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MANAGEMENT BRIEF

Effects of Fishery-Related Fight Time and Air Exposure on Prespawn Survival and Reproductive Success of Adult Hatchery Steelhead

Don W. Whitney*
Idaho Department of Fish and Game, 3316 16th Street, Lewiston, Idaho 83501, USA

Kevin A. Meyer and Joshua L. McCormick
Idaho Department of Fish and Game, 1414 East Locust Lane, Nampa, Idaho 83686, USA

Brett J. Bowersox
Idaho Department of Fish and Game, 3316 16th Street, Lewiston, Idaho 83501, USA

Abstract

In recent years, increased scrutiny has been placed on the physiological effects of exhaustive exercise and air exposure on caught-and-released fish. Steelhead *Oncorhynchus mykiss* broodstock in the South Fork Clearwater River, Idaho, were collected by anglers during a winter fishery (water temperatures of 2–5°C); this enabled fight and air exposure times to be recorded to determine their influence on prespawn survival and progeny survival to the fry stage in the hatchery. The average fight time during angling was 164 s. Air exposure was measured when anglers landed fish and again during fish transport from the river to the hatchery vehicle; the longest interval of air exposure averaged 23 s during angling and 28 s during transport. Three-year average prespawn survival was 97.0% for 1,148 angler-caught fish, compared to 91.9% for 3,325 swim-in broodstock collected at the hatchery. The top mixed-effects logistic regression model estimated that the odds of progeny survival increased by 1.027 times with each additional day of the year until an adult fish spawned; this was likely a reflection of peak spawn time in the hatchery. Fight time and air exposure time did not influence progeny survival or prespawn mortality of adult steelhead captured by anglers.

Catch-and-release angling regulations are a management tool often used to reduce the exploitation of specific species when abundance is low or to improve overall fishing quality (Policansky 2002). Although catch-and-release regulations generally reduce mortality associated with recreational angling activities (reviewed by Wydoski 1977 and Muoneke and Childress 1994), sublethal and lethal impacts can still occur and are associated with a variety of factors, such as terminal gear type, water temperature, exercise stress, net mesh, and air exposure, among others. Understanding the effects of catch-and-release angling is especially important in fisheries like Idaho's steelhead *Oncorhynchus mykiss* fisheries, where fishing regulations mandate the release of all wild fish that are caught by anglers.

In recent years, numerous studies have evaluated the lethal and sublethal effects of exhaustive exercise (fight time) and air exposure on caught-and-released fish (see reviews by Arlinghaus et al. 2007 and Cook et al. 2015). Many study results have demonstrated no lethal or serious sublethal impacts (e.g., Schreer et al. 2005; Donaldson et al. 2010a; Raby et al. 2013) associated with fight and air exposure times that are typically imposed by actual anglers in real fisheries (Lamansky and Meyer 2016; Chiaramonte et al. 2018; Roth et al. 2018a). However, a few studies have concluded that even nominal fight and air exposure times can greatly elevate the mortality rates of released fish (Ferguson and Tufts 1992; Schisler and Bergersen 1996). In fact, a recent study concluded that only 10 s of air exposure, in conjunction with associated fight time during landing, diminished the reproductive success of Atlantic Salmon *Salmo salar* (Richard et al. 2013).

This suggests that angling-induced exercise and nominal air exposure result in direct reproductive impairment of

*Corresponding author: donald.whitney@idfg.idaho.gov
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spawning adults or diminishes the viability of eggs or milt. Indeed, simulated fight and air exposure times have been shown to trigger stress responses in adult salmonids (Gale et al. 2011; Raby et al. 2013), and acute stress during the reproductive cycle can negatively impact salmonid gamete quality (Carragher et al. 1989; Campbell et al. 1992). However, it is unclear whether fight and air exposure times typical of actual angling events would create stress levels high enough to cause such a reduction in gamete quality, as suggested by Richard et al. (2013). If gamete quality in wild fish is reduced by exhaustive exercise and air exposure associated with catch-and-release practices, it is plausible that such an impact would manifest itself in a hatchery setting as well. Therefore, the objective of this study was to evaluate whether progeny survival was reduced for hatchery steelhead that were landed by anglers, exposed to air, and then brought into the hatchery as broodstock to spawn.

