Evaluating the Effects of Air Exposure on Salmonids

A Thesis
Presented in Partial Fulfillment of the Requirements for the
Degree of Master of Science
with a
Major in Natural Resources
in the
College of Graduate Studies
University of Idaho
by
Curtis J. Roth

Major Professor: Michael C. Quist, Ph.D.
Committee Members: Timothy R. Johnson, Ph.D.; Ryan A. Long, Ph.D.;
Daniel J. Schill, Ph.D.
Department Administrator: Lisette Waits, Ph.D.

May 2018

Authorization to Submit Thesis

This thesis of Curtis J. Roth, submitted for the degree of Master of Science with a Major in Natural Resources and titled "Evaluating the Effects of Air Exposure on Salmonids" has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor: ________________________ Date: __________

Michael C. Quist, Ph.D.

Committee members: ________________________ Date: __________

Timothy R. Johnson, Ph.D.

________________________ Date: __________

Ryan A. Long, Ph.D.

________________________ Date: __________

Daniel J. Schill, Ph.D.

Department Administrator: ________________________ Date: __________

Lisette P. Waits, Ph.D.

Abstract

Fishing regulations are used by natural resource agencies to accomplish a variety of management objectives, including a focus on improving the quality of a fishery or maintaining the viability of a population. Catch-and-release regulations have largely been successful in reducing exploitation and increasing density and size structure of fish populations. In recent years, concerns have been raised regarding anglers exposing fish to air during catch-and-release angling. This thesis quantified how long anglers expose fish to air during catch-and-release angling, evaluated the effects of air exposure on the survival of Yellowstone Cutthroat Trout, Bull Trout, and Rainbow Trout, and evaluated the effect of air exposure on the fitness of Yellowstone Cutthroat Trout. Results of this study suggest that anglers typically do not expose fish to air long enough during catch-and-release angling to incur the negative effects associated with prolonged air exposure. Additionally, evaluation of the effects of air exposure on survival and fitness indicated that air exposure has no effect at up to 60 s of air exposure.

Acknowledgements

I would first like to thank Dr. Michael Quist and Dr. Daniel Schill for all of the guidance, support, and the countless hours of mentoring that they provided me during my master's program. I thank Brett High for providing me with logistical support as well as insight into the systems that we worked in, without which this project would not have been possible. I am grateful for the support that John Cassinelli, Jeff Dillion, Jon Flinders, Bart Gammet, Dan Garren, Joe Kozfkay, and Chuck Warren provided me which allowed me to achieve the scope of the second chapter of this thesis. I thank Joe Dupont from the Idaho Department of Fish and Game for helping me develop handling procedures for chapter four of this thesis. I also thank a number of additional people from the Idaho Department of Fish and Game including Nick Birmingham, Forest Bohlen, Jake Calvitti, Kayden Estep, Kevin Johnson, Jared Kunz, Will Lubenau, Darcy McCarrick, Jorge Rosales, Devon Skidmore, Skylar Smith, Troy Smouse, Jason Spillet, Chuck Traughber, Dillion Thompson, and Dylan Whitaker for their help with fieldwork. I thank my committee members (Dr. Timothy Johnson and Dr. Ryan Long) for their insights and support. I am grateful to my fellow graduate students (Zach Beard, Shannon Blackburn, Phil Branigan, Tucker Brauer, Stacey Feeken, John Heckel, Zach Klein, and Conor McClure) for their friendship over the past few years and all the positive reinforcement and sincerely helpful critiques. I also thank undergraduate technicians Shane Cossel, Charlie Kerrick, Chris Rudfelt, and Jack Wu for their many hours of help with field work. Lastly, I thank my wife Erica Roth for supporting me through my master's program.

Table of Contents

List of Figures

List of Tables

Chapter 2

Chapter 3

Chapter 4

Chapter 1: General Introduction

North American inland fisheries can be divided into three primary categories: commercial, recreational, and subsistence (Isermann and Paukert 2010). Although these types of fisheries occur across North America, the majority of fisheries are recreational. Sport fishing is an important form of recreation in the United States with an estimated 46 million anglers (ASA 2011). Angling for recreation is not only a popular form of recreation, it is also an important part of the nation's economy supporting approximately 828,000 jobs and contributes US$1.15 $\times 10^{11}$ to the nation's economy. A variety of regulations are implemented by fisheries managers to manage recreational fisheries (Isermann and Paukert 2010). Regulations in recreational fisheries are typically implemented to maintain population viability or to improve the quality of the fishery, but can also be implemented to alter the community dynamics or remove undesirable fish species.

Fisheries managers have a variety of regulations at their disposal when managing recreational fisheries (Isermann and Paukert 2010). The most commonly used types of regulations are creel and possession limits, length limits, seasons, gear restrictions, and catch-and-release regulations. Catch-and-release regulations are one of the most popular types of regulations for managing recreational fisheries. When catch-and-release regulations have been implemented, anglers were required to release all of their catch. Fisheries managers can choose to implement catch-and-release regulations for a variety of reasons, such as preventing the consumption of contaminated fish (Carline et al. 1991), protect species that are particularly susceptible to exploitation (Chapman et al. 1972), improving the size structure of one species by regulating another (Schneider and Lockwood 2002), and improving the overall quality of a fishery (Perry et al. 2005). For catch-and-release regulations to be successful in achieving management goals, fish that have been caught and released must experience low mortality rates (Wydoski 1977).

One of the first places to implement catch-and-release regulations in the United States was a salmonid fishery in the Great Smoky Mountains National Park (Thompson 1958). Catch-and-release regulations in the Great Smoky Mountains National Park were successful with Rainbow Trout *Oncorhynchus mykiss* densities nearly doubling in the West Prong of the Little Pigeon River from 1955 to 1956 following implementation. Since then, catch-and-release regulations have been used throughout the United States and have largely been successful (e.g., Graff and Hollender 1977; Johnson and Bjorn 1978; Anderson and Nehring 1984). For example, after 5 years of catch-and-release regulations on Kelly Creek, Idaho, Westslope Cutthroat Trout *Oncorhynchus clarki lewisi* catch rates doubled from 1 fish/angler-hour to 2 fish/angler-hour. In addition to improving catch rates, catch-and-release regulations have successfully improved biomass, density, and length structure of fish populations (Anderson and Nehring 1984). One such example is the South Platte River, Colorado, where biomass, density, and length structure improved after catch-and-release regulations were implemented. After 4 years of catch-and-release regulations, Rainbow Trout density increased four times and biomass increased nine times. After 6 years, the number of fish over 300 mm increased by 58%.

The success and popularity of catch-and-release regulations has not completely dissuaded the concerns of some anglers. One such concern recently garnering attention is the potentially negative effects of fish being exposed to air during catch-and-release angling. Concerns about the negative effects of exposing fish to air during catch-and-release angling have arisen from a number of sources including social media campaigns (e.g., #Keepemwet), scientific literature (e.g., Cook et al. 2015), and natural resource agencies. For instance, it is now illegal to remove a salmon *Oncorhynchus* spp., steelhead *O. mykiss*, or Bull Trout *Salvelinus confluentus* from the water if it cannot be legally harvested in the state of Washington (Washington Department of Fish and Wildlife 2016). Additionally, the Alaska Department of Fish and Game has implemented regulations that make it unlawful to remove any salmon from the water that the angler intends to release (Alaska Department of Fish and Game 2017).

Possible negative effects of air exposure are either indirect or direct. Indirect effects are those that are not caused directly by air exposure, but result from air exposure affecting another parameter. The only indirect effect of air exposure reported to date was behavioral modification in Largemouth Bass *Micropterus salmoides* and Smallmouth Bass *M. dolomieu* (Philipp et al. 1997). Largemouth Bass and Smallmouth Bass captured via angling in four different systems in southern Ontario took longer to return to their nest when they had been air exposed during a catch-and-release event compared to fish that had not been exposed. Because the fish that had been air exposed took longer to return to their nests than fish that had not been air exposed, Philipp et al. (1997) suggested that air exposure had indirectly increased the risk of nest predation.

Direct effects are those where air exposure directly influences a parameter (e.g., mortality, reproductive success, ability to cope with thermal stress, and swimming performance). Direct effects are believed to be due to a suppression of gas transfer across the gills leading to hypoxia and increased levels of carbon dioxide in the bloodstream (Ferguson and Tufts 1992). However, the question of how long a fish must be exposed to air before it experiences long-term negative effects remains largely unknown. A number of studies have tried to address this question and have largely reported little to no effect at 2 or 3 min of air exposure (e.g., Schisler and Bergersen 1996; Schreer et al. 2005; Suski et al. 2007; Gale et al. 2011; Raby et al. 2013). Only three studies have reported negative effects with air exposure durations of 1 min or less (i.e., Ferguson and Tufts 1992; Richard et al. 2013; Graves et al. 2016). However, the results of the studies are suspect given issues with small sample sizes (Richard et al. 2013; Graves et al. 2016), handling procedures more stressful than those experienced during typical catch-and-release angling (Ferguson and Tufts 1992), and control fish being caught 8 years earlier and largely in a different location than fish exposed to air (Graves et al. 2016). Unfortunately, results of studies that found no negative effects (e.g., Schreer et al. 2007; Raby et al. 2013) of air exposure are largely ignored in favor of the studies finding a negative effect (e.g., Cook et al 2015).

Since the results of air exposure literature are variable and often even contradictory, further study on the effects of air exposure is necessary to understand how it affects catch-and-release fisheries. The goal of this research was to provide fisheries managers with more information regarding the effects of air exposure on salmonids so that they can make informed decisions regarding air exposure. The specific objectives of this study were to (1) evaluate how long anglers typically expose fish to air during catch-and-release events on the South Fork Snake River (SFSR), a nationally renowned catch-and-release fishery, (2) evaluate the effect of air exposure on the survival of Yellowstone Cutthroat Trout *Oncorhynchus clarkii bouvieri*, Bull Trout, and Rainbow Trout captured via angling during the summer, and (3) evaluate the effects of air exposure on survival and production of progeny of Yellowstone Cutthroat Trout in Burns Creek, a tributary of the South Fork Snake River.

Thesis Organization

This thesis is divided into five chapters. Chapter two describes a field study that was conducted to quantify the length of time that anglers exposed fish to air during catch-and-release angling on the South Fork Snake River during the summer of 2016. This chapter was recently accepted for publication in *Fisheries Research*. Chapter three describes a field study designed to evaluate the effects of air exposure during catch-and- release angling on the survival on Yellowstone Cutthroat Trout *Oncorhyncus clarkii bouvieri*, Bull Trout *Salvelinus confluentus*, and Rainbow Trout *O. Mykiss* during the summers of 2016 and 2017. This chapter has been submitted to the *North American Journal of Fisheries Management*. Chapter four describes a study conducted on Burns Creek, Idaho that evaluated the effects of air exposure on the short-term survival and fitness of Yellowstone Cutthroat Trout, and will be submitted to the *North American Journal of Fisheries Management.* Chapter five provides general conclusions and recommendations drawn from this work.

References

Alaska Department of Fish and Game. 2016. North Alaska sport fishing regulations summary. Alaska Department of Fish and Game, Juneau.

American Sportfishing Association (ASA). 2011. Sportfishing in America, an economic force for conservation. American Sportfishing Association, Alexandria, VA.

Anderson, R. M., and R. B. Nehring. 1984. Effects of catch-and-release regulation on a wild trout population in Colorado and its acceptance by anglers. North American Journal of Fisheries Management 4:257–265.

Chapman, D. W., S. Pettit, and K. Ball. 1972. Evaluation of catch and release regulations on Cutthroat Trout in the North Fork of the Clearwater River. Idaho Department of Fish and Game, Federal aid in Sport Fish Restoration, Project F-59-R-3, Annual Progress Report, Boise.

Cook, K. V., Lennox, R. J., Hinch, S. G., and S. J. Cooke. 2015. Fish out of water: how much air is too much? Fisheries 40:452–461.

Gale, M. K., S. G. Hinch, E. J. Eliason, S. J. Cooke, and D. A. Patterson. 2011. Physiological impairment of adult Sockeye Salmon in fresh water after simulated capture-and-release across a range of temperatures. Fisheries Research 112:85–95.

Graff, D.R., and B. A. Hollender. 1977. Catch-and-release fishing – the Pennsylvania experience. Pages 137–149 *in* R. A. Barnhart and T. D. Roelofs editors. Catch-and-release fishing as a management tool. Humboldt State University, Arcata, California.

Graves, J. E., B. J. Marcek, and W. M. Goldsmith. 2016. Effects of air exposure on postrelease mortality rates of White Marlin caught in the U.S. offshore recreational fishery. North American Journal of Fisheries Management 36:1121-1228.

Carline, R. F., T. Beard Jr., and B. A. Hollender. 1991. Response of wild Brown Trout to elimination of stocking and to no-harvest regulations. North American Journal of Fisheries Management 11:253–266.

Isermann, D. A., and C. P. Paukert. 2010. Regulating harvest. Pages 185-212 *in* W. A. Hubert, and M. C. Quist, editors. Inland fisheries management in North America, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Johnson, T. H., and T. C. Bjornn. 1978. Evaluation of angling regulations in management of Cutthroat Trout. Cooperative Fishery Research Unit, University of Idaho, Federal Aid in Fish Restoration, Project F-59-R-7, Job Completion Report, Moscow.

Perry, W. B., W. A. Janowsky, and F. J. Margraf. 1995. A bioenergetics simulation of the potential effects of angler harvest on growth of Largemouth Bass in a catch-and-release fishery. North American Journal of Fisheries Management 15:705–712.

Philipp, D. P., C. A. Toline, M. F. Kubacki, D. B. F. Philipp, and F. J. S. Phelan. 1997. The impact of catch-and-release angling on the reproductive success of Smallmouth Bass and Largemouth Bass. North American Journal of Fisheries Management 17:557–567.

Raby, G. D., S. J. Cooke, K. V. Cooke, S. H. McConnachie, M. R. Donaldson, S. G. Hinch, C. K. Whitney, S. M. Dreener, D. A. Patterson, T. D. Clark, and A. P. Farrell. 2013. Resilience of Pink Salmon and Chum Salmon to simulated fisheries capture stress incurred upon arrival at spawning grounds. Transactions of the American Fisheries Society 142:524–539.

Richard, A., M. Dionne, J. Wang, and L. Bernatchez. 2013. Does catch and release affect the mating system and individual reproductive success of wild Atlantic Salmon (*Salmo salar L.*)? Molecular Ecology 22:187–200.

Schisler, G. J., and E. P. Bergersen. 1996. Postrelease hooking mortality of Rainbow Trout caught on scented artificial baits. North American Journal of Fisheries Management 16:570–578.

Schneider, J. C., and R. N. Lockwood. 2002. Use of Walleye stocking, antimycin treatments, and catch-and-release angling regulations to increase growth and length of stunted Bluegill populations in Michigan lakes. North American Journal of Fisheries Management 22:1041–1052.

Schreer, J. F., D. M. Resch, M. L. Gately, and S. J. Cooke. 2005. Swimming performance of Brook Trout after simulated catch-and-release angling: looking for air exposure thresholds. North American Journal of Fisheries Management 25:1513–1517.

Suski, C. D., S. J. Cooke, A. J. Danylchuk, C. M. O'Connor, M. Gravel, T. Redpath, K. C. Hanson, A. J. Gingerich, K. J. Murchie, S. E. Danylchuk, J. B. Koppelman, and T. L. Goldberg. 2007. Physiological disturbance and recovery dynamics of Bonefish (*Albula vulpes*), a tropical marine fish, in response to variable exercise and exposure to air. Comparative Biochemistry and Physiology 148:664–673.

Thompson, P. E. 1958. Fishing is fun. Sports Afield (May):19–23.

Washington Department of Fish and Wildlife. 2016. Washington sport fishing rules. Washington Department of Fish and Wildlife, Olympia.

Wydoski, R. S. 1977. Relation of hooking mortality and sublethal hooking stress to quality fishery management. Pages 43–87 *in* R. A. Barnhart & T. D. Roelofs, editors Catch-and-release fishing as a management tool. Humboldt State University, Arcata, California.

Chapter 2: Fight and Air Exposure Times of Caught and Released Salmonids from the South Fork Snake River

"Roth, C. J., Schill, D. J., Quist, M. C. (2018). Fight and air exposure times of caught and released salmonids from the South Fork Snake River. *Fisheries Research*, 201, 38–43."

