by angled fish (Brobbel et al., 1996). Blood acidosis can be correlated with the buildup of carbon dioxide (CO_2) in the bloodstream, which can be caused by air exposure and damaged gill lamella preventing gas exchange in the water (Ferguson and Tufts, 1992). This is consistent with our results that showed mean pH values were highest (i.e., low acidity) for golden dorado in the baseline group and lowest (e.g., higher acidity) for golden dorado exposed to air for 2 min following capture (Fig. 2). Blood acidosis can also be linked to the build up of lactic acid (Milligan and Wood, 1986), which may make it difficult to single out air exposure as the only stressor responsible for this physiological response (Cooke et al., 2013).

Fish physiological processes are tightly correlated with water temperature (reviewed by Gale et al., 2013). While water temperature can often influence blood physiology response to angling stress (Portz et al., 2006; Gale et al., 2013; Brownscombe et al., 2015), it was only selected as a predictor in the blood pH (with temperature compensation) linear model selection. This is likely due to the limited range and distribution of water temperatures observed during the current study. Since there is a second fishing season for golden dorado on the Juramento River in warmer months (September–December) when water temperatures can exceed 23 °C, it would be prudent for future studies to determine whether higher water temperatures exacerbate the stress response for this species.

Reflex impairment can act as a simple tool for assessing condition of fish exposed to stressors (Davis, 2010). Increasingly higher reflex impairment scores occurred for golden dorado exposed to greater angling times and air exposure could be related to higher levels of muscular exhaustion and cognitive impairment (Raby et al., 2012). As with other species (e.g., bonefish, Danylchuk et al., 2007; coho salmon, Raby et al., 2012), the loss of equilibrium was a useful and simple indicator of air exposure stress in golden dorado (Fig. 3) and may help reduce post-release predation risk (Danylchuk et al., 2007). No significant relationship between blood physiology metrics and reflex impairment in our study could be a product of a small sample size, or the tendency of physiological measures to fail at predicting reflexive and behavioral impairment in fish (Davis, 2010). The relationships detected between reflex impairment, air exposure, and movement response support the idea that reflex scoring could be more effective at explaining universal stress response in fish (Davis, 2010).

Fallback (downstream movement) can occur as a result of cumulative physical and physiological impacts associated with capture and handling in a C&R recreational fishery (Makinen et al., 2000; Havn et al., 2015). Departures from traditional migratory patterns immediately after release has been observed for catch-and-release of Atlantic Salmon (Makinen et al., 2000; Havn et al., 2015). While C&R fisheries can result in low mortality, downstream movement may be detrimental for potadromous species such as golden dorado, which travel upstream to spawn (Hahn et al., 2011). Reflex impairment was correlated with air exposure in golden dorado (Table 3 and Fig. 3) and also correlated with fallback distance downstream post-release (Fig. 5). The relationship between fallback distance and reflex impairment was bolstered by its selection in the linear model development as a key predictor of release movement (Table 2 and Fig. 5). As downstream movement and reflex loss may be cumulative indicators of stress, they could act as useful visual indicators that anglers can employ to ensure a positive outcome of a C&R event for fish. Conceivably the easiest reflex for anglers to monitor is the loss of equilibrium due to its simplicity and the ease of scoring (pass/fail within 3 s).

The higher rates of upstream movement for translocated fish (Fig. 6) are likely an important consideration for energy use post-release. The propensity of translocated golden dorado to make large (+300 m/day) movements upstream in the direction of the capture site implies that site fidelity may be important to golden dorado spatial ecology. This finding of increased rates of movement and capture site return for translocated fish is some of the first fine-scale work to look at golden dorado spatial ecology, and it would be judicious to further explore the implications of site fidelity and territoriality related to post-release movement. While recovery bags could aid in recovery in golden dorado and other species (Table 1; Brownscombe et al., 2013), the nature of this fishery (consistent downstream floating) adds an additional confounding effect for the use of these tools for fish recovery following C&R.

C&R angling for golden dorado is an important component of the emerging economy along the Juramento River, and has the potential to act as a catalyst for stakeholder engagement focused on broader environmental issues in the watershed. Working collaboratively, guides, anglers, and researchers were able to evaluate the potential impacts of a growing C&R fishery in Argentina. Understanding the fishery specific angling events that elicit the greatest stress response, reflex impairment, behavioral alteration, or injury, can lead to the development and employment of species specific, contextually relevant best practices. Ultimately, as the first study of C&R for this species, golden dorado appear to be a relatively resilient species to C&R, however anglers and resource managers should consider minimizing handling time and air exposure. Furthermore, continued evaluation is recommended to more clearly elucidate the specific C&R impacts, whether at periods of higher water temperatures or in other recreational fisheries (e.g., conventional tackle).

Contributions

Gagne developed and implemented this project, conducted sampling, data analysis, and wrote the manuscript. Ovitz and Griffin contributed to study design, project facilitation, conducted sampling, data analysis, and manuscript preparation. Cooke and Brownscombe contributed to study design and manuscript preparation. Danylchuk contributed to funding, project implementation, study design, conducted sampling, and manuscript preparation.

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