METHODS

Fight time and air exposure.— The study took place during February and March of 2015, 2016, and 2017 in the South Fork Clearwater River. A large segment of the Dworshak National Fish Hatchery (DNFH) steelhead broodstock is collected via a cooperative angler capture program in the South Fork Clearwater River; the hatchery is located on the Clearwater River, and the confluence of the South Fork Clearwater River is 55 river kilometers upstream from the hatchery. Angler-caught broodstock were collected throughout the lower 40 river kilometers of the South Fork Clearwater River. The remainder of DNFH steelhead broodstock are collected after they swim into the DNFH trap on their own volition; the trap is located in the North Fork Clearwater River just upstream of its confluence with the Clearwater River. Adults returning to the South Fork Clearwater River are the progeny of broodstock collected from both locations; thus, the only difference between adult groups is their release location as smolts.

Anglers participating in broodstock collections consisted entirely of recreational anglers using their preferred legal method of angling and terminal tackle. Although we did not record angler terminal tackle in this study, in a companion study conducted in the South Fork Clearwater River, anglers generally landed fish by using lures (58% of landed fish), flies (22%), and bait-type tackle (20%; L. Chiaramonte, Idaho Department of Fish and Game [IDFG], unpublished data). Hooking location was also not of interest in this study, but in the companion study, most fish were hooked in the mouth, and deep hooking was extremely rare (<1%; Chiaramonte et al. 2018). All anglers signed a volunteer form to participate, but their skill levels varied widely. To maximize brood collection, we selected areas known to produce higher catch rates.

During broodstock collection efforts, IDFG personnel in uniform were present and recorded fight and air exposure times for landed fish. Anglers were given no instruction that might alter potentially stressful angling practices. When a volunteer angler hooked a steelhead, stopwatches were used to record fight time; when the immediate hooking event was not observed, fight time was not recorded. Fight time began when an angler hooked a fish, and it ended upon landing. Once the fish was landed, we timed how long the fish was exposed to air by the angler. Occasionally, fish were put back in the water and then re-exposed to air one or two more times. We recorded all air exposure intervals; however, for the purposes of our analyses, we used only the longest air exposure interval. Water temperature was measured using a Campbell Scientific CS451 pressure transducer and temperature probe; temperature at the time that fish were landed ranged from 2.4°C to 4.4°C.

Steelhead acquired for broodstock by anglers were placed in a 112- × 15-cm, perforated polyvinyl chloride (PVC) tube. Tubes were either carried immediately to a hatchery transport vehicle or were placed in the river and carried to a transport vehicle later in the day (usually within 2 h of capture). Air exposure that occurred when carrying the fish in the PVC tube to the transport vehicle was also measured using stopwatches. Each steelhead that was landed and acquired for broodstock was measured for FL and individually marked with a uniquely coded wire tie, which was secured around the caudal peduncle. Throughout the duration of this study, no mortality was observed during transport, and only one angling mortality was observed; this fish was excluded from analysis.

Hatchery evaluation.— Steelhead were transported to DNFH and placed in a holding pond designated for the localized brood program. Water temperature in the holding pond was determined using U.S. Geological Survey water data (station number 13341000; USGS 2018) and ranged from 4.8°C to 5.2°C while fish were being held.

The fish were examined each week to determine ripeness. Ripe fish were randomly crossed, with one male to each female. Individual spawn crosses were placed in unique vertical incubation trays. Each male and female used as broodfish were tracked by spawn cross to determine potential effects of fight time(s) and air exposure(s) on eye-up rates and progeny survival. Eggs from these spawn crosses were held at DNFH until they reached the eye-up stage (~350 daily temperature units), at which time they were transferred to Clearwater Fish Hatchery and were enumerated using an egg sorter/counter (Jensorter JM4). Eye-up success was determined from the sorter/counter data, with dead eggs being removed from trays.

Eggs from each spawn cross were enumerated individually and returned to unique vertical tray incubators at Clearwater Fish Hatchery until they reached approximately 1,000 daily temperature units; they were then ponded in hatchery rearing units. All mortality after enumeration was tracked until the resulting fish were ponded as fry (i.e., progeny survival) at approximately 27 mm FL. Progeny survival was determined by subtracting the post-enumeration mortality from the sorter/counter data.