Abstract

Catch-and-release regulations are among the most common types of fishing regulations. In recent years, concerns have arisen regarding the exposure of fish to air during catch-and-release angling. The purpose of our study was to quantify the length of time angled fish were exposed to air by anglers in a typical catch-and-release fishery and relate it to the lengths of time reported to produce negative effects. In total, 312 individual anglers were observed on the South Fork Snake River, Idaho, from May through August 2016. Fight time varied from 1.1 s to 230.0 s, and average fight time was 40.0 s (SD = 36.8). Total air exposure times varied from 0.0 s to 91.8 s and averaged 19.3 s (SD = 15.0). Though not statistically significant, a trend in reduced fight times was observed when anglers were guided and increased air exposure times when a net was used and a picture was taken. Results of the current study suggest that anglers expose fish to air for periods that are much less than those reported to cause mortality.

Introduction

Unregulated harvest of fish by humans can affect the quality and viability of a fishery (Isermann and Paukert 2010). As a result, natural resource agencies often implement regulations to manage harvest. Harvest regulations are typically aimed at improving the quality of a fishery or maintaining the viability of a population, or both. One of the most common types of harvest regulations are catch-and-release regulations (C&R), where anglers are required to release all or a large portion of their catch. A basic premise of C&R regulations is that released fish survive and can be caught again by anglers (Wydoski 1977). Although C&R regulations were originally limited to salmonid fisheries (Thompson 1958), they have become increasingly popular in other recreational fisheries (Isermann and Paukert 2010). Natural resource agencies typically use C&R regulations as a tool to reduce exploitation and increase density and(or) size structure of fish, and the approach has generally proven effective. For instance, after implementation of C&R regulations, increases in density (Graff and Hollender 1977; Anderson and Nehring 1984; Carline et al. 1991), biomass (Thompson 1958; Anderson and Nehring 1984; Carline et al. 1991), length structure (Anderson and Nehring 1984; Jones 1987; Wells 1987; Carline et al. 1991), and catch rates (Varley 1980; Hunt 1981; Anderson and Nehring 1984; Jones 1987; Carline et al. 1991) have been reported.

Despite the success and popularity of C&R regulations, concerns remain regarding this approach to harvest management. One such concern is the length of time a fish is played before it is landed (Cooke and Suski 2005). The primary concern with duration of angling is that longer fight times may cause physiological disturbances that lead to increased mortality of released fish. Recently, the most high-profile concern has been the potentially negative effects of exposing fish to air during C&R angling (Cook et al. 2015), including a decline in swimming performance (Schreer et al. 2005), reduced ability to cope with thermal stress (Gingerich et al. 2007), reduced reproductive success (Richard et al. 2013), and increased risk of nest predation (Philipp et al. 1997). Such concerns have emerged from a variety of sources such as social media campaigns and the scientific literature (e.g., #Keepemwet; Cook et al. 2015; Cooke et al. 2016). Natural resource agencies have also contributed to the concern. For example, the Washington Department of Fish and Wildlife recently implemented regulations making it illegal to remove salmon *Oncorhynchus* spp., steelhead *O. mykiss*, and Bull Trout *Salvelinus confluentus* from the water if it cannot be legally harvested (Washington Department of Fish and Wildlife 2016). In addition, although concerns about sub-lethal effects of air exposure have received some attention, most research has focused on direct mortality resulting from prolonged exposure to air (Ferguson and Tufts 1992; Davis and Parker 2004; Suski et al. 2007; Graves et al. 2016; Gagne et al. 2017). Despite the concerns associated with air exposure, there is a lack of information regarding how long anglers actually expose fish to air during C&R angling.

Several studies have attempted to address the question of whether air exposure increases mortality and, if so, how long a fish must be exposed to air to cause mortality, but results of such studies are inconsistent. For example, some studies have reported that air exposure has no effect on mortality (Rapp et al. 2014; Louison et al. 2016), others have reported a minimal effect (Davis and Parker 2004; Suski et al. 2007; Gagne et al. 2017), and some have reported a relatively large effect (Ferguson and Tufts 1992; Graves et al. 2016). However, the two studies showing high mortality, Graves et al. (2016) and Ferguson and Tufts (1992), should be interpreted with caution. Graves et al. (2016) had few White Marlin *Kajikia albida* in each air exposure treatment (i.e., 1 min, n = 6; 3 min, n = 5; 5 min, n = 7). In addition, the control fish were from a study conducted 8 years earlier (Graves and Horodysky 2008) and largely collected in a different location. Caution should also be used when interpreting the results of Ferguson and Tufts (1992) because fish (n = 21) were cannulated and repeatedly subjected to blood draws in a hatchery setting. In fact, Ferguson and Tufts (1992) explicitly noted that their results were not applicable to wild populations. Nevertheless, results of the study are regularly used to support claims of air exposure causing high mortality in wild populations subjected to C&R angling (e.g., Louison et al. 2017). Despite the growing body of literature evaluating the effects of air exposure on fishes, air exposure times used in prior studies may bear little resemblance to the length of time anglers actually expose fish to air during C&R angling. As previously mentioned, there is a paucity of studies evaluating how long anglers expose fish to air during typical C&R angling events. The only study to date to quantify air exposure times of actual anglers (unaware they were being observed) reported that on average, the longest continuous interval during which trout anglers exposed fish to air was 26.1 s (Lamansky and Meyer 2016). Additionally, the total amount of air exposure time averaged 29.4 s, and 96% of fish were exposed to air for 60.0 s or less. Because these air exposure times were far less than times thought to produce negative effects in wild salmonids, Lamansky and Meyer (2016) recommended that additional studies should be conducted to better contextualize the issue of air exposure in C&R fisheries. To this end, we observed anglers discreetly in a nationally known C&R trout fishery on the South Fork Snake River (SFSR), Idaho, to provide information on how long anglers actually exposed fish to air. The SFSR was chosen as the study location because it supports one of the most high-profile C&R fisheries for Yellowstone Cutthroat Trout *Oncorhynchus clarkii bouvieri* and other salmonids in the western U.S. (High 2010). In fact, the C&R fishery on the South Fork Snake River generates approximately US$12 million annually in local income.

Study Area

Angler observations were conducted from May through August, 2016 on the SFSR (Fig 1), which originates in Yellowstone National Park, Wyoming. The SFSR flows south from Yellowstone National Park through Grand Teton National Park, after which it turns west and flows into Idaho where it is impounded by Palisades Dam. Following impoundment, the river continues to flow west to its confluence with the Henrys Fork Snake River, where the river is called the Snake River from that point onward. The SFSR drains an area of 16,078 km^2 (Idaho Department of Fish and Game 2007).

The sport fishery of the SFSR includes Yellowstone Cutthroat Trout, Rainbow Trout *O. mykiss*, Rainbow Trout × Yellowstone Cutthroat Trout hybrids, Brown Trout *Salmo trutta*, and Mountain Whitefish *Prosopium williamsoni*. It is not uncommon for anglers to catch all of these species in the SFSR, but the catch-and-release fishery is almost exclusively composed of anglers targeting Yellowstone Cutthroat Trout (Brett High, Idaho Department of Fish and Game, unpublished information). Regulations on the SFSR require that anglers release all Yellowstone Cutthroat Trout. Harvest of Rainbow Trout and Rainbow Trout × Yellowstone Cutthroat Trout hybrids is unlimited. Anglers can harvest two Brown Trout over 406 mm and 25 Mountain Whitefish daily.

Methods

Field Sampling

Anglers were observed from discrete locations so that the presence of observers would not alter angler behavior (e.g., McCormick et al. 2012). In addition, anglers were observed from a distance using either binoculars or spotting scopes to maintain discretion. Once an angler was observed hooking or playing a fish, the angler was observed to determine how long the fish was exposed to air during the C&R angling event. For each C&R event, the air exposure interval was timed using a stopwatch. Fish were considered air exposed when the fish had its gills removed from the water. The longest continuous interval of air exposure (LCIE) was recorded following Lamansky and Meyer (2016; i.e., the longest continuous interval that the fish was exposed to air at one time). In cases where anglers removed the fish from the water more than once, individual air exposure events were recorded, and the total amount of air exposure was calculated as the sum of individual exposure events. The first observed C&R event for each angler was recorded. In some cases, multiple C&R events per angler were also recorded. The length of time the fish was fought (fight time) was recorded when possible.

In addition to duration of air exposure and fight time, data were also collected on angler characteristics. How the angler accessed the river (i.e., boat or foot) was recorded. Observers also recorded whether a net was used to land the fish, whether the angler was guided, and whether a photograph was taken. Anglers that accessed the river initially by boat, but then got out of the boat and fished from shore were recorded as having accessed the river by foot. Observers determined if an angler was guided by observing the boat the angler used to access the river. All guides on the SFSR are required to display a sticker on the boat indicating they are guiding anglers.

Data Analysis

Data were analyzed using only one C&R event per angler. In the event that multiple C&R events were recorded for an angler, one event was chosen at random for analysis. Note that fight times were not recorded for every individual C&R event because anglers often had begun fighting fish prior to being noticed by observers. Average fight time, total air exposure, and LCIE were calculated separately for each level of angler characteristic. Linear models were used to evaluate the relationship between fight time, LCIE, and angler characteristics. For modeling purposes, LCIE was used as the response variable because anglers rarely exposed fish to air more than once (i.e., 2.6% of observed anglers). A total 15 candidate models was developed for predicting fight time and 8 candidate models was developed for predicting LCIE. Models were compared using Akaike Information Criterion corrected for small sample size (AIC_c), and the top model was the model that had the lowest AIC_c value (Burnham and Anderson 2002). Models that had an AIC_c score within 2.0 AIC_c values of the best model were also considered top models. Additionally, the sum of the Akaike weights (*w*) for all models in which a given predictor variable was present was used as a measure of relative importance (i.e., Burnham and Anderson 2002; Quist et al. 2004).

Results

Fight time was recorded for 114 individual anglers (Table 1). The length of time that anglers fought a fish varied from 1.1 s to 230.0 s across angler characteristics. Average fight time was 40.0 s (SD = 36.8). The majority of anglers (83.3%) landed fish in under 60 s (Fig 2A; Fig 2C).

Linear regression analysis of fight times revealed that top models consistently contained the variables guide and net (Table 2). The top model for predicting fight time only included guide (i.e., whether the angler was guided or unguided) as a predictor variable and the sum of *w* for guide (0.79) also indicated that guide was of relatively high importance compared to the other predictor variables used in modeling. Based on the parameter estimates of the top model, a pattern was observed where anglers that used a guide fought fish for an average of 12.7 s (SE = 7.4) less than anglers that did not use a guide. Even though the model containing guide as the sole predictor was considered the best model, the model had poor fit (adjusted $R^2 = 0.02$) suggesting the use of a guide did not have a significant effect on fight time.

Air exposure duration was recorded for 312 C&R events (Table 1). Total air exposure and LCIE varied from 0.0 s to 91.8 s across angler characteristics. The total length of time a fish was exposed to air during a C&R event averaged 19.3 s (SD = 15.0), and the LCIE averaged 18.8 s (SD = 14.2). Nearly all anglers (99.7%) exposed fish to air (i.e., LCIE) for < 60.0 s. Observations also revealed that 84.3% of anglers exposed fish to air for < 30.0 s, 64.4% exposed fish to air for a LCIE of <20.0 s, and 27.9% of anglers exposed fish to air for a LCIE of < 10.0 s (Fig 2B; Fig 2D).

Linear regression analysis indicated that the top model for predicting LCIE included net, picture, and guide as covariates (Table 2). Both the use of a net and taking a picture increased LCIE, whereas employing a fishing guide was associated with a reduced LCIE. In fact, based on the parameter estimates from the top model, anglers that used a net exposed fish to air for 7.2 s (SE = 1.6) longer than anglers that landed the fish by hand, anglers that took a picture exposed fish to air for 16.2 s (SE = 2.9) longer than anglers that did not take a picture, and anglers that used a guide exposed fish to air for 2.8 s (SE = 1.6) less than anglers that did not use a guide. When the sums of Akaike weights were calculated to evaluate the relative importance of each variable, two of the three variables (i.e., net and picture) had relatively high importance compared to the other predictor variables used for modeling. The sums of *w* for both net and picture were 1.00. However, the model only explained 16.1% of the variation in air exposure times. As with the models predicting fight time, it is important to recognize that poor fit of the models indicates the effect of both net and picture was not significant.

Discussion

Results of the current study corroborate the findings of Lamansky and Meyer (2016) in that air exposure and fight times experienced by trout in an actual C&R fishery were low, and considerably less than times evaluated in air exposure experiments. In the study conducted by Lamansky and Meyer (2016), 280 catch-and-release events were observed for trout anglers in two lotic systems (Silver Creek, Idaho and Owyhee River, Oregon) and three lentic systems (Henry's Lake, Chesterfield Reservoir, and Horsethief Reservoir, Idaho). In the systems observed by Lamansky and Meyer (2016), average fight time was 53.0 s, average total air exposure was 29.4 s, and the longest air exposure interval averaged 26.1 s. Similar results were observed in our study where average fight time was 40.0 s, average total air exposure was 19.3 s, and LCIE averaged 18.8 s in the SFSR. The majority of previous studies evaluating the effects of air exposure on mortality of salmonids have used longer fight times and have exposed fish to air for far longer than those observed in the current study. For example, Ferguson and Tufts (1992) used manual chasing and tail grabbing for 600 s to simulate fight time, and other authors have employed simulated fight times of 240 s (Suski et al. 2007). Furthermore, most studies have exposed fish to air for a minute or more (e.g., Davis and Parker 2004; Suski et al. 2007; Rapp et al. 2014; Graves et al. 2016; Louison et al. 2016). For instance, Bonefish *Albula vulpes* were exposed to air in a laboratory setting at Cape Eleuthera Institute, The Bahamas, for either 1 min or 3 min (Suski et al. 2007).

Northern Pike *Esox lucius* from Grand Lake, Wisconsin, were exposed to air for either 2 min or 4 min (Louison et al. 2016). Studies using air exposure times similar to those observed on the SFSR have typically reported that air exposure had little or no effect on mortality. Specifically, in a laboratory study at the State University of New York, Potsdam, New York, Brook Trout *Salvelinus fontinalis* were exposed to air for 30 s and no mortality was observed (Schreer et al. 2005). Similarly, Bluegill *Lepomis macrochirus* from Lake Opinicon, Ontario, were exposed to air for 30 s and no mortality was reported (Gingerich et al. 2007). Regression models revealed that of the variables used to predict fight time, the use of a guide was the most important. Although the use of guide did not significantly affect how long a fish was played, the data suggested that the use of a guide may reduce fight time. The use of a guide likely reduces fight time because anglers are able to focus on playing the fish while the guide maneuvers the boat and(or) assists in landing the fish. Guides may also have encouraged faster playing, but this could not be evaluated using our methods. Fight time was also longer when a picture of the fish was subsequently taken. The process of taking a picture likely did not cause an increase in fight time; rather, the increase was likely due to the angler catching a large fish. Regardless, only 7.4% of anglers took a picture. Although various factors were related to fight time, the models had poor fit suggesting high variation in fight times within and among angler groups.

Linear regression modeling revealed that of the predictor variables used to predict LCIE, net and picture were the most important. Although not statistically significant, using a net generally increased the length of time a fish was exposed to air. Increased air exposure times due to the use of a net were also observed by Lamansky and Meyer (2016). The authors hypothesized that increased air exposure was due to the fish and(or) hook becoming entangled in the net. A pattern was also observed where taking a picture increased the length of time a fish was exposed to air by adding a step to the release process. Taking a picture also increases the chances of the fish struggling to escape the angler's grasp and(or) dropping the fish, thereby increasing air exposure time. As with models predicting fight time, models predicting air exposure had relatively poor fit.

Although salmonids have been shown to be among the most sensitive taxa with regard to hypoxic stress (Doudoroff and Shumway 1970), the average air exposure times reported in the current study and those reported by Lamansky and Meyer (2016) are far less than what has been reported to cause mortality in salmonids and other taxa (e.g., Suski et al. 2007). As such, it is unlikely that the catch-and-release fishery on the SFSR, or similar systems, would benefit from implementing regulations that limit the length of time anglers can expose fish to air. Further research into how long anglers expose fish to air during C&R angling for other fisheries should be conducted before regulations limiting air exposure are considered. In particular, research on anadromous fisheries or fisheries targeting species of conservation concern may be warranted.

Acknowledgements

We thank T. Brauer, E. Roth, S. Smith, T. Smouse, and J. Wu for their assistance with field work. R. Long, T. Johnson, and three anonymous reviewers provided helpful comments on a previous version of the manuscript. Funding for this project was provided by the Idaho Department of Fish and Game through the Federal Aid in Sport Fish Restoration Act and by Idaho anglers via license fees. Additional support was provided by the U.S. Geological Survey, Idaho Cooperative Fish and Wildlife Research Unit. The Unit is jointly sponsored by the University of Idaho, U.S. Geological Survey, Idaho Department of Fish and Game, and Wildlife Management Institute. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. government. This project was conducted under the University of Idaho Institutional Animal Care and Use Committee Protocol 2015-48.

References

Anderson, R. M., & Nehring, R. B. (1984). Effects of a catch-and-release regulation on a wild trout population in Colorado and its acceptance by anglers. *North American Journal of Fisheries Management*, *4*, 257–265.

Burnham, K. P., & Anderson, D. R. (2002). *Model selection and multimodel inference: a practical information-theoretic approach,* 2nd edn. New York, NY: Springer-Verlag.

Carline, R. F., Beard Jr, T., & Hollender B. A. (1991). Response of wild Brown Trout to elimination of stocking and no-harvest regulations. *North American Journal of Fisheries Management,* 11, 253–266.

Cook, K. V., Lennox, R. J., Hinch, S. G., & Cooke, S. J. (2015). Fish out of water: how much air is too much? *Fisheries,* 40, 452–461.

Cooke, S. J., & Suski, C. D. (2005). Do we need species-specific guidelines for catch-and-release recreational angling to effectively conserve diverse fishery resources? *Biodiversity and Conservation*, 14, 1195–1209.

Cooke, S. J., Cooke, C. J. A., & Brownscombe, J. W. (2016). Ultralight or heavyweight? The interactive effects of gear strength and air exposure on reflex impairment in Largemouth Bass. *Transactions of the American Fisheries Society,* 145, 1202–1207.

Davis, M. W., & Parker, S. J. (2004). Fish size and exposure to air: potential effects on behavioral impairment and mortality rates in discarded Sablefish. *North American Journal of Fisheries Management,* 24, 518–524.

Doudoroff, P., and D. L. Shumway. 1970. Dissolved oxygen requirements of freshwater fishes. FAO (Food and Agricultural Organization of the United Nations) Fisheries Technical Paper 86, Rome.

Ferguson, R. A., & Tufts, B. L. (1992). Physiological effects of brief air exposure in exhaustively exercised Rainbow Trout (*Oncorhynchus mykiss*): Implications for "catch and release" fisheries. *Canadian Journal of Fisheries and Aquatic Sciences,* 49, 1157–1162.

Gagne, T. O., Ovitz, K. L., Griffin, L. P., Brownscombe, J. W., Cooke, S. J., & Danylchuk, A. J. (2017). Evaluating the consequences of catch-and-release recreational angling on Golden Dorado (*Salminus brasiliensis*) in Salta, Argentina. *Fisheries Research*, 186, 625–633.

Gingerich, A. J., Cooke, S. J., Hanson, K. C., Donaldson, M. R., Hasler, C. T., Suski, C. D., & Arlinghaus, R. (2007). Evaluation of the interactive effects of air exposure duration and water temperature on the condition and survival of angled and released fish. *Fisheries Research,* 86, 169–178.

Graff, D.R. , & Hollender, B. A. (1977). Catch-and-release fishing – the Pennsylvania experience. In: R. A. Barnhart & T. D. Roelofs (eds) *Catch-and-release fishing as a management tool.* Arcata, California, USA: Humboldt State University, 137–149 pp.

Graves, J. E., & Horodysky, A. Z. (2008). Does hook choice matter? The effects of three circle hook models on post-release survival of White Marlin. *North American Journal of Fisheries Management,* 28, 471–480.

Graves, J. E., Marcek, B. J., & Goldsmith, W. M. (2016). Effects of air exposure on postrelease mortality rates of White Marlin caught in the U.S. offshore recreational fishery. *North American Journal of Fisheries Management,* 36, 1121–1228.

High, B. 2010. Yellowstone Cutthroat Trout conservation efforts on the South Fork Snake River. In: R.F. Carline and C. LoSapio (eds) *Wild Trout X: conserving wild trout*. Bozeman, Montana, USA: Wild Trout Symposium, 275–284 pp.

Hunt, R. L. (1981). A successful application of catch and release regulations on Wisconsin trout streams. *Wisconsin Department of Natural Resources, Technical Bulletin,* 119, 30 pp.

Idaho Department of Fish and Game. (2007). Management plan for conservation of Yellowstone Cutthroat Trout in Idaho. *Idaho Department of Fish and Game.* Boise, Idaho, USA: Idaho Department of Fish and Game.

Isermann, D. A., & Paukert, C. P. (2010). Regulating harvest. In: W. A. Hubert, and M. C. Quist (eds) *Inland fisheries management in North America,* 3rd edn. Bethesda, MD, USA: American Fisheries Society, 185–212 pp.

Jones, R. D. (1987). The Yellowstone experience: a decade of catch-and-release experience. In: R. A. Barnhart and T. D. Roelofs (eds) *Catch-and-release fishing, a decade of experience*. Arcata, CA, USA: Humboldt State University, 94–99 pp.

Lamansky, J. A., & Meyer, K. A. (2016). Air exposure time of trout released by anglers during catch and release. *North American Journal of Fisheries Management,* 36, 1018–1023.

Louison, M. J., Hasler, C. T., Fenske, M. M., Suski, C. D., & Stein, J. A. (2017). Physiological effects of ice-angling capture and handling of Northern Pike, *Esox lucius*. *Fisheries Management and Ecology,* 24, 10–18.

McCormick, J. L., Quist, M. C., & Schill, D. J. (2012). Effect of survey design and catch rate estimation on total catch estimates in Chinook Salmon fisheries. *North American Journal of Fisheries Management,* 32, 1090–1101.

Philipp, D. P., Toline, C. A., Kubacki, M. F., Philipp, D. B. F., & Phelan, F. J. S. (1997). The impact of catch-and-release angling on the reproductive success of Smallmouth Bass and Largemouth Bass. *North American Journal of Fisheries Management,* 17, 557–567.

Quist. M. C., Rahel, F. J., & Hubert, W. A. (2004). Hierarchical faunal filters: an approach to assessing effects of habitat and nonnative species on native fishes. *Ecology of Freshwater Fish,* 14, 24–39.

Rapp, T., Hallermann, J., Cooke, S. J., Hetz, S. K., Wuertz, S., & Arlinghaus, R. (2014). Consequences of air exposure on the physiology and behavior of caught-and-released Common Carp in the laboratory and under natural conditions. *North American Journal of Fisheries Management,* 34, 232–246.

Richard, A., Dionne, M., Wang, J., & Bernatchez, L. (2013). Does catch and release affect the mating system and individual reproductive success of wild Atlantic Salmon (*Salmo salar L.*)? *Molecular Ecology,* 22, 187–200.

Schreer, J. F., Resch, D. M., Gately, M. L., & Cooke, S. J. (2005). Swimming performance of Brook Trout after simulated catch-and-release angling: looking for air exposure thresholds. *North American Journal of Fisheries Management,* 25, 1513–1517.

Suski, C. D., Cooke, S. J., Danylchuk, A. J., O'Connor, C. M., Gravel, M., Redpath, T., Goldberg, T. L. (2007). Physiological disturbance and recovery dynamics of Bonefish (*Albula vulpes*), a tropical marine fish, in response to variable exercise and exposure to air. *Comparative Biochemistry and Physiology,* 148, 664–673.

Thompson, P. E. (1958). Fishing is fun. *Sports Afield (May)*, 19–23.

Varley, J. D. 1980. Catch-and-release fishing in Yellowstone Park. In: W. King (ed) *Wild trout II. Trout Unlimited and Federation of Fly Fishermen,* Vienna, Virginia, USA: Trout Unlimited, 137–142 pp.

Washington Department of Fish and Wildlife . (2016). Washington sport fishing rules. *Washington Department of Fish and Wildlife*. Olympia, WA, USA: Washington Department of Fish and Wildlife.

Wells, J. (1987). Catch-and-release fishing, the Montana experience. In: R. A. Barnhart and T. D. Roelofs (eds) *Catch-and-release fishing, a decade of experience*. Arcata, CA, USA: Humboldt State University, 68–79 pp.

Wydoski, R. S. (1977). Relation of hooking mortality and sublethal hooking stress to quality fishery management. In: R. A. Barnhart & T. D. Roelofs (eds) *Catch-and-release fishing as a management tool.* Arcata, CA, USA: Humboldt State University, 43–87 pp.

Table 2.1. Average of fight time, total air exposure, and longest continuous interval of air exposure by angler characteristic for catch-and-release angling on the South Fork Snake River, ID (May – August, 2016). Standard deviation (SD) is included for each metric.

Angler characteristics	Level	Average fight time (s)	SD	*n*	Average total air exposure (s)	SD	*n*	Average longest continuous interval of air exposure (s)	SD	*n*
Access	Boat	40.2	36.8	81	19.5	15.0	225	18.9	14.2	225
	Foot	39.3	36.1	33	19.0	15.3	87	18.7	14.4	87
Net	Yes	41.8	36.9	87	22.2	15.0	211	21.5	14.2	211
	No	34.0	37.6	27	13.3	15.1	101	13.3	14.3	101
Picture	Yes	75.2	36.8	10	41.1	15.5	23	35.8	14.6	23
	No	37.0	36.8	104	17.6	15.0	289	17.5	14.2	289
Guide	Yes	36.1	34.5	79	18.6	15.0	200	18.4	14.3	200
	No	48.8	37.0	35	20.7	15.1	112	19.7	14.2	112
Overall		40.0	36.8	114	19.3	15.0	312	18.8	14.2	312

Table 2.2. Top regression models predicting the length of time anglers fought fish and the longest continuous interval of air exposure anglers exposed fish to based on angler observations in the South Fork Snake River, Idaho (May - August, 2016). Covariates include whether the angler was guided, net use, how the angler accessed the river, whether a photograph was taken, and angler sex. Models were evaluated using the number of parameters in the model (K), Akaike's information criterion (AIC_c), the change in Akaike's information criterion between models (ΔAIC_c), and Akaike's weight (*w*). The adjusted coefficient of determination (R^2) was used to evaluate model fit.

Response variable	Model parameters	K	AIC_c	ΔAIC_c	*w*	Adjusted R^2
Fight time	$48.75 - 12.70 \bullet \text{Guide}_{yes}$	3	1147.67	0.00	0.28	0.02
	$41.90 + 10.44 \bullet \text{Net}_{yes} - 14.30 \bullet \text{Guide}_{yes}$	4	1148.14	0.47	0.22	0.02
	$36.10 \bullet \text{Net}_{yes} - 3.81 \bullet \text{Guide}_{yes} - 14.62 \bullet \text{Net}_{yes} \times \text{Guide}_{yes}$	5	1149.53	1.86	0.11	0.02
	$50.33 - 13.44 \bullet \text{Guide}_{yes} - 3.70 \bullet \text{Access}_{foot}$	4	1149.58	1.91	0.11	0.01
	$33.95 - 7.86 \bullet \text{Net}_{yes}$	3	1149.67	2.00	0.10	0.00
Longest continuous interval of air exposure	$17.55 + 7.18 \bullet \text{Net}_{yes} + 16.17 \bullet \text{Picture}_{yes} - 2.75 \bullet \text{Guide}_{yes}$	5	2490.14	0.00	0.34	0.16
	$13.69 + 7.54 \bullet \text{Net}_{yes} + 16.27 \bullet \text{Picture}_{yes} - 2.60 \bullet \text{Guide}_{yes} + 1.85 \bullet \text{Access}_{foot}$	6	2491.01	0.87	0.22	0.16
	$13.16 + 6.61 \bullet \text{Net}_{yes} + 16.31 \bullet \text{Picture}_{yes}$	4	2491.22	1.07	0.20	0.16
	$12.27 + 7.06 \bullet \text{Net}_{yes} + 16.42 \bullet \text{Picture}_{yes} + 2.10 \bullet \text{Access}_{foot}$	5	2491.71	1.57	0.16	0.16

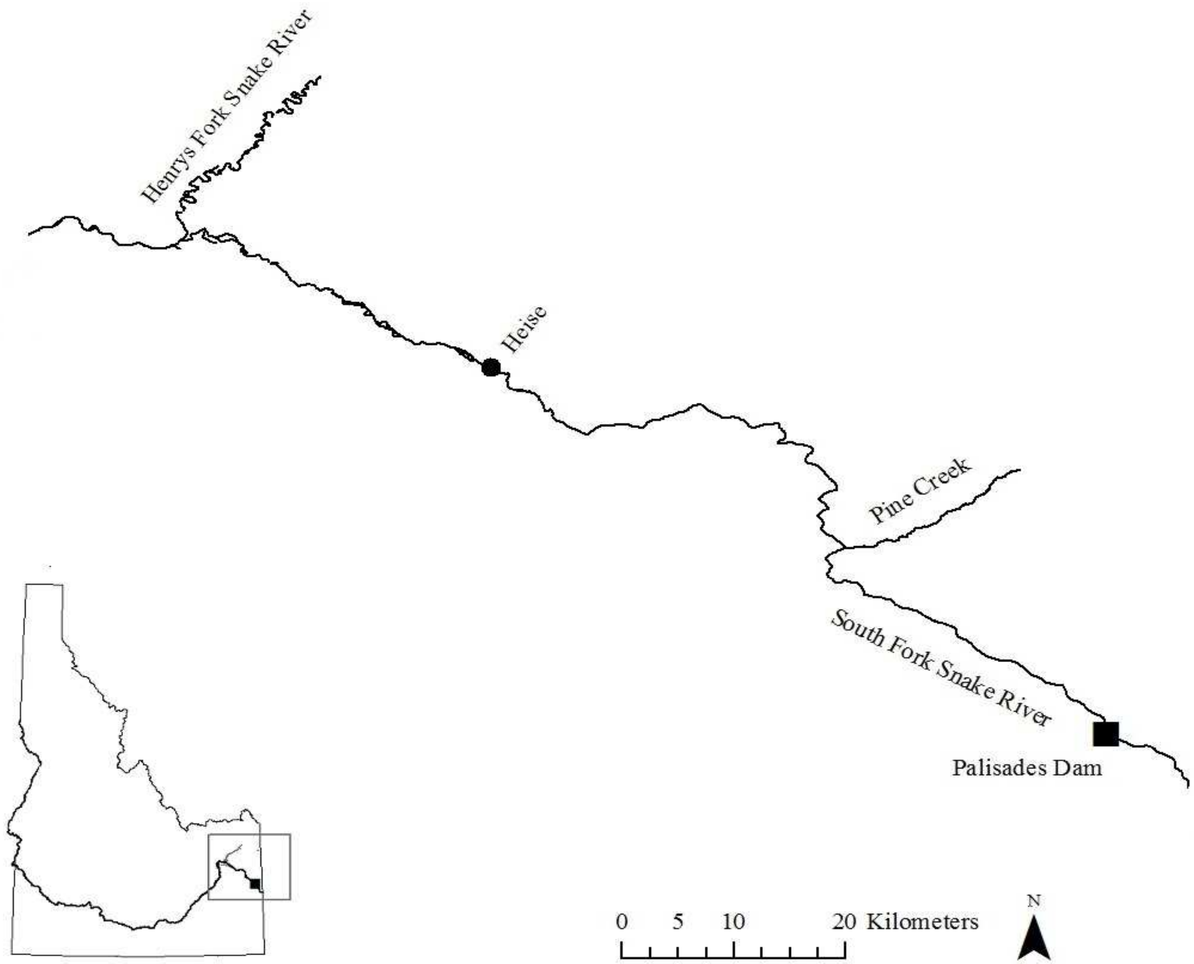

Fig 2.1. South Fork Snake River from Palisades Dam to the confluence with the Henrys Fork Snake River, Idaho.