For the three study years, we recorded the prespawn mortalities of all broodstock that were collected after volitionally swimming into the DNFH trap ("swim-in" broodstock), and the prespawn survival rates of these fish were calculated and compared to the prespawn survival of angler-caught broodstock. Prespawn mortality rate was calculated as the number of mortalities removed from holding divided by the number of adults that were ponded for brood purposes. No further reproductive comparisons were conducted between swim-in broodstock and angler-caught broodstock due to the different rearing conditions experienced by their respective progeny.

Data analyses.— Mixed-effects logistic regression models (Zuur et al. 2009) were used to evaluate factors that influenced progeny survival. For all models, pairs of parents were treated as a random effect in the form of a random intercept. We fitted 11 models that included several explanatory variables, including the fight time and transport air exposure time of each parent, the day of year (DOY) of spawning, the number of days each parent was held in the hatchery before spawning, and the FL of each parent, as well as an intercept-only model that did not include any explanatory variables. Transport air exposure was evaluated in the model given that it represented, on average, the longest-duration air exposure interval and provided an increased sample size compared to angler air exposure. The DOY on which fish were spawned in the hatchery and the number of days held in the hatchery prior to spawning were not highly correlated for males ($r = 0.31$) or females ($r = 0.46$); thus, these two variables were not excluded from being in the same models.

Each model represented a hypothesis about the factors that influenced progeny survival, and Akaike's information criterion corrected for small sample size (AIC_c) was used to evaluate the relative plausibility of each model (Akaike 1973; Burnham and Anderson 2002). The difference in AIC_c value (ΔAIC_c) relative to the top model (i.e., the model with the lowest AIC_c value) was used as a measure of support for each model. Values of ΔAIC_c greater than 2 suggest substantial evidence for the top model; ΔAIC_c values between 3 and 7 indicate less support for a candidate model; and ΔAIC_c values greater than 10 indicate that the candidate model is very unlikely compared to the top model. The AIC_c weights were also calculated to provide a relative measure of support for each model in the candidate set. Because fight times were only available for a subset of fish, the model that included fight time was not part of the candidate set in the multi-model analysis.

When exponentiated, coefficients of logistic regression models represent odds ratios. For instance, if an estimated regression coefficient for a variable (e.g., air exposure time) is 1.01, then the odds of ponding survival are estimated to increase 1.01 times with a 1-unit increase for that variable. In this analysis, 95% confidence intervals (CIs) were estimated using profile likelihood methods (Zuur et al. 2009). If the 95% CI around the coefficient estimate overlapped 1.0, then we assumed that there was no significant effect at the $\alpha = 0.05$ level. Models were fitted using R (R Development Core Team 2011).

RESULTS

Prespawn survival of swim-in broodstock collected at the DNFH trap in 2015, 2016, and 2017 was 90.7, 88.1, and 96.8%, respectively. In comparison, prespawn survival of angler-caught broodstock was 95.9, 96.0, and 99.1%, respectively.

During the present study, 162 angling fight times, 180 angling air exposure times, and 635 transport air exposure times were recorded (Table 1). Mean fight time averaged 164 s, whereas the longest intervals of air exposure averaged 23 s during angler activities and 28 s during transfer to the hatchery transport vehicle. Of the 180 angling air exposures, 80 fish were exposed to air a second time (mean air exposure = 9 s), and 35 fish were exposed for a third time (mean air exposure = 4 s). Mean FL of angler-caught broodstock was 830 mm (range = 720–1,000 mm). The number of days the fish were held at the hatchery prior to spawning averaged 12 d.

The top regression model included a term for DOY of spawning and accounted for 31% of the AIC_c weight (Table 2). Two other models were within 2 AIC_c units of the top model (i.e., $\Delta AIC_c < 2$). Both models included additive effects of the amount of time fish were held in the hatchery (Table 2). Collectively, the three individual models that included the effects of air exposure accounted for less than 8% of AIC_c weight.

Based on the top model, the estimated odds of progeny survival increased by 1.027 times (95% CI = 1.004–1.051) with each additional day of the year until a fish was spawned (Table 3; Figure 1); this result was statistically significant based on 95% CIs that did not overlap 1.0. Estimated progeny survival also increased as the number of days fish were held in the hatchery increased (Table 3). There was little support in any models that fight time or air exposure time influenced progeny survival (Table 3; Figures 2, 3).

TABLE 1. Sample size, mean (SE in parentheses), and range for fight time, longest single interval of angling air exposure, transport air exposure, and days held at the hatchery for adult hatchery steelhead that were caught by anglers in the South Fork Clearwater River and used as broodstock, 2015–2017.