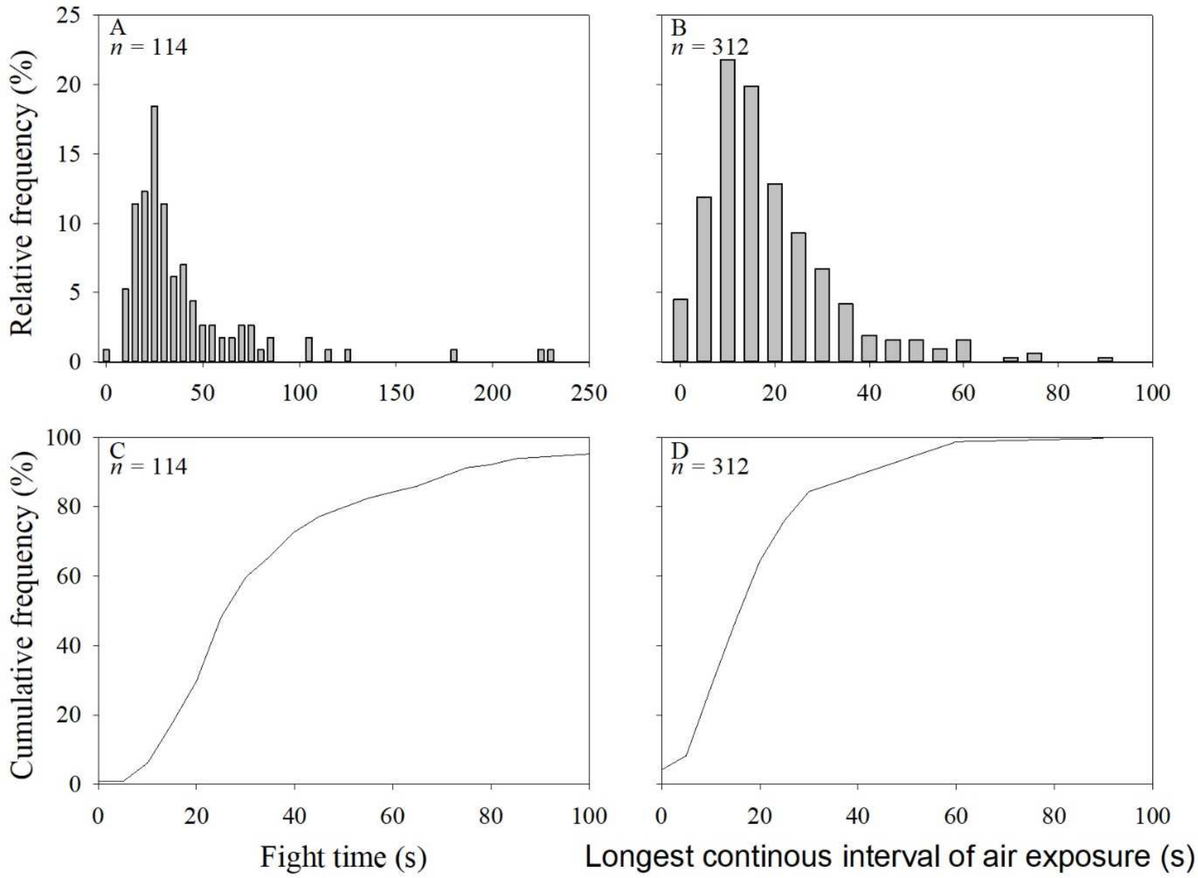

Fig 2.2. Frequency distributions and cumulative frequencies of the time anglers fought fish and the longest continuous interval of air exposure that anglers exposed fish to during catch-and-release angling in the South Fork Snake River, Idaho (May - August, 2016).

Chapter 3: Effects of Summer Air Exposure on the Survival of Caught and Released Salmonids

A manuscript submitted for publication in the *North American Journal of Fisheries Management*

Curtis J. Roth, Daniel J. Schill, Michael C. Quist, Brett High

Abstract

Despite the success of catch-and-release regulations, exposing fish to air during release has emerged as a growing concern over the past two decades. We evaluated the effect of air exposure during mid-summer catch and release on survival of Yellowstone Cutthroat Trout *O. clarkii bouvieri,* Bull Trout *Salvelinus confluentus,* and Rainbow Trout *Oncorhynchus mykiss* exposed to catch-and-release angling. Fish were sampled by angling on Palisades Creek (August 2016), Sawmill Creek, and the Main Fork of the Little Lost River, Idaho (July – August 2017). After capture, fish were kept underwater while they were measured and individually tagged. Anglers in groups of two to four people caught study fish and exposed them to air for 0, 30, or 60 s. Single-pass backpack electrofishing was then used to recapture tagged fish and estimate relative survival. In total, 328 Yellowstone Cutthroat Trout were sampled (0 s, n = 110; 30 s, n = 110; 60 s, n = 108), 278 Bull Trout (0 s, n = 92; 30 s, n = 94; 60 s, n = 92), and 322 Rainbow Trout (0 s, n = 103; 30 s, n = 106; 60 s, n = 113). No difference in survival was observed among treatments for all three species. Results from the present study along with those from prior studies with real-world air exposure times suggest that mortality from exposing fish to air for 60 s or less is not a concern in catch-and-release fisheries for these species.

Introduction

Catch-and-release regulations are among the most popular forms of fishing regulations (Isermann and Paukert 2010), and are implemented for a variety of reasons such as to prevent the consumption of contaminated fish (Carline et al. 1991), protect species that are easily over exploited (Sullivan 2003), and improve the quality of the fishery (Perry et al. 1995; Schneider and Lockwood 2002). When catch-and-release regulations are implemented to improve the quality of a fishery, their success depends on whether released fish survive (Wydoski 1977; Iserman and Paukert 2010). A number of factors have been shown to influence the survival of fish that have been caught and released, including the species of fish (Gale et al. 2011), hook location (Pauley and Thomas 1993), water depth at which the fish was hooked (Gitschlag and Renaud 1994), type of hook used (Mongillo 1984), type of bait or lure used (Schisler and Bergersen 1996), size of fish (Taylor and White 1992), how the fish was handled (Gale et al. 2011), and air exposure.

In recent years, studies on the effects of air exposure during catch-and-release angling have become increasingly prevalent in the fisheries literature. Concerns surrounding exposing fish to air include alterations to reproductive success (e.g., Raby et al. 2013; Richard et al. 2013), the ability to cope with thermal stress (e.g., Gale et al. 2011), and swimming performance (Schreer et al. 2013). However, the majority of air exposure studies have evaluated whether or not air exposure increases mortality rates in caught and released fish (Ferguson and Tufts 1992; Davis and Parker 2004; Gingerich et al. 2007; Suski et al. 2007; Graves et al. 2016). A few of these studies have reported that air exposure increases mortality of fish that have been caught and released (i.e., Ferguson and Tufts 1992; Graves et al. 2016). However, the majority of studies that have evaluated the effects of air exposure on mortality have reported that air exposure causes little or no increase in mortality of released fish (i.e., Schreer et al. 2005; Gingerich et al. 2007; Suski et al. 2007; Thompson et al. 2008; Rapp et al. 2014; Louison et al. 2016; Gagne et al. 2017).

Despite the preponderance of studies showing little or no mortality from air exposure, some constituents have continued to express concerns, with proponents of air exposure limitation consistently citing Ferguson and Tufts (1992) to support regulating the amount of time that anglers can expose fish to air (e.g., Cook et al. 2015). This reliance on Ferguson and Tufts (1992) to argue in favor of limiting air exposure is concerning. The Rainbow Trout *Oncorhynchus mykiss* used by Ferguson and Tufts (1992) had a 72% rate of mortality when exposed to air for 60 s. However, those fish were chased, in a laboratory setting, for 600 s, cannulated, and subjected to five blood sampling events. Due to the artificial nature of the study, Ferguson and Tufts (1992) cautioned that the results of their study were not applicable to actual fisheries for wild fishes (page 1161; Ferguson and Tufts 1992).

A number of factors have made it difficult to apply the results of previous air exposure studies, including Ferguson and Tufts (1992), to wild fishes. For instance, fish have been held in tanks prior to or after exposure to air (i.e., Ferguson and Tufts 1992; Davis and Parker 2004; Gingerich et al. 2007; Suski et al. 2007), fish have been exposed to longer fight times than they would experience in actual catch-and-release fisheries (i.e., Ferguson and Tufts 1992), or fish were exposed to air longer than they would experience in actual catch-and-release fisheries (i.e., Gingerich et al. 2007; Suski et al. 2007; Thompson et al. 2008; Rapp et al. 2014; Louison et al. 2016). In the only study (to date) that reports actual air exposure and fight times, fight and air exposure times were much shorter than those evaluated in nearly all air exposure studies (Lamansky and Meyer 2016). Further, the use of hatchery fish in lieu of wild fishes in raceways or a laboratory setting makes it difficult for fisheries managers to make informed decisions associated with actual catch-and-release fisheries. Our objective was to evaluate the effects of air exposure on survival of uncaged Yellowstone Cutthroat Trout *Oncorhynchus clarkii bouvieri,* Bull Trout *Salvelinus confluentus,* and Rainbow Trout caught via hook-and-line angling in multiple locations in Idaho.

Methods

Study Area

We evaluated the effects of air exposure on survival of Yellowstone Cutthroat Trout in Palisades Creek, Idaho, a tributary of the South Fork Snake River that enters the river 5.62 km downstream of Palisades Dam (Figure 1). Discharge in Palisades Creek is typically 0.2 to 17.0 m^3/s (Moore and Schill 1984). Angling occurred from 1 to 4 August, 2016, beginning 0.73 km upstream of Lower Palisades Lake and continuing upstream for 2.26 km. Water temperatures in Palisades Creek were monitored during the study with in-stream thermographs. Water temperatures in Palisades Creek during the study averaged 11.5 °C (SE = 0.03) and varied diurnally from 9.9 °C to 13.6 °C. Stream temperatures during actual angling sessions (0800 – 1800 hrs) averaged 11.6 °C (SE = 0.1) and varied from 10.4 °C to 13.2 °C. Because air temperatures could also influence survival, they were monitored using Natural Resources Conservation Service data from a nearby site (Snotel Site 695). Average diurnal air temperature was 18.4 °C (SE = 1.0) and varied from 4.7 °C to 30.6 °C during the study period.

Bull Trout and Rainbow Trout were sampled in two tributaries of the Little Lost River, Idaho: Sawmill Creek, Main Fork of the Little Lost River (Figure 2). The Main Fork of the

Little Lost River is renamed Sawmill Creek after its confluence with Timber Creek. Sawmill Creek and the Main Fork of the Little Lost River were divided into two contiguous sections for angling. The lowermost section (Section One) began in Sawmill Creek directly upstream of an existing fish weir and continued upstream into the Main Fork of the Little Lost River for 2.73 km. Section One was angled during 10 to 14 July, 2017. The second section (Section Two) began at the upstream terminus of Section One and continued upstream for 2.79 km. Angling took place in Section Two during 7 to 11 August, 2017. Water temperatures were monitored using in-stream thermographs in both sections. Water temperature averaged 10.1 °C (SE = 0.1) and varied from 6.6 °C to14.4 °C in Section One. Average water temperature was similar in Section Two (mean ± SE; 9.8 ± 0.1 °C) and varied from 6.8 °C to 16.7 °C. Stream temperatures during actual angling (0800 – 1800 hrs) in Section One averaged 11.4 °C (SE = 0.2) and varied from 8.7 to 13.8. Temperatures were similar during angling (0800 – 1800 hrs) in Section Two (10.8 ± 0.1 °C) and varied from 9.3 °C to 12.6 °C. Air temperature data for both sections were obtained from the Natural Resources Conservation Service (Snotel Site 636). Air temperatures averaged 15.8 °C (SE = 0.5) and varied from 5.7 °C to 28.4 °C in Section Once. Air temperature in Section Two was slightly cooler (12.0 ± 0.7 °C) and varied from 4.0 °C to 23.7 °C.

Field Sampling

Fish were caught by hook-and-line angling using artificial lures or flies and general methods used by a typical angler. Barbed hooks were used since barbed and barbless hooks have similar unhooking times and mortality rates (Schill and Scarpella 1997), but the capture efficiency is higher for barbed hooks (DuBois and Kuklinski 2004; Bloom 2013). Anglers, spanning a considerable range of angling experience, worked in groups of two to four people.

The amount of time it took to play the fish (fight time), the type of gear (i.e., artificial lure or fly), and where the fish was hooked (e.g., corner of the mouth, lower jaw, upper jaw) was recorded for each capture event (Sullivan et al. 2013). After capture, fish remained in the water while they were measured for total length (mm) and tagged in the upper dorsal musculature using a T-bar anchor tag (Del 1968). Each fish received a pelvic fin clip as a secondary mark to evaluate tag retention. Tag retention rates were high for all three angling events. Only one Yellowstone Cutthroat Trout (<1% of all tagged fish), four Bull Trout (1%), and no Rainbow Trout (0%) were found with a pelvic fin clip and no tag during recapture efforts.

For each angling group, the first fish captured was randomly assigned to a treatment group and exposed to air for 0, 30, or 60 s. Air exposure treatments were then systematically cycled. Air exposure times were based on the findings of Lamansky and Meyer (2016), who reported that anglers in catch-and-release fisheries in Oregon and Idaho exposed trout to air for an average of 29.4 s and that 96% of anglers exposed trout to air for less than 60 s. After approximately two weeks (Palisades Creek = 12 days; Section One = 10 days; Section Two = 12 days), single-pass backpack electrofishing was conducted in each study section to recapture tagged fish. Electrofishing was conducted using two backpack units, beginning at the downstream boundary of the study sections and moving upstream in tandem. Power output and pulse frequency during electrofishing was optimized to elicit a galvanotaxic response from the fish, and all available habitat was sampled. An additional four to five people accompanied the operators of the electrofishing units to net and process fish.

The number of individuals, by species, recaptured in each treatment group divided by the total number tagged in that group provided an estimate of relative survival. Data from angling events for Rainbow and Bull Trout that took place in Section One and Section Two were pooled by species for analysis because they were contiguous and comprised virtually the same water body. The effects of air exposure on survival were then evaluated by calculating confidence bounds around the differences between proportions of recaptured fish (Fleiss 1981; Johnson 1999). Estimates of relative survival were considered significantly different among the three groups for each species when confidence bounds around the differences did not contain zero (Fleiss 1981; Meyer et al. 2011; Schill et al. 2016). Additionally, length-frequency distributions were constructed to evaluate whether length distributions were similar among treatment groups.

Results

In total, 328 Yellowstone Cutthroat Trout were caught on Palisades Creek. Of the fish sampled, 110 received 0 s of air exposure, 110 were exposed to air for 30 s, and 108 were exposed to air for 60 s. The majority of fish were captured with flies (92%) and hooked in the corner of the mouth, lower jaw, or upper jaw (78%; Figure 3). Few fish (<2%) were hooked in vital areas such as the esophagus, gills, or eye. Length distributions were similar among treatments with an average length of 232.8 mm (SE = 2.8; Figure 4). The average fight time for Yellowstone Cutthroat Trout was 16.9 s (SE = 0.5) and was similar among treatment groups (i.e., 0 s = 17.4 ± 0.9 s; 30 s = 16.5 ± 0.9 s; 60 s = 17.0 ± 0.9 s). Of the 328 tagged fish, 204 were recaptured with electrofishing (0 s, *n* = 75, 69%; 30 s, *n* = 63, 57%; 60 s *n* = 66, 61 %; Figure 5). Recaptured fish were slightly larger on average (i.e., 240.9 ± 3.6 mm) than fish that were not recaptured (i.e., 219.9 ± 4.6 mm). No significant difference in relative survival was observed among the three groups (i.e., confidence intervals around their differences overlapped zero; Table 1).

A total of 278 Bull Trout was caught in Sawmill Creek and in the Main Fork of the Little Lost River. The number of fish in each air exposure treatment group was similar, 92 fish received no air exposure, 94 received 30 s of air exposure, and 92 fish received 60 s of air exposure. Bull Trout were predominantly captured with flies (99%) and hooked in the corner of the mouth, lower jaw, or upper jaw (90%; Figure 3). As with Yellowstone Cutthroat Trout, few fish (<1%) were hooked in vital locations. Length distributions were also similar among the treatment groups (197.2 ± 2.3 mm; Figure 4). Average fight time for Bull Trout was 14.6 s (SE = 0.6) and was similar among treatment groups (0 s = 15.9 ± 1.1 s; 30 s = 14.4 ± 1.1 s; 60 s = 13.7 ± 1.1 s). We recaptured 163 Bull Trout (0 s, n = 48, 52%; 30 s, n = 56, 60%; 60 s n = 59, 64%; Table 1). Fish that were recaptured had a slightly larger length (202.5 ± 3.1 mm) than fish that were not recaptured (189.6 ± 3.7 mm). No difference in relative survival was observed among the three groups (Table 1).

Three-hundred-and-twenty-two Rainbow Trout were sampled from Sawmill Creek and the Main Fork of the Little Lost River. Sample sizes in each treatment group were similar, 103 received no air exposure, 106 received 30 s of air exposure, and 113 received 60 s of air exposure. The majority of Rainbow Trout were captured with flies (99%) and most were hooked in the corner of the mouth, lower jaw, or upper jaw (79%; Figure 3). As with Yellowstone Cutthroat Trout and Bull Trout, few Rainbow trout were hooked in vital areas. Rainbow Trout were fought for an average of 14.7 s (SE = 0.6). Additionally, fight times were similar among treatment groups (0 s = 15.7 ± 1.0 s; 30 s = 13.4 ± 1.0 s; 60 s = 14.9 ± 1.0 s). (<1%). One-hundred-and-eighty-four fish were recaptured (0 s, n = 65, 63%; 30 s, n = 61, 68%; 60 s n = 58, 51%; Figure 5). The average length of sampled Rainbow Trout was 190.5 mm (SE = 2.2) and length distributions were similar among treatment groups (Figure 4). Recaptured fish were somewhat larger (192.4 ± 2.9 mm) than fish that were not recaptured (188.0 ± 3.4 mm). No differences in survival among groups were observed (Table 1).

Discussion

No increase in mortality was observed Yellowstone Cutthroat Trout, Bull Trout, or Rainbow Trout exposed to air for up to 60 s. Previous studies evaluating the effect of air exposure on mortality have also reported low mortality when fish were exposed to air for times similar to those in our study (e.g., Schreer et al. 2005; Gingerich et al. 2007; Suski et al. 2007; Thompson et al. 2008). For example, Brook Trout *Salvelinus fontinalis* were exposed to air in a laboratory setting at the State University of New York, Potsdam, New York for either 0, 30, 60, or 120 s and no mortality was reported (Schreer et al. 2005). Bluegill *Lepomis macrochirus* from Lake Opinicon, Ontario, had a mortality rate of 7% at 30 s of air exposure and 9% at 60 s of air exposure (Gingerich et al. 2007). Bonefish *Albula vulpes* exposed to air for 60 s in a laboratory setting at Cape Eleuthera Institute, The Bahamas, displayed no increase in mortality relative to fish that were not exposed to air (Suski et al. 2007). Warm water temperatures have been shown to increase stress and hooking mortality in salmonids (Strange et al. 1977, Dotson 1982), and it should be noted that our study occurred in mid-summer when water and air temperatures were higher than they would be during other portions of the angling season. In addition to warmer water temperatures, the handling protocol associated with our study (e.g., the difficult act of floy-tagging, collecting a length measurement, and administering a pelvic fin clip all while the fish remains underwater) was more intensive than the handling treatment fish would receive in a typical catch-and-release fishery. Even under these conditions, no increase in mortality was observed due to air exposure.

The majority of previous studies on the effect of air exposure have limited applicability to wild fish populations. Only a handful of studies have studied wild, uncaged fish and most have reported no effect on mortality (Thompson et al. 2008; Louison et al. 2016; Gagne et al. 2017). For instance, wild Northern Pike *Esox lucius* from Grand Lake, Wisconsin, exposed to air for up to 4 min during ice angling displayed no immediate mortality (Louison et al. 2016). Similarly, wild Golden Dorado *Salminus brasiliensis* captured via angling from the Juramento River, Argentina, displayed no immediate mortality after 2 min of air exposure (Gagne et al. 2017). The one exception was a study of White Marlin *Kajikia albida* captured off the coast of Virginia Beach, Virginia (Graves et al. 2016). In that study, fish experienced a 17% rate of mortality when exposed to air for 1 min compared to a 2% rate of mortality when not exposed to air. However, results of Graves et al. (2016) must be interpreted with caution. The sample size of fish in each treatment was small (i.e., 1 min, n = 6; 3 min, n = 5; 5 min, n = 7), and control fish were captured 8 years prior in other locations as part of a different study (Graves et al. 2008). Determining whether increased mortality rates were due to the fish being exposed to air or some other unknown factor is impossible given the study design. When results of the current study are combined with the results of prior studies, it seems unlikely that increased mortality due to air exposure is a concern in most catch-and-release fisheries. Further support for this conclusion is provided by Lamansky and Meyer (2016) and Roth et al. (*in press*), who both reported the length of time anglers actually expose fish to air in a catch-and-release fishery. In those studies, five species of salmonids were, on average, exposed to air for 19.3 s to 29.4 s—far less than times used in previous air exposure studies (e.g., Thompson et al. 2008; Louison et al. 2016; Gagne et al. 2017).

The length of recaptured fish was slightly larger than for all tagged fish. One possible reason is that there was differential survival between larger fish and smaller fish. However, this is unlikely because a wide distribution of fish of differing lengths was recaptured, including very small fish. Specifically, recaptured Yellowstone Cutthroat Trout varied in length from 129 to 355 mm, Bull Trout varied from 130 to 320 mm, and Rainbow Trout varied from 124 to 288 mm. A more plausible explanation is simply the sampling bias associated with electrofishing. Electrofishing routinely selects for larger individuals (Coopler and Lagler 1956; McFadden 1961; Dolan and Miranda 2003). Compounding the selective nature of the gear is that large fish are often easily observed and preferentially (though inadvertently) captured by netters (Reynolds and Kilz 2010).

The results of the current study, coupled with prior studies, suggest that concerns regarding air exposure in catch-and-release fisheries are largely a social issue given the lack of research demonstrating increased mortality from air exposure in wild fish populations (e.g., Thompson et al. 2008; Louison et al. 2016; Gagne et al. 2017). In the past, regulations have been implemented in response to perceived biological concerns, but have occasionally been implemented for social reasons regardless of existing studies (Schill and Scarpella 1997; Isermann and Paukert 2010). In the case of air exposure, addressing the issue via regulations seem unnecessary because the vast majority of trout anglers (> 96%) release fish in less than 60 s without specific regulations mandating such behavior (Lamansky and Meyer 2016; Roth et al. *in press*). Without putting actual angler exposure times in perspective relative to the existing catch-and-release mortality literature regulations limiting air exposure could possibly be perceived by the public as an indication that catch-and-release fishing as currently practiced is detrimental to fish, when in fact, with very few exceptions (e.g., Hunt 1977) they have been shown to protect and enhance fish populations (e.g., Thompson 1958; Johnson and Bjornn 1978; Anderson and Nehring 1984). In an era of ever-decreasing recruitment of new anglers in U.S. fisheries (Maillett et al. 2017), purveying the notion to new or novice anglers that quickly removing a fish from the water to admire it actually endangers a meaningful proportion of caught-and-released fish seems both inaccurate and counterproductive to effective fisheries management in the future. Therefore, the exercise of considerable caution seems warranted when considering regulations that place limits on air exposure times in catch-and-release fisheries.

Acknowledgements

We thank K. Barney, N. Birmingham, F. Bohlen, J. Calvitti, J. Cassinelli, S. Cossel, J. Dillon, K. Estep, B. Gamett, D. Garren, B. Gregory, J. Gregory, K. Johnson, C. Kerrick, J. Kozfkay, J. Kunz, A. Lambert, W. Lubenau, D. McCarrick, C. McClure, C. Michaelson, S. Nielson, A. Notara, J. Rosales, C. Rosenkrance, C. Rudfelt, D. Skidmore, S. Smith, T. Smouse, S. Smyer, J. Spillet, D. Thompson, C. Traughber, K. Vada, C. Warren, D. Whitaker, M. Williams, and J. Wu for their assistance with fieldwork. T. Johnson and R. Long provided helpful comments on an earlier version of the manuscript. Funding for this project was provided by the Idaho Department of Fish and Game through the Federal Aid in Sport Fish Restoration Act and by Idaho anglers via license fees. Additional support was provided by the U.S. Geological Survey, Idaho Cooperative Fish and Wildlife Research Unit. The Unit is jointly sponsored by the University of Idaho, U.S. Geological Survey, Idaho Department of Fish and Game, and Wildlife Management Institute. The use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. government. This project was conducted under the University of Idaho Institutional Animal Care and Use Committee Protocol 2015-48.

References

Anderson, R. M., and R. B. Nehring. 1984. Effects of catch-and-release regulation on a wild trout population in Colorado and its acceptance by anglers. North American Journal of Fisheries Management 4:257–265.

Bloom, R. K. 2013. Capture efficiency of barbed versus barbless artificial flies for trout. North American Journal of Fisheries Management 33:493–498.

Carline, R. F., T. Beard Jr., and B. A. Hollender. 1991. Response of wild Brown Trout to elimination of stocking and to no-harvest regulations. North American Journal of Fisheries Management 11:253–266.

Chiaramonte, L. V., D. W. Whitney, J. L. McCormick, and K. A. Meyer. 2017. Air exposure and fight times for anadromous fisheries in Idaho. Pages 335-341 *in* R.F. Carline and C. LoSapio, editors. Wild Trout XII: who's driving and where are we going? Wild Trout Symposium, Bozeman, Montana.

Cook, K. V., R. J. Lennox, S. G. Hinch, and S. J. Cooke. 2015. Fish out of water: how much air is too much? Fisheries 40:452–461.

Cooper, G. P., and K. F. Lagler. 1956. The measurement of fish population size–Part III. Trans. N. Amer. Wildl. Conf 21:281–297.

Davis, M. W., and S. J. Parker. 2004. Fish size and exposure to air: potential effects on behavioral impairment and mortality rates in discarded Sablefish. North American Journal of Fisheries Management 24:518–524.

Dell, M. B. 1968. A new fish tag and rapid cartridge fed applicator. Transactions of the American Fisheries Society 97:57–59.

Dolan, C. R., and L. E. Miranda. 2003. Immobilization thresholds of electrofishing relative to fish size. Transactions of the American Fisheries Society 132:969–976.

Dotson, T. 1982. Mortalities in trout caused by gear type and angler-induced stress. North American Journal of Fisheries Management 2:60–65.

Dubois, R. B., and K. E. Kuklinski. 2004. Effect of hook type on mortality, trauma, and capture efficiency of wild, stream-resident trout caught by active baitfishing. North American Journal of Fisheries Management 24:617–623.

Ferguson, R. A., and B. L. Tufts. 1992. Physiological effects of brief air exposure in exhaustively exercised Rainbow Trout (Oncorhynchus mykiss): Implications for "catch and release" fisheries. Canadian Journal of Fisheries and Aquatic Sciences 49:1157–1162.

Fleiss, J. L. 1981. Statistical methods for rates and proportions, 2nd edition. Wiley, New York.

Gale, M. K., S. G. Hinch, E. J. Eliason, S. J. Cooke, and D. A. Patterson. 2011. Physiological impairment of adult Sockeye Salmon in fresh water after simulated capture-and-release across a range of temperatures. Fisheries Research 112:85–95.

Gagne, T. O., K. L. Ovitz, L. P. Griffin, J. W. Brownsombe, S. J. Cooke, and A. J. Danylchuk. 2017. Evaluating the consequences of catch-and-release recreational angling on Golden Dorado (Salminus brasiliensis) in Salta, Argentina. Fisheries Research 186:625–633.

Gingerich, A. J., S. J. Cooke, K. C. Hanson, M. R. Donaldson, C. T. Hasler, C. D. Suski, and R. Arlinghaus. 2007. Evaluation of the interactive effects of air exposure duration and water temperature on the condition and survival of angled and released fish. Fisheries Research 86:169–178.

Gitschalg, G. R., and M. L. Renaud. 1994. Field experiments on survival rates of caged and released Red Snapper. North American Journal of Fisheries Management 14:131–136.

Graves, J. E., and A. Z. Horodysky. 2008. Does hook choice matter? The effects of three circle hook models on post-release survivial of White Marlin. North American Journal of Fisheries Management 28:471–480.

Graves, J. E., B. J. Marcek, and W. M. Goldsmith. 2016. Effects of air exposure on postrelease mortality rates of White Marlin caught in the U.S. offshore recreational fishery. North American Journal of Fisheries Management 36:1121–1228.

Hunt, R. L. 1977. An unsuccessful use of catch and release regulatios for a wild brook trout fishery. Pages 125–136 in R. A. Barnhart & T. D. Roelofs, editors Catch-and-release fishing as a management tool. Humboldt State University, Arcata, California.

Isermann, D. A., and C. P. Paukert. 2010. Regulating harvest. Pages 185-212 in W. A. Hubert, and M. C. Quist, editors. Inland fisheries management in North America, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Johnson, D. 1999. The insignificance of significance testing. Journal of Wildlife Management 63:763–772.

Lamansky, J. A., and K. A. Meyer. 2016. Air exposure time of trout released by anglers during catch and release. North American Journal of Fisheries Management 36:1018–1023.

Louison, M. J., C. T. Hasler, M. M. Fenske, C. D. Suski, and J. A. Stein. 2017. Physiological effects of ice-angling capture and handling of Northern Pike, Esox lucius. Fisheries Management and Ecology 24:10–18.

Johnson, T. H., and T. C. Bjornn. 1978. Evaluation of angling regulations in management of Cutthroat Trout. Cooperative Fishery Research Unit, University of Idaho, Federal Aid in Fish Restoration, Project F-59-R-7, Job Completion Report, Moscow.

Maillet, E., R. Aiken, and M. Fuller. 2017. The demographic and economic trends of trout anglers: implications for recruitment, retention, and restoration and habitat management support. Pages 15–22 in R.F. Carline and C. LoSapio (eds) Wild Trout XII: science, politics, and wild trout management: who's driving and where are we going? Wild Trout Symposium, West Yellowstone, Montana, USA.

McFadden, J. T. 1961. A population study of the Brook Trout, Salvelinus Fontinalis. Wildlife Monographs 7:3–73.

Meyer, K. A., B. High, N. Gastelecutto, E. R. J. Mamer, and F. S. Elle. 2011. Retention of passive integrated transponder tags in stream-dwelling Rainbow Trout. North American Journal of Fisheries Management 31:236–239.

Mongillo, P. E. 1984. A summary of salmonid hooking mortality. Washington Department of Fish and Wildlife, Fish Management Division Report, Olympia, Washington.

Moore, V. K., and D. J. Schill. 1984. Fish distributions and abundance in the South Fork Snake River. Idaho Department of Fish and Game, Federal aid in Sport Fish Restoration, Project F-73-R-5, Job Completion Report, Boise.

Pauley, G. B., and G. L. Thomas. 1993. Mortality of anadromous Costal Cutthroat Trout caught with artificial lures and natural bait. North American Journal of Fisheries Management 13:337–345.

Perry, W. B., W. A. Janowsky, and F. J. Margraf. 1995. A bioenergetics simulation of the potential effects of angler harvest on growth of Largemouth Bass in a catch-and-release fishery. North American Journal of Fisheries Management 15:705–712.

Raby, G. D., S. J. Cooke, K. V. Cooke, S. H. McConnachie, M. R. Donaldson, S. G. Hinch, C. K. Whitney, S. M. Dreener, D. A. Patterson, T. D. Clark, and A. P. Farrell. 2013. Resilience of Pink Salmon and Chum Salmon to simulated fisheries capture stress incurred upon arrival at spawning grounds. Transactions of the American Fisheries Society 142:524–539.

Rapp, T., J. Hallermann, S. J. Cooke, S. K. Hetz, S. Wuertz, and R. Arlinghaus. 2014. Consequences of air exposure on the physiology and behavior of caught-and-released Common Carp in the laboratory and under natural conditions. North American Journal of Fisheries Management 34:232–246.

Reynolds, J. B. and A. L. Kolz. 2010. Electrofishing. Pages 305-361 in A. V. Zale, D. L. Parrish, and T. M. Sutton, editors. Fisheries Techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Richard, A., M. Dionne, J. Wang, and L. Bernatchez. 2013. Does catch and release affect the mating system and individual reproductive success of wild Atlantic Salmon (Salmo salar L.)? Molecular Ecology 22:187–200.

Roth, C. J., D. J. Schill, and M. C. Quist. 2018. Fight and air exposure times of caught and released salmonids from the South Fork Snake River. Fisheries Research 201:38–43.

Schill, D. J., and R. L. Scarpella. 1997. Barbed hook restrictions in catch-and-release trout fisheries: A social issue. North American Journal of Fisheries Management 17:873–881.

Schill, D. J., J. A. Heindel, M. R. Campbell, K. A. Meyer, and E. R. Mamer. 2016. Production of a YY male Brook Trout broodstock for potential eradication of undesired Brook Trout populations. North American Journal of Aquaculture 78:72–83.

Schisler, G. J., and E. P. Bergersen. 1996. Postrelease hooking mortality of Rainbow Trout caught on scented artificial baits. North American Journal of Fisheries Management 16:570–578.

Schneider, J. C., and R. N. Lockwood. 2002. Use of Walleye stocking, antimycin treatments, and catch-and-release angling regulations to increase growth and length of stunted Bluegill populations in Michigan lakes. North American Journal of Fisheries Management 22:1041–1052.