Measure	Sex	*n*	Mean	Range
Fight time (s)	Female	82	173.2 (15.5)	16–554
	Male	80	153.8 (16.9)	2–668
Angling air exposure (s)	Female	100	20.3 (1.9)	2–123
	Male	80	25.8 (3.0)	3–178
Transport air exposure (s)	Female	346	25.7 (0.8)	7–131
	Male	289	30.8 (1.0)	8–91
Days held at hatchery	Female	348	11.9 (0.4)	1–38
	Male	306	11.4 (0.4)	1–31

TABLE 2. Model selection results for logistic regression models of progeny survival for hatchery steelhead (days held = number of days held in the hatchery prior to spawning; AIC_c = Akaike's information criterion corrected for small sample size; ΔAIC_c = difference in AIC_c value between the given model and the top model). All models also included a random effect for trial (i.e., set of parents).

Model	df	AIC_c	ΔAIC_c	AIC_c weight
Day of year of spawning	3	4,704.6	0.0	0.31
Female days held	3	4,704.8	0.2	0.28
Male days held + female days held	4	4,706.5	1.9	0.12
Intercept only	2	4,707.7	3.1	0.07
Male FL	3	4,708.3	3.7	0.05
Female FL	3	4,708.7	4.1	0.04
Male days held	3	4,709.0	4.4	0.04
Female air exposure	3	4,709.0	4.4	0.03
Male air exposure	3	4,709.2	4.6	0.03
Male FL + female FL	4	4,709.6	5.0	0.03
Male air exposure + female air exposure	4	4,710.8	6.2	0.01

DISCUSSION

Results from this study indicate that neither the survival of adults to spawning nor the subsequent hatchery survival of their progeny was negatively influenced by fight time and air exposure time for hatchery steelhead caught by recreational anglers for use as broodstock. Both angler-related air exposure time and tube-transport air exposure time observed in this study were similar to mean air exposures reported in trout and steelhead fisheries, whereas fight time was higher than those previously observed in trout fisheries but similar to those observed in other steelhead fisheries (Lamansky and Meyer 2016; Chiaramonte et al. 2018; Roth et al. 2018a).

The lack of an effect on prespawn adult mortality and subsequent progeny survival suggests that the stress associated with being fought and caught by anglers and exposed to air upon landing is a short-term effect with no long-term impact. In a similar study on wild Atlantic

TABLE 3. Estimated coefficients [i.e., odds ratios; with lower and upper 95% confidence limits (CLs)] for the top model of progeny survival for hatchery steelhead [day of year (DOY) of spawning], the top days held models (days held = number of days held in the hatchery prior to spawning), the top air exposure model, and the fight time models. All models also included a random effect for trial (i.e., set of parents).

Parameter	Parameter estimate	Lower 95% CL	Upper 95% CL
DOY of spawning model			
Intercept	0.777	0.141	4.269
DOY of spawning	1.027	1.004	1.051
Female days held model			
Intercept	4.197	3.170	5.556
Female days held	1.023	1.003	1.044
Female days held + male days held model			
Intercept	3.940	2.797	5.551
Female days held	1.022	1.002	1.043
Male days held	1.006	0.987	1.026
Air exposure model			
Intercept	4.658	3.240	6.698
Male air exposure	1.003	0.994	1.011
Female air exposure	1.004	0.993	1.014
Female fight time model			
Intercept	7.541	5.106	9.975
Female fight time	1.000	−0.962	2.962
Male fight time model			
Intercept	5.015	2.960	8.499
Male fight time	0.998	0.995	1.000