Schreer, J. F., D. M. Resch, M. L. Gately, and S. J. Cooke. 2005. Swimming performance of Brook Trout after simulated catch-and-release angling: looking for air exposure thresholds. North American Journal of Fisheries Management 25:1513–1517.

Strange, J. R., C. B. Schreck, and J. T. Golden. 1977. Corticoid stess response to handling and temperature in salmonids. Transactions of the American Fisheries Society 106 213–218.

Sullivan, M. G. 2003. Active management of Walleye fisheries in Alberta: Dilemmas of managing recovering fisheries. North American Journal of Fisheries Management 23:1343–1358.

Sullivan, C. L., K. A. Meyer, and D. J. Schill. 2013. Deep hooking and angling success when passively and actively fishing for stream-dwelling trout with baited j and circle hooks. North American Journal of Fisheries Management 33:1–6.

Suski, C. D., S. J. Cooke, A. J. Danylchuk, C. M. O'Connor, M. Gravel, T. Redpath, K. C. Hanson, A. J. Gingerich, K. J. Murchie, S. E. Danylchuk, J. B. Koppelman, and T. L. Goldberg. 2007. Physiological disturbance and recovery dynamics of Bonefish (Albula vulpes), a tropical marine fish, in response to variable exercise and exposure to air. Comparative Biochemistry and Physiology 148:664–673.

Taylor, M. J., and K. R. White. 1992. A meta-analysis of hooking mortality of nonanadromous trout. North American Journal of Fisheries Management 12:760–767.

Thompson, P. E. 1958. Fishing is fun. Sports Afield (May):19–23.

Thompson, L. A., S. J. Cooke, M. R. Donaldson, K. C. Hanson, A. Gingerich, T. Klefoth and R. Arlinghaus. 2008. Physiology, behavior, and survival of angled and air-exposed Largemouth Bass. North American Journal of Fisheries Management 28:1059–1068.

Wydoski, R. S. 1977. Relation of hooking mortality and sublethal hooking stress to quality fishery management. Pages 43–87 in R. A. Barnhart & T. D. Roelofs, editors Catch-and-release fishing as a management tool. Humboldt State University, Arcata, California.

Table 3.1. Comparison of the proportion of tagged fish recaptured by air exposure treatment. Confidence bounds on the difference between proportions were calculated to determine if the proportion of fish recaptured were significantly different between air exposure treatments. Fish were sampled, treated, and tagged via angling and then recaptured using single-pass backpack electrofishing. Air exposure treatments were 0, 30, or 60 s. Angling for Yellowstone Cutthroat Trout took place in Palisades Creek, Idaho (July 2016). Bull Trout and Rainbow Trout angling took place in Sawmill Creek and the Main Fork of the Little Lost River, Idaho (July – August 2017).

Comparison	Difference	Lower confidence bound	Upper confidence bound
		Yellowstone Cutthroat Trout	
0 s versus 30 s	0.11	-0.25	0.03
0 s versus 60 s	0.07	-0.21	0.07
30 s versus 60 s	-0.04	-0.10	0.18
		Bull Trout	
0 s versus 30 s	-0.07	-0.08	0.23
0 s versus 60 s	-0.12	-0.03	0.27
30 s versus 60 s	-0.05	-0.10	0.20
		Rainbow Trout	
0 s versus 30 s	0.06	-0.20	0.09
0 s versus 60 s	0.12	-0.26	0.02
30 s versus 60 s	0.06	-0.20	0.08

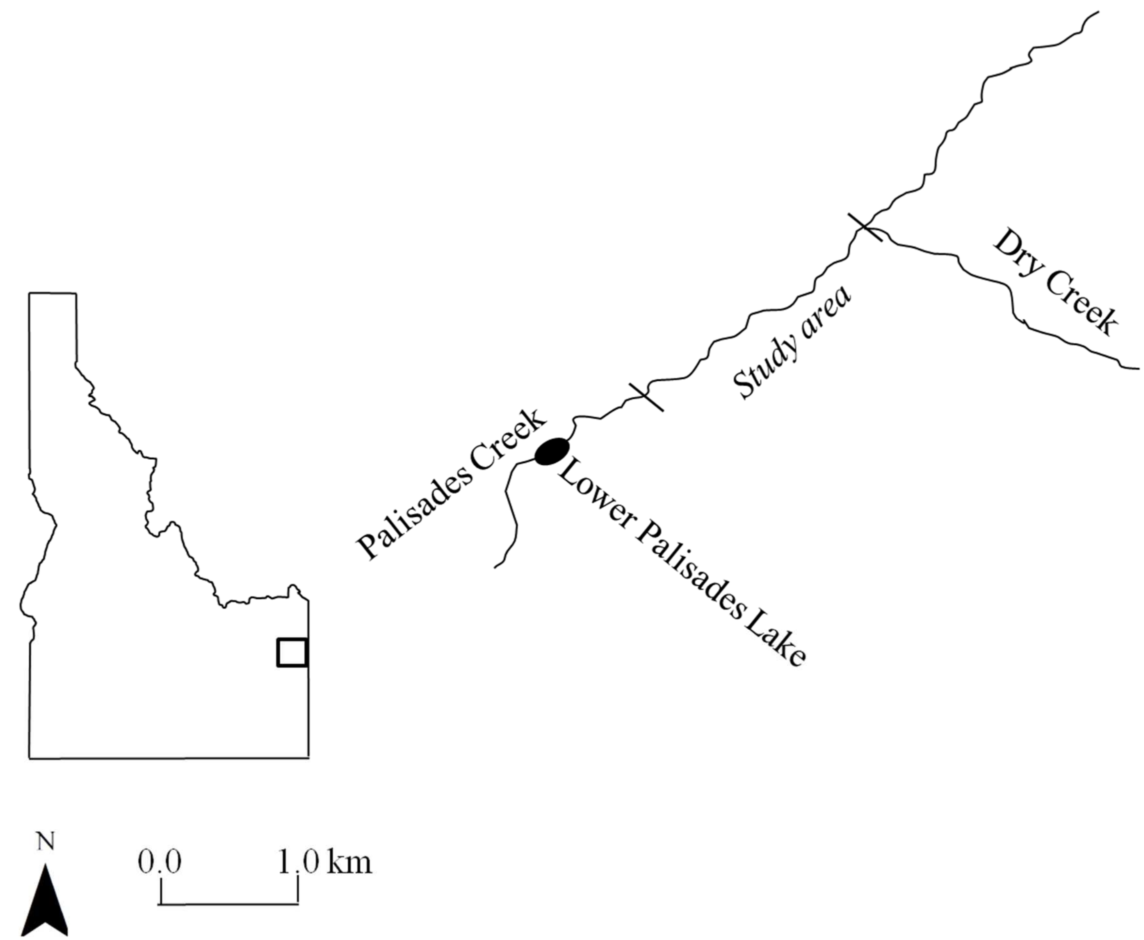

Figure 3.1. Palisades Creek from Lower Palisades Lake its confluence with Dry Creek, Idaho. Angling took place during July, 2016, to evaluate the effects of air exposure on Yellowstone Cutthroat Trout.

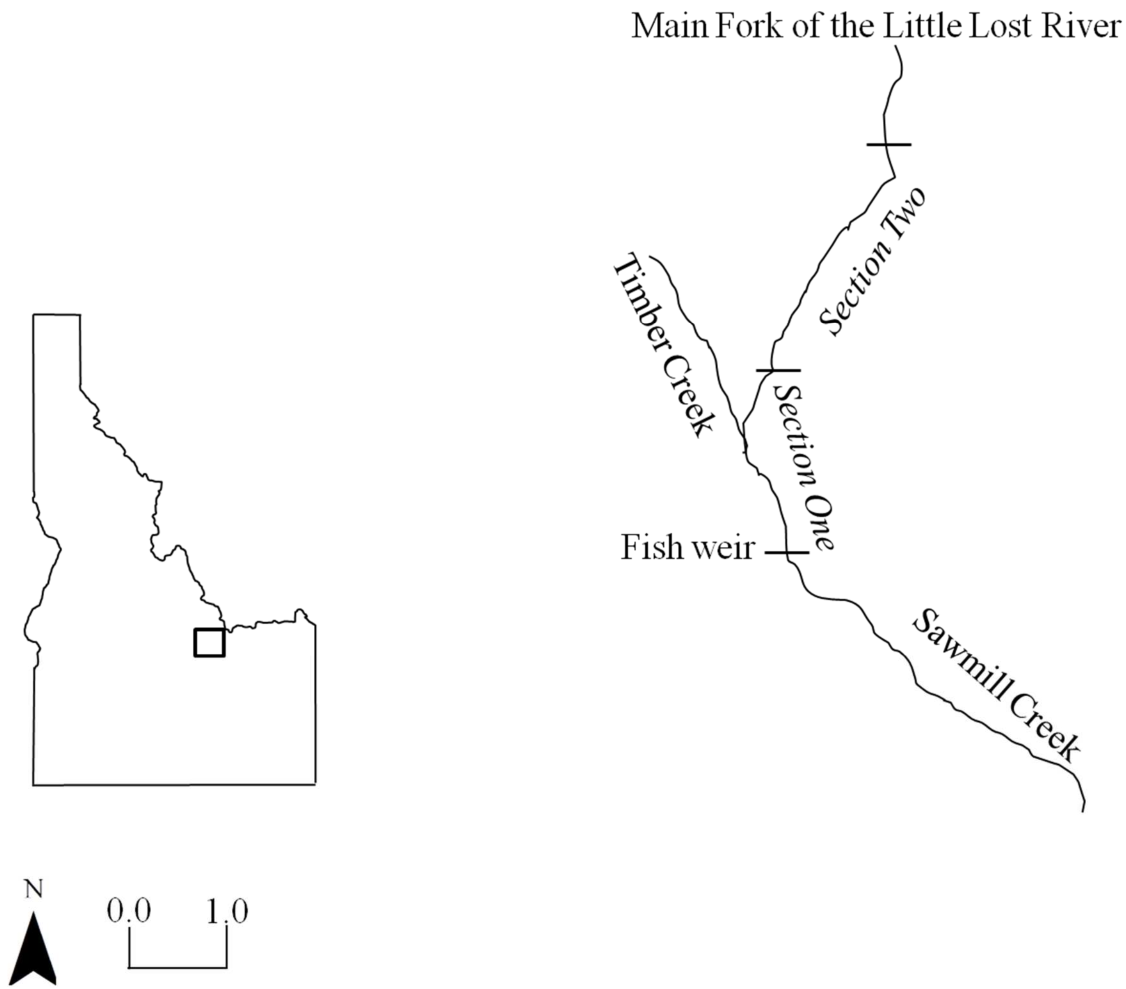

Figure 3.2. Main Fork of the Little Lost River Idaho to its confluence with Timber Creek where it is renamed Sawmill Creek, Idaho. Angling took place during July and August, 2017, to evaluate the effects of air exposure on Bull Trout and Rainbow Trout.

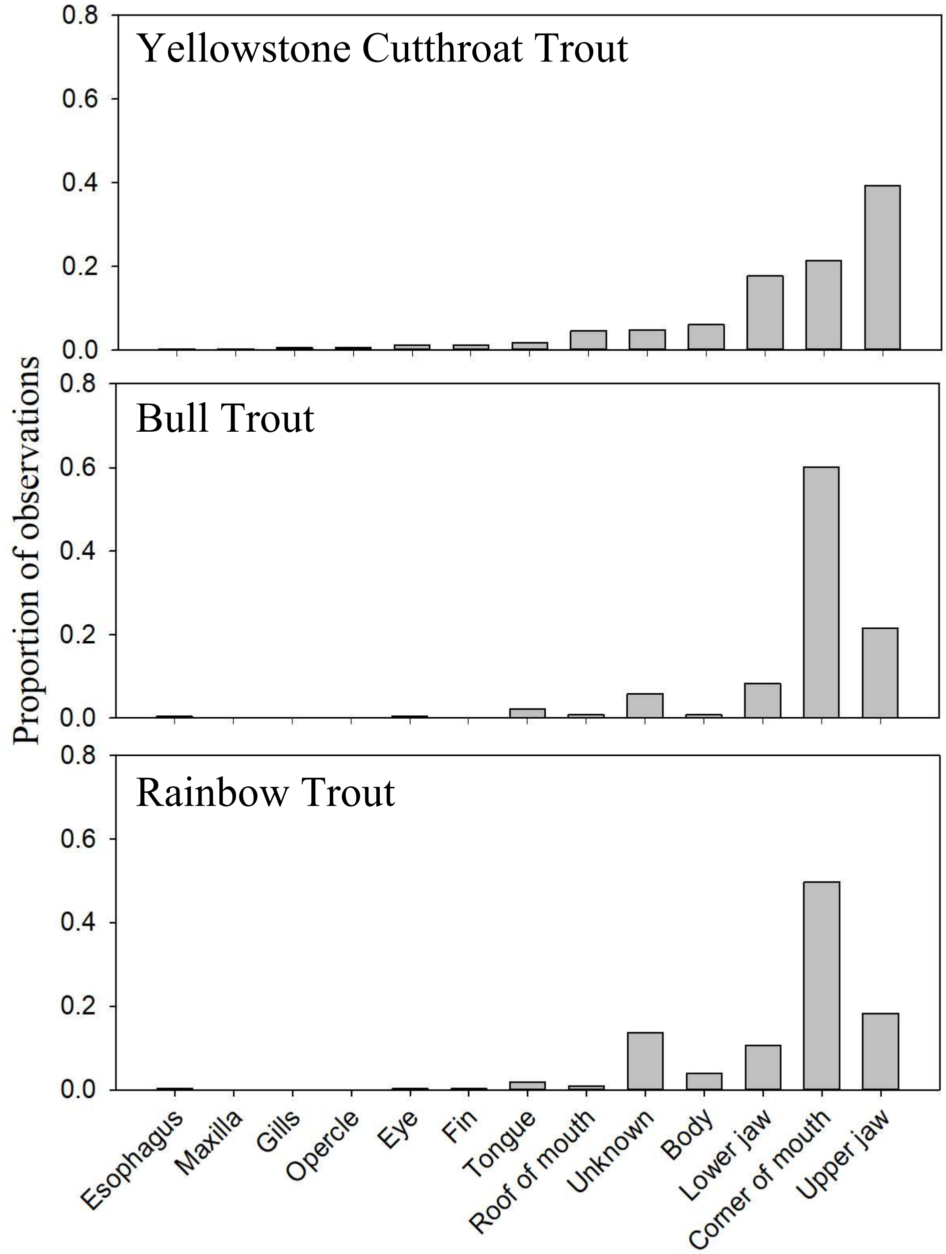

Figure 3.3. The proportion of fish hooked in various locations during hook-and-line angling surveys. Yellowstone Cutthroat Trout were sampled in Palisades Creek, Idaho (August 2016). Bull Trout and Rainbow Trout were sampled in Sawmill Creek and the Main Fork of the Little Lost River, Idaho (July – August 2017).