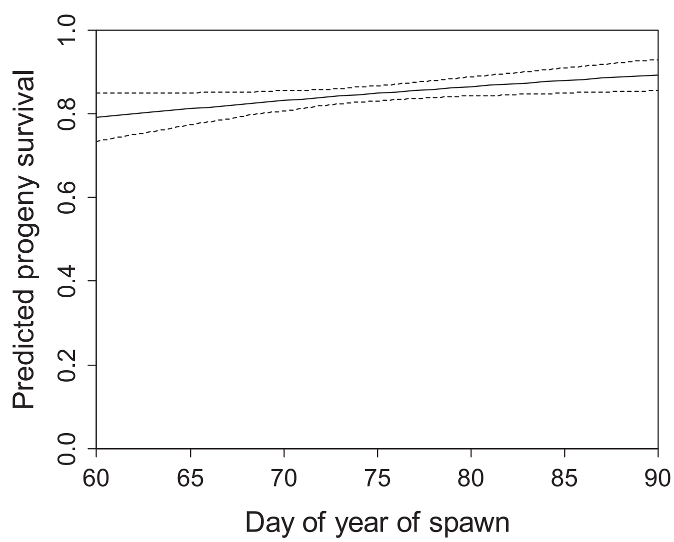

FIGURE 1. Predicted progeny survival probability for steelhead as a function of the day of year of spawning in the hatchery. Dashed lines represent the 95% prediction interval.

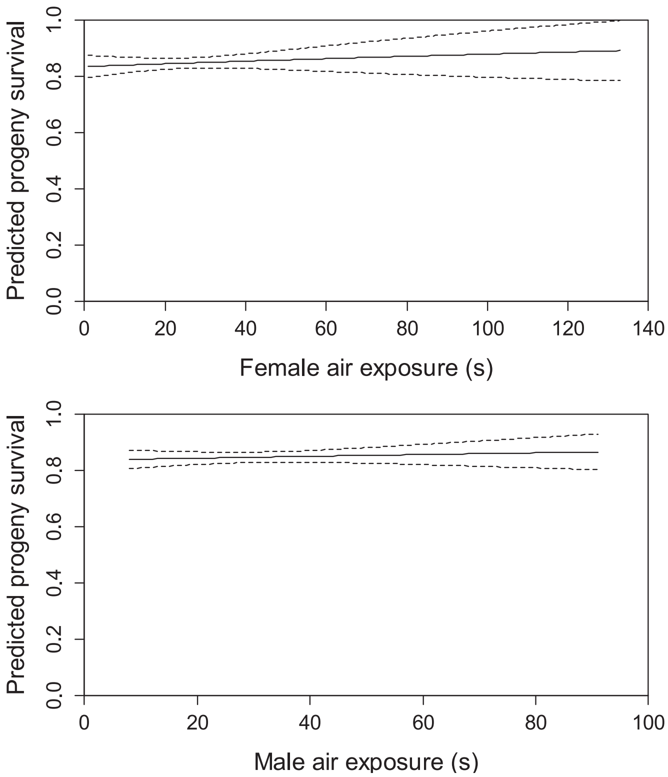

FIGURE 2. Predicted progeny survival probability for steelhead as a function of air exposure experienced by female and male broodfish during transport to the hatchery. Dashed lines represent the 95% prediction interval.

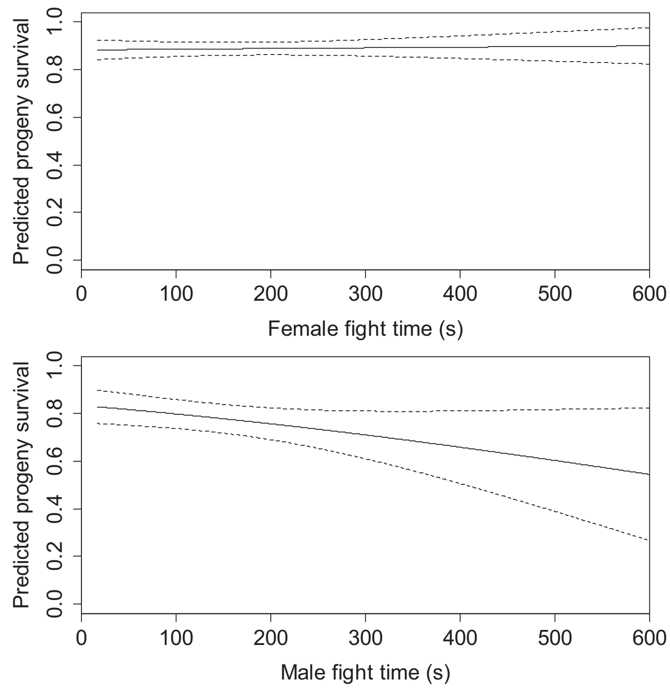

FIGURE 3. Predicted progeny survival probability for steelhead as a function of fight time experienced by female and male broodfish during angling. Dashed lines represent the 95% prediction interval.

Salmon, adults that were exercised to exhaustion (with minimal air exposure) by anglers showed rapid recovery from short-term impairments to muscle physiology, with no impact to adult survival or egg viability after being transported to a hatchery (Booth et al. 1995). Similar results have also been reported for Pacific salmon (Raby et al. 2013) and steelhead (Pettit 1977). However, as was pointed out by Raby et al. (2013), anadromous salmonids experience a metabolic shift as they approach their natal spawning grounds, increasing their use of anaerobic exercise and protein catabolism (Brett 1995; Miller et al. 2009) as they expend energy migrating into shallow streams and initiating courtship behaviors and predator evasion during the final stages of spawning (Quinn and Buck 2001; Hruska et al. 2010). In such settings, they may be well adapted to moderately stressful handling conditions associated with most salmonid catch-and-release angling, resulting in high survival (Twardek et al. 2018). In contrast, other studies have presented evidence suggesting that migrating salmonids are more vulnerable to postrelease mortality earlier in their spawning migration route (e.g., Donaldson et al. 2010b).

To our knowledge, only one study has produced results suggesting that reproductive success is negatively impacted by nominal levels of air exposure in association with typical fight times. According to Richard et al. (2013), wild Atlantic Salmon that were fought and landed by anglers and then exposed to air for as little as 10 s had two to three times lower reproductive success than fish that were not exposed to air. However, the sample size in the Richard et al. (2013) study was extremely low (i.e., only 40 fish were subjected to catch and release), perhaps making that study vulnerable to spurious results. Indeed, they found that when water temperature was warmer (>17°C), longer air exposure resulted in increased reproductive success, which contrasts with other studies relating salmonid reproductive fitness to water temperature (Beacham and Murray 1985; Vladic and Jätrvi 1997). In a study similar to that of Richard et al. (2013) but with a much larger sample size (i.e., >2,000 adults), fight times and air exposure times typically imposed upon trout during catch-and-release angling events did not affect wild adult Cutthroat Trout *O. clarkii* survival or progeny production (Roth et al. 2018b).

The results from the top model, which indicated that the DOY of spawning influenced progeny survival, are likely due to egg take dates progressively nearing optimal fertility, whereas early egg takes likely included underripe eggs, resulting in lower fertility (Leitritz and Lewis 1976). The increased progeny survival associated with greater holding time at the hatchery, as observed in this study, may be influenced by a variety of factors. Short-term effects (up to 2 weeks) from stressors such as confinement, poor water quality, and agonistic behavior can affect fish health (Portz et al. 2006), and even common stressors (e.g., noise and crowding) at a hatchery may affect reproduction (Contreras-Sanchez et al. 1998). In contrast, increased progeny survival from longer holding times in the hatchery may result as fish become habituated or desensitized to stressors to a greater extent than fish with less holding time (Barton 2002). Furthermore, the hatchery environment requires reduced energetic demand compared to a free-flowing river system (Hoffnagle et al. 2006); therefore, study fish that were held longer in the hatchery setting may have had additional energy reserves.

Several aspects of this study should be considered prior to applying the present results to other fisheries. First, the artificial nature of the hatchery environment is known to enhance progeny survival. Second, as mentioned above, the adult hatchery steelhead broodstock caught by anglers in this study were in close spatial proximity to their spawning grounds, where anadromous salmonids exhibit greater hardiness than earlier in their spawning migration (Raby et al. 2013). Third, water temperatures in the stream were low (2–5°C) during our study, and air exposure may be more detrimental at higher water temperatures (reviewed by Gale et al. 2013; but see Richard et al. 2013). Nevertheless, the results reported herein concur with most previous studies showing a lack of impact on adult and egg survival for salmonids that have been fought and caught by anglers and exposed to air upon capture. Only when fight times or air exposure times are very prolonged have serious negative impacts become evident (Ferguson and Tufts 1992); these prolonged times far exceed those documented in actual fisheries (Lamansky and Meyer 2016; Chiaramonte et al. 2018; Roth et al. 2018a). We encourage anglers to continue to land fish as quickly as possible; furthermore, for fish they intend to release, anglers should limit the fish's exposure to as little air as necessary to capture the moment with a photograph or to admire their catch. [Correction added on March 14, 2019, after first online publication: The wording in the following sentence was incorrect, and it is now corrected and shortened.] Continuing to minimize angler related fight times and air exposure will help to ensure that catch-and-release practices have positive benefits in popular recreational fisheries.

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