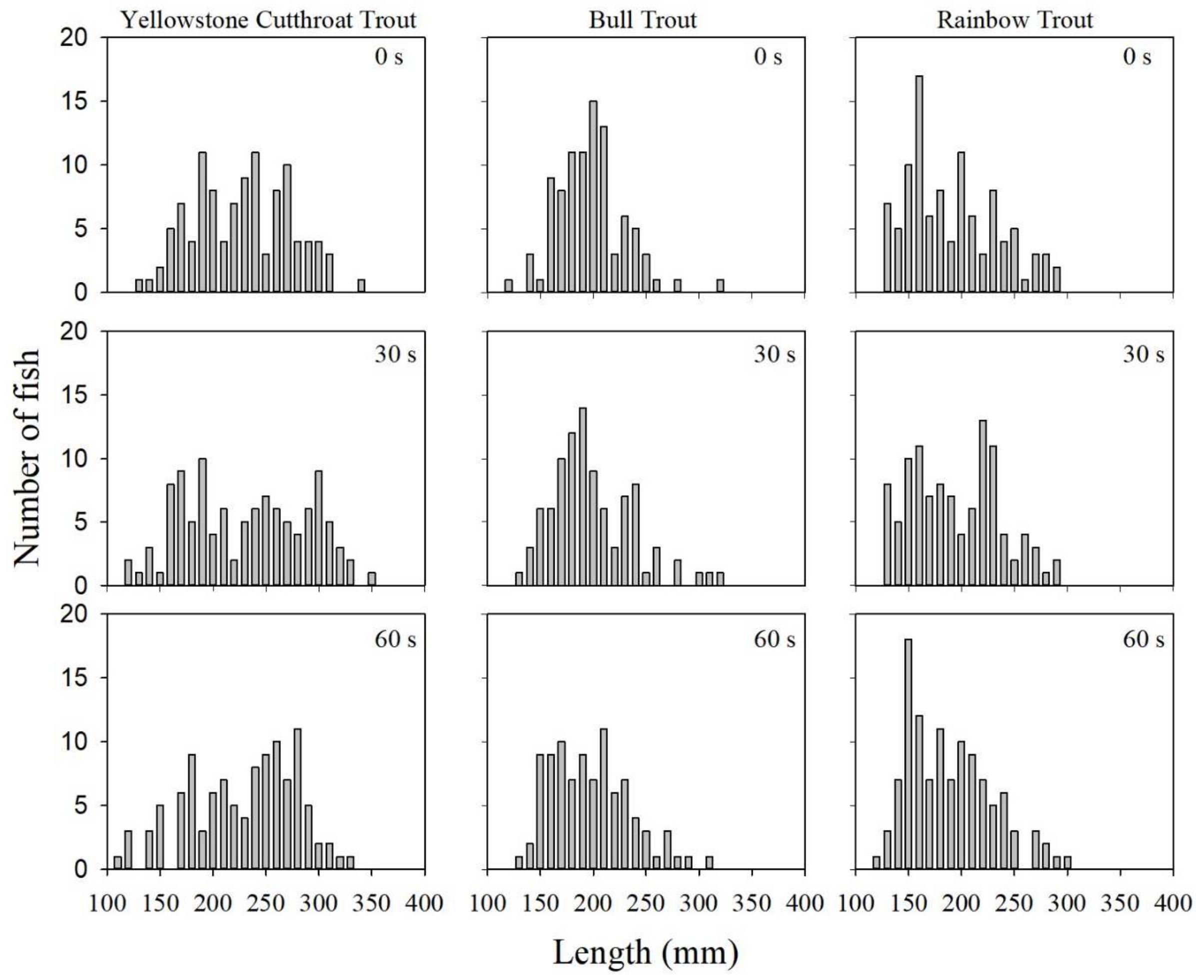

Figure 3.4. Length distributions of Yellowstone Cutthroat Trout, Bull Trout, and Rainbow Trout sampled via hook-and-line surveys by air exposure treatment group. Air exposure treatments were 0, 30, and 60 s. Yellowstone Cutthroat Trout were sampled in Palisades Creek, Idaho (August 2016). Both Bull Trout and Rainbow Trout were sampled in Sawmill Creek and the Main Fork of the Little Lost River, Idaho (July – August 2017).

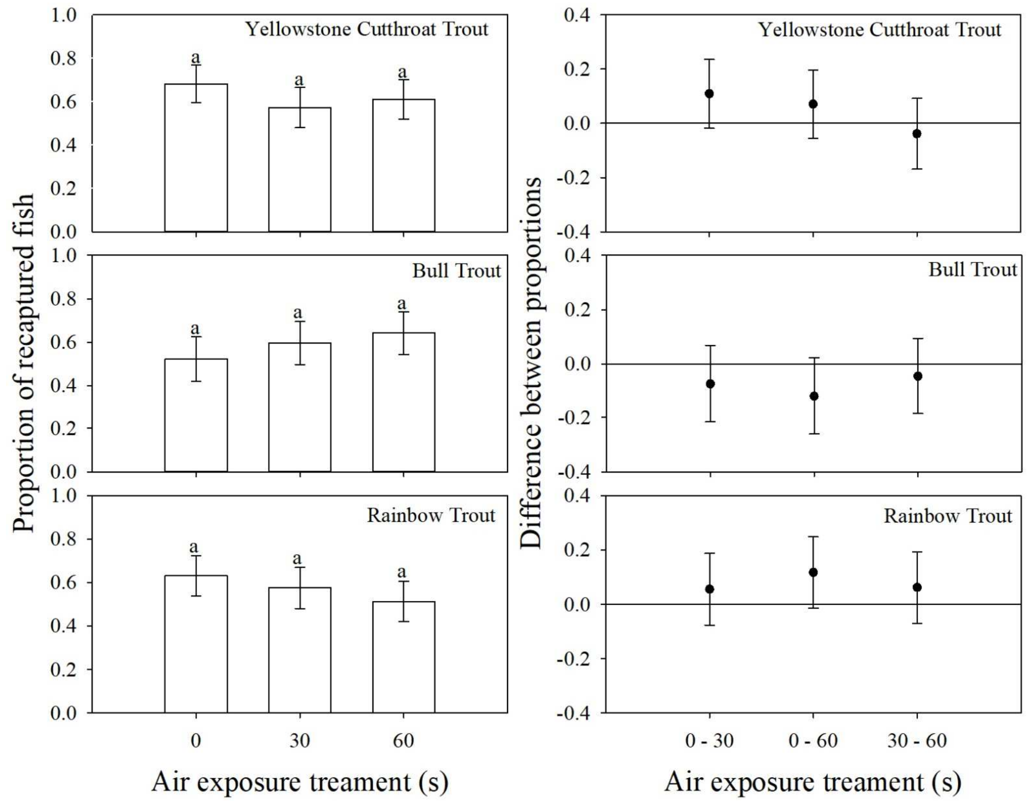

Figure 3.5. Proportions of fish recaptured via single-pass backpack electrofishing by species including 95% confidence intervals on the proportion. Proportions of recaptured fish were also compared between groups to evaluate whether proportions differed significantly between groups. Comparison were made by constructing confidence bounds on the difference between proportions and were considered significantly different if the confidence bound did not contain zero. Fish were originally sampled using hook-and-line surveys and then given one of three air exposure treatments (i.e., 0, 30, and 60 s). Sampling for Yellowstone Cutthroat took place in Palisades Creek, Idaho (August 2016). Sampling for Bull Trout and Rainbow Trout took place in Sawmill Creek and, the Main Fork of the Little Lost River, Idaho (July – August 2017).

Chapter 4: Effects of Air Exposure by Anglers on Survival and Fitness of Yellowstone Cutthroat Tout

A manuscript to be submitted for publication in the *North American Journal of Fisheries Management*

Curtis J. Roth, Daniel J. Schill, Michael C. Quist, Brett High, Matthew R. Campbell, Ninh V. Vu

Abstract

In recent years, concerns have been raised regarding the practice of exposing fish to air during catch-and-release (C&R) angling. The purpose of this study was to evaluate the effects of air exposure on short- and long-term survival and production of progeny (fitness) of Yellowstone Cutthroat Trout *Oncorhynchus clarkii bouvieri* on a tributary of the South Fork Snake River (SFSR) during 2016 and 2017. Fish were sampled at a weir during upstream migration. Fish were randomly assigned an air exposure treatment of 0, 30, or 60 s. An additional treatment group was added during 2017 where fish were not played or exposed to air (NF). In total, 1,519 fish were sampled (0 s, n = 485; 30 s, n = 494; 60 s, n = 534) in 2016, and 744 fish were sampled (NF, n = 176; 0 s, n = 167; 30 s, n = 206; 60 s, n = 195) in 2017. Additionally, age-0 fish (2016, n = 2,924; 2017, n = 1,492) were collected to evaluate the effects of air exposure on the production of progeny. No effect of the act of angling or air exposure was observed on short-term (≤ 60 d post-treatment) or long-term (> 1 year post-treatment) survival of adults with one exception. During 2016, fish that had been air exposed for 60 s had a statistically higher short-term survival rate than fish that received no air exposure. Air exposure had no effect on the proportion of fish that successfully spawned. Regression analysis revealed that neither the act of angling nor air exposure effected progeny production. Considering that the majority of the literature and the results of this study report little to no effect of air exposure

on mortality and reproductive success, it seems unlikely that exposing fish to air during C&R angling is truly a problem.

Introduction

Fishing regulations are used by natural resource agencies to accomplish an array of management objectives, including a focus on improving the quality of a fishery or maintaining the viability of a population (Isermann and Paukert 2010). In some cases, managers use regulations to manipulate fish assemblages (Schneider and Lockwood 2002), to remove undesirable species (Goeman et al. 1993), or perhaps misunderstanding their biological merits, for social purposes (Schill and Scarpella 1997). The most commonly implemented are seasonal closures, bag and length limits, gear restrictions, and catch-and-release (C&R) regulations (Isermann and Paukert 2010).

Catch-and-release regulations originally meant a fishery where anglers were required to release all of their catch, but has also come to imply most of the catch (Lamansky and Meyer 2016). Catch-and-release regulations were first envisioned and implemented in salmonid fisheries (Thompson 1958), but have become increasingly popular in other recreational fisheries (Isermann and Paukert 2010). Natural resource agencies implement C&R regulations for a variety of reasons, but the primary purpose is to reduce exploitation and increase density, size structure, or both. A number of studies have shown the benefits of C&R regulations on fish populations that experience high angler use. For example, following implementation of C&R regulations, density and size structure of Rainbow Trout *Oncorhynchus mykiss* increased in the South Platte River, Colorado (Anderson and Nehring 1984). Rainbow Trout densities were four times higher and the biomass was nine times greater in the C&R section of the river compared to the sections that allowed angler harvest. When harvest was allowed, 26% of the Rainbow Trout were over 300 mm. After 6 years of C&R regulations, 84% of the Rainbow Trout were over 300 mm. Kelly Creek, Idaho, displayed similar results after C&R regulations were implemented for Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* (Johnson and Bjorn 1978). When regulations allowed for angler harvest in Kelly Creek, catch rates were 1 fish/angler-hour. After 5 years of C&R regulations, catch rates doubled to 2 fish/angler-hour.

Despite the resounding success and popularity of C&R regulations, some concerns have been raised regarding the practice. Exposing fish to air during release is one of the most high-profile of these concerns (Cook et al. 2015). Air exposure effects can be classified as either indirect or direct. Indirect effects are those that are not caused directly by air exposure but result from air exposure affecting another parameter. Indirect effects of air exposure were reported in Largemouth Bass *Micropterus salmoides* and Smallmouth Bass *M. dolomieu* captured by angling from four different systems in southern Ontario (Philipp et al. 1997). Direct effects are those where air exposure directly influences mortality or has sublethal effects (e.g., reproductive success, ability to cope with thermal stress, swimming performance). For example, air exposure is believed to temporarily suppress gas transfer across the gills which can lead to hypoxia and increased levels of carbon dioxide in the bloodstream (Ferguson and Tufts 1992). Numerous studies have attempted to address the question of how long a fish must be exposed to air before it experiences negative effects. Although the results are highly variable, the majority of studies have reported little to no effect on fish after 2 min, or longer, of air exposure (e.g., Schisler and Bergersen 1996; Schreer et al. 2005; Suski et al. 2007; Gale et al. 2011; Raby et al. 2013).

Despite the fact that the majority of studies have shown little or no effect in a C&R context, a single study is frequently cited as evidence regarding air exposure effects (Ferguson and Tufts 1992). Ferguson and Tufts (1992) reported that hatchery Rainbow Trout exposed to air for 60 s after a 600 s exercise event in a laboratory setting had a 72% mortality rate compared to a 12% mortality rate for fish that were only exercised and a 10% mortality rate for control fish. Results of Ferguson and Tufts (1992) are often used to argue for limiting air exposure in wild C&R fisheries. However, test fish were cannulated and subjected to multiple blood drawings (n = 5) and handlings and the authors note in the paper's discussion that their results should not be applied to wild fisheries.

In addition to direct mortality, a small number of studies have evaluated the effects of air exposure on reproductive success with vastly different conclusions. Atlantic Salmon *Salmo salar* in the Escoumins River, Quebec, displayed decreased reproductive success when exposed to air (Richard et al. 2013). Fish exposed to air for more than 10 s reportedly had two to three times lower reproductive success compared to fish exposed to air for < 10 s. Proponents of limiting air exposure often cite the decline in reproductive success reported in Richard et al. (2013) as evidence for limiting air exposure (e.g., Cook et al. 2015). Conversely, it has been reported that upon reaching their spawning grounds in Weaver Creek, British Columbia, Chum Salmon *Oncorhynchus keta* and Pink Salmon *O. gorbuscha* were resilient to any effects of C&R angling (Raby et al. 2013). In fact, no decline in spawning success was reported after simulated capture and 1 min of air exposure.

Given the variable and often contradictory results reported in the air exposure literature, further study on the effects of air exposure on sport fishes is warranted before regulations limiting the amount of time that anglers can expose fish to air during C&R angling are seriously contemplated or implemented. Further, the artificial nature of many past air exposure studies (e.g., hatchery fish, tail grabbing, lack of actual angling) calls for additional studies on wild fish under conditions transferable to real-world C&R events. The overall goal of this study was to better understand the influence and relevance of air exposure on wild Yellowstone Cutthroat Trout *Oncorhynchus clarkii bouvieri* under conditions similar to those fish would experience during actual C&R angling. Yellowstone Cutthroat Trout are an ideal species for evaluating the effects of air exposure because salmonids are among the most sensitive taxa with regards to hypoxia (Doudoroff and Shumway 1970) and support important recreational fisheries throughout the intermountain west (Quist and Hubert 2004). The specific objectives of this study were to evaluate the effects of air exposure during the spring on i) short- and long-term survival and ii) reproductive success of Yellowstone Cutthroat Trout.

Study Area

Evaluation of the effects of air exposure was conducted in the South Fork Snake River (SFSR) drainage on Burns Creek, Idaho (Figure 1), from May–October, 2016, and May–September, 2017. Burns Creek is a third-order tributary of the SFSR (Moore and Schill 1984). Discharge in Burns Creek typically varies from 0.1 to 9.0 m^3/s and channel gradient is 3-6%. A large portion of the Yellowstone Cutthroat Trout population in the SFSR displays a fluvial life history, where fish move from the main-stem SFSR into Burns Creek and other tributaries to spawn (Thurow et al. 1988). Yellowstone Cutthroat Trout in the SFSR mature around age 4; spawning begins in late May and continues through early July. Approximately two weeks after spawning, adults migrate from Burns Creek back to the main-stem SFSR.

Fry typically emerge from mid-July through September and out-migrate to the SFSR as age-0 fish (Moore and Schill 1984; Thurow et al. 1988).

Methods

Field Sampling

Adult Yellowstone Cutthroat Trout were sampled at an existing Idaho Department of Fish and Game (IDFG) velocity-barrier weir 0.9 km upstream of the mouth of Burns Creek during May–July, 2016, and May–June, 2017. Fish must enter a fish ladder to navigate the weir and continue upstream. While the gills remained underwater, a 12-mm full-duplex passive integrated transponder (PIT) tag was inserted into the peritoneal cavity of each fish (Prentice et al. 1990). Returning fish that already had a PIT tag from a prior spawning year were scanned to record the tag number and a needle was inserted into the peritoneal cavity to mimic a PIT tag injection. All newly PIT-tagged fish had their adipose fin removed as a secondary mark and the sample was retained for individual genetic identification. Tissue samples were taken from the upper caudal fin of fish lacking an adipose fin. Tissue samples were stored on Whatman 3MM chromatography paper (Thermo Fisher Scientific, Inc., Pittsburgh, Pennsylvania) for genetic analysis at the IDFG Eagle Genetics Lab. The phenotypic sex of each fish was identified in the field and confirmed using genetic analysis to produce accurate sex assignments (i.e., 99% accuracy in field-based assignments; Schill et al. 2016). While remaining underwater, fish had a 1/0 barbed circle hook manually inserted through the middle of their lower jaw and were randomly assigned a treatment of 0 (control), 30, or 60 s of air exposure. An additional treatment group was added during 2017 where fish were not played or exposed to air (NF). Fish were quickly maneuvered into a submerged

102.0 mm acrylic tube, measured for total length (mm), and carried upstream of the weir, all while remaining underwater. Angling gear was attached to the circle hook in the fish's lower jaw and the fish was returned to the river while underwater and played. Fish were played for 102 s, the average fight time for spawning-sized Yellowstone Cutthroat Trout in a C&R fishery on the Yellowstone River (Schill et al. 1986). However, it is worth noting that average fight times on the SFSR were subsequently reported to be much lower (i.e., 40 s; Roth et al. 2018). After being played, fish were netted using a rubber-meshed net, unhooked, treated with their prescribed amount of air exposure, and returned to the river to move upstream and spawn. Two post-release survival estimates for these fish were obtained. An estimate of short-term relative survival by treatment group was calculated using two fixed PIT-tag antennas located 0.5 km downstream of the weir to detect adult fish as they out-migrated back to the SFSR. Specifically, fish that moved past the PIT-tag antenna within 60 d of their tagging date were used to characterize short-term survival similar to Rapp et al. (2014). It is important to note that relative survival does not reflect actual survival; rather, it is the difference in proportions of fish from each treatment group detected. Estimates of short-term relative survival could differ from actual survival for a number of reasons including tag loss or antenna error. Adults recorded by the PIT-tag antenna were assigned back to their air exposure treatment as an estimate of relative survival. Additionally, an estimate of relative survival at one year (long-term survival) was calculated. Relative survival at one year was calculated by matching genotypes of fish sampled in 2016 and 2017. Again, long-term survival likely differs from actual survival for a number of reasons. Fish may not return to the weir due to skipped spawning, lack of fidelity to Burns Creek, or spawning downstream of the weir.

Once adult trapping had concluded, we began collection of out-migrating age-0 Yellowstone Cutthroat Trout to evaluate the effect of air exposure on the subsequent production of progeny. Fry collection was conducted using two trapping methods and electrofishing. Fry were collected using a modified picket weir located approximately 25 m downstream of the IDFG velocity-barrier weir and two Kray-Meekin traps placed in the thalweg downstream of the picket weir. Trapping took place during July–October in 2016 and 2017. During 2016, only one Kray-Meekin trap and the modified picket weir were used to trap fry. Fry were trapped using two Kray-Meekin traps in 2017. A random subsample of fish captured in the traps each day was used for the genetic analysis (see below). Single-pass backpack electrofishing was conducted to collect fry for genetic analysis during September and October, 2016, and September, 2017 (Richard et al. 2013). In both 2016 and 2017, fry sampled via backpack electrofishing were placed into buckets. Caudal fin tissue was removed from a random subsample of fry from each bucket. Burns Creek was sampled from the existing IDFG velocity-barrier weir upstream for 4 km, which is where the majority of fluvial Yellowstone Cutthroat Trout spawn (Brett High, unpublished information). Tissue samples were analyzed at the IDFG Eagle Genetics Lab.

Genetic Analysis

A suite of 141 single nucleotide polymorphisms (SNPs) were used to sequence adult DNA samples, and parentage-based tagging (PBT) assignment was subsequently conducted to determine the parentage of each fry (Steele et al. 2013). Thus PBT allowed us to reliably discern the relative number of progeny produced by individual fish after differing air exposure treatments (Richard et al. 2013).

Data Analysis

The effects of air exposure on the short-term survival of adult Yellowstone Cutthroat Trout was evaluated by calculating the proportion of fish from each treatment group that were detected moving downstream past the PIT-tag antenna located in lower Burns Creek. The proportions of recaptured fish were compared between groups by calculating confidence intervals around the differences between treatment-group proportions (Fleiss 1981; Johnson 1999). Differences between proportions were considered statistically significant if the calculated confidence interval did not include zero. The same method was used to evaluate long-term survival between 2016 and 2017.

Evaluation of the effects of air exposure on the reproductive success of spawning Yellowstone Cutthroat Trout was first done by evaluating the proportion of fish that successfully spawned in each treatment by calculating the proportion of fish that produced at least one offspring in each treatment group. Proportions were then compared by calculating confidence bounds on the difference between proportions (Fleiss 1981; Johnson 1999). Generalized linear models with a negative binomial distribution (Burnham and Anderson 2002; Richard et al. 2013) were also used to evaluate the effects of air exposure on reproductive success in more detail. Models were analyzed using the MASS package in statistical package R (R Core Team 2017). For the purpose of modeling, data were pooled between years as handling protocols were the same between years with the exception of fish in the NF treatment group. Fish in the NF treatment group were removed from the pooled data analysis because 2016 lacked a NF treatment group and preliminary analysis of the 2017 data indicated no difference between NF and the other treatments (see below). Two sets of candidate models were developed: one set using only data collected from adult male

Yellowstone Cutthroat Trout (male-only models) and a second set using only data collected from adult female Yellowstone Cutthroat Trout (female-only models). Eight candidate models were developed for both male- and female-only models. *A priori* models included the following (1) a model including only fish length and year; (2) a model including air exposure treatment and year; (3) a model including air exposure treatment, fish length, and year; and (4) a model including air exposure treatment, fish length, the interaction between fish length and air exposure treatment, and year. All four models were repeated without year as a covariate. Models were compared using Akaike Information Criterion corrected for small sample size (AIC_c) and the top model was the model that had the lowest AIC_c value (Burnham and Anderson 2002). Models that had an AIC score within 2.0 AIC values of the best model were also considered top models. Models were assessed for overdispersion using the dispersion parameter ($\hat{c}$) and were considered overdispersed when $\hat{c}$ was greater than one (Burnham and Andersen 2002). The dispersion parameter was calculated by dividing Pearson's residual deviance by the residual degrees of freedom. Overdispersed models had an additional parameter added to adjust for the estimation of dispersion. Model fit was assessed using McFadden's pseudo R^2 (McFadden 1974). McFadden's pseudo R^2 values of 0.20 – 0.40 are considered to provide excellent model fit (Hosmer and Lemshow 1989). Additionally, the NF treatment was evaluated by comparing the NF treatment to the other three treatments using only the 2017 data. The top male- and female-only model were used for this analysis without year as a covariate. Based on this analysis, no difference was observed between the NF treatment and the other treatment groups. To further contextualize the effects of air exposure on reproductive success, marginal effects were calculated for the top male- and female-only models using the trtools package (Johnson 2018) in statistical package R (R Core

Team 2017). Marginal effects are calculated as the difference in predicted response between levels of one explanatory variable while holding all other explanatory variables in the model constant (Long 1997). For example, to evaluate the marginal effect of 0 s of air exposure compared to 30 s of air exposure, one would predict the average number of offspring produced for fish treated with 0 s of air exposure and fish treated with 30 s of air exposure while holding length and year constant. The predicted number of offspring of fish treated with 30 s of air exposure would then be subtracted from the predicted number of offspring of fish treated with no air exposure. If the marginal effect between fish treated with 0 s of air exposure and fish treated with 30 s of air exposure was -0.055, fish not exposed to air produced 0.055 less fry, on average, than fish exposed to 30 s of air exposure.

Results

In total, 1,519 upstream migrating adult fish were sampled in 2016 and assigned to a treatment group (0 s, n = 485; 30 s, n = 494; 60 s, n = 534). In 2017, 744 fish were sampled (NF, n = 176; 0 s, n = 167; 30 s, n = 206; 60 s, n = 195). Length distributions were virtually identical among treatment groups by sex in 2016 (Figure 2) and 2017 (Figure 3). Two hundred and twelve adult fish were detected out-migrating (0 s, n = 55; 30 s, n = 72; 60 s, n = 85) in 2016 and 314 adult fish (NF n = 64; 0 s, n = 71; 30 s, n = 92; 60 s, n = 87) were detected in 2017. Short-term relative survival was similar among treatments, and varied from 11% to 16% among treatments groups (0 s = 11%, 30 s = 15%, 60 s = 16%) in 2016 and from 35% to 45% in 2017 (NF = 35%, 0 s = 41%, 30 s = 44%, 60 s = 45%; Figure 4). No statistical difference in short-term survival was observed in 2016 between fish treated with 0 s or 30 s or between fish treated with 30 s or 60 s (Figure 4). However, fish exposed to air for

60 s had a statistically higher estimated short-term survival rate than fish not exposed to air. No statistical difference in short-term survival was observed among all four treatments in 2017 (Figure 4). Long-term survival for 2016 adults varied from 6.6% to 7.5% (0 s = 6.6%; 30 s = 7.5%; 60 s = 6.4%) and was similar among treatment groups (Figure 5).

In 2016, 2,924 fry were sampled (electrofishing, *n* = 2,175; Kray-Meekin, *n* = 583; picket weir *n* = 166); 1,492 fry were sampled in 2017 (electrofishing, *n* = 1,100; Kray-Meekin, *n* = 392). All 2,924 fry sampled in 2016 were successfully genotyped. Of those, 2,310 were assigned back to two parents that were part of the study. In 2017, 1,490 fry of the 1,492 sampled were successfully genotyped and 650 were assigned back to two parents that were part of the study.

Air exposure treatment had no statistical effect on the number of male and female fish that successfully spawned and produced one or more progeny (Figure 6). The proportion of male fish that successfully spawned varied from 47% to 55% (0 s = 48%; 30 s = 55%; 60 s = 51%) in 2016 and from 28% to 33% (NF = 28%; 0 s = 32%; 30 s = 33%; 60 s = 31%) in 2017. Results were similar for female fish with the proportion of fish that successfully spawned varying from 59% to 66% (0 s = 66%; 30 s = 59%; 60 s = 60%) in 2016. The proportion of female fish that successfully spawned in 2017 varied from 44% to 48% (NF = 48%; 0 s = 45%; 30 s = 44%; 60 s = 45%).

The top male-only model predicting the number of progeny produced contained air exposure treatment, fish length, and year as predictors (Table 1). However, model fit was poor (i.e., McFadden's pseudo-R^2 = 0.06; well below the 0.20 – 0.40 guideline). Based on the top model, the number of offspring produced by male Yellowstone Cutthroat Trout increased with length (Figure 7). Results of regression analysis for the female-only models were similar to those for males with the top model containing air exposure treatment, fish length, and year (Table 1). As with the male-only model, model fit was poor (McFadden's pseudo-R^2 = 0.02). Again, the number of offspring produced increased with length (Figure 8). Results were similar for the models evaluating the effects of the NF treatment using only the 2017 data (data not presented). In both male- and female-only models, production of progeny increased with length; however, model fit was poor (i.e., male-only model, McFadden's pseudo-R^2 = 0.04; female-only model, McFadden's pseudo-R^2 = 0.01).

Analysis of the marginal effects from the top models revealed that differences in the production of progeny among treatment groups were meaningless. For instance, a male fish with a total length of 300 mm not exposed to air in 2016 would, on average, produce 0.010 less offspring than a fish treated with 60 s of air exposure (Table 2). Similarly, a male fish with a total length of 300 mm not exposed to air in 2017 would, on average, produce 0.004 less offspring than a fish treated with 60 s of air exposure. Results of marginal effects analysis were similar for females. Based on the top model, a female fish not exposed to air that had a length of 300 mm in 2016 would, on average, produce 0.046 more offspring than a 300 mm female fish exposed to air for 60 s. Furthermore, a 300 mm female fish not exposed to air in 2017 would produce 0.038 more offspring on average than the same length female fish that had been air exposed for 60 s.

Discussion

A number of studies have been conducted to evaluate the effects of removing fish from the water during C&R angling, particularly the effects of air exposure on mortality (e.g., Ferguson and Tufts 1992; Davis and Parker 2004; Gingerich et al. 2007; Suski et al. 2007;

Rapp et al. 2014; Thompson et al. 2008; Graves et al. 2016; Louison et al. 2016; Gange et al. 2017). However, much of the existing air exposure literature suffers from limitations that make it difficult to apply results to wild fish populations. The use of holding tanks and hatchery fish (Ferguson and Tufts 1992; Davis and Parker 2004; Suski et al. 2007) is concerning because the conditions are unlikely to apply to wild fishes in natural systems. Several of these studies are limited by unrealistic simulations of angling. Ferguson and Tufts (1992) and Suski et al. (2007) used tail grabbing to simulate angling. In addition, fish were chased for 4 min (Suski et al. 2007) or 10 min (Ferguson and Tufts 1992). Although the literature on actual fight times is sparse, these times are likely unrealistically long. For instance, Schill et al. (1986) reported that average fight times were 102 s on Yellowstone Cutthroat Trout in Yellowstone National Park, Wyoming. Recent research on salmonids in Idaho has shown that fight time average <1 min (Lamansky and Meyer 2016; Roth et al. 2018). Even trophy steelhead have an average fight time of 3 min (Chiaramonte et al. 2017). Average fight times for warmwater and coolwater species (e.g., black bass *Micropterus* spp., crappie *Pomoxis* spp., Yellow Perch *Perca flavescens*) have recently been observed to be even lower (i.e., 10 s; Kevin Meyer, IDFG, unpublished data).

The artificial a nature of previous studies is not the only concern associated with the existing air exposure literature and application to wild fisheries. Perhaps most concerning is that the air exposure durations in previous research are likely far greater than those experienced in C&R fisheries. Surprisingly, few studies have reported air exposure times in actual fisheries. Lamansky and Meyer (2016) reported that 96% of trout *Oncorhynchus* spp. in a C&R fishery in Idaho were held out of water for ≤ 60 s and approximately 70% were exposed to air for < 30 s. Average air exposure was 29 s. Similar results were reported by

Roth et al. (2018) on the SFSR, Idaho. Roth et al. (2018) reported that 99% of anglers exposed fish to air for < 60 s, 84% of anglers exposed fish to air for < 30 s, and 64% of anglers exposed fish to air for < 20 s. Average air exposure was only 19 s. Recent, observations for steelhead *Oncorhynchus mykiss* (average = 29 s; Chiaramonte et al. 2017) and warmwater and coolwater species (average = 22 s; Kevin Meyer, unpublished data) species suggest nearly identical air exposure durations. In contrast, the minimum time most studies have used in as air exposure treatments is 30 s (excluding control treatments; Ferguson and Tufts 1992; Schreer et al. 2005; Gingerich et al. 2007). The maximum amount of air exposure has been 2 min (Schreer et al. 2007), 3 min (Suski et al. 2007), 4 min (Louison et al. 2017), 5 min (Graves et al. 2016), 10 min (Rapp et al. 2014; Thompson et al. 2008), 16 min (Gingerich et al. 2016), 19 min (Brownscombe et al. 2017), and even 60 min (Davis and Parker 2004).

Despite these extremely long air exposure durations relative to the only real world results reported above, nearly all studies have reported little to no increase in mortality (Schreer et al. 2005; Suski et al. 2007; Rapp et al. 2014; Louison et al. 2017 Brownscombe et al. 2017). In fact, only two studies have reported mortality rates over 20% (Davis and Parker 2004; Gingerich et al. 2007). Bluegill *Lepomis macrochirus* were exposed to air for 0, 30, 60, 120, 240, 480, or 960 s, held in tanks at varying water temperatures (18.3 ^{o}C, 22.8 ^{o}C, or 27.4^{o}C), and observed for mortality (Gingerich et al. 2007). When water temperatures were ≤ 22.8 ^{o}C, mortality was less than 11%, even up to 960 s of air exposure. Mortality did not increase to over 20% until water temperature was 27.4 ^{o}C and air exposure duration was ≥ 30 s (highest mortality was 80% at 960 s). In contrast, Suski et al. (2007) exposed Bonefish *Albula vulpes* held in tanks at the Cape Eleuthera Institute, The Bahamas, to air for up to 180 s of air exposure and reported no increase in mortality. Other studies that exposed fish to air for 2 min (Schreer et al. 2005), 10 min (Rapp et al. 2014), or even 19 min (Brownscombe et al. 2017) have reported no increase in mortality due to air exposure.

We are aware of only four studies that have evaluated the effects of air exposure on mortality for wild fish under conditions similar to those experienced in actual C&R fisheries (Thompson et al. 2008; Graves et al. 2016; Louison et al. 2016; Gagne et al. 2017). White Marlin *Kajikia albida* captured via angling off the coast of Virginia Beach, Virginia, had a mortality rate of 17% when exposed to air for 1 min (Graves et al. 2016). Mortality of fish exposed to air for 5 min increased to 43%. However, results of Graves et al. (2016) must be interpreted cautiously. Not only were the sample sizes used in each treatment group exceptionally small (i.e., 1 min, n = 6; 3 min, n = 5; 5 min, n = 7), but no control treatment (i.e., fish that received no air exposure) was used during the study. Thompson et al. (2008) evaluated mortality for wild Largemouth Bass and Smallmouth Bass in Lake Opinicon, Ontario. Both species were sampled with angling gear and randomly assigned to and given an air exposure treatment varying from 1 s to 900 s. No mortality was observed for either species. No increase in mortality due to air exposure (up to 120 s) was reported for Golden Dorado *Salminus brasiliensis* captured via angling in the Juramento River, Argentina (Gagne et al. 2017). Similarly, Northern Pike *Esox lucius* captured via angling in Grand Lake, Wisconsin, displayed no increase in mortality after 4 min of air exposure (Louison et al. 2016).

Results of our study are in concordance with the above studies reporting little to no effect of air exposure on mortality. No effect of air exposure on short-term post-spawning survival was observed during both years of study. Furthermore, no difference in short-term survival was observed between fish that were played and those not played or air exposed in 2017. The number of out-migrating adult fish detected in 2016 was lower than those in 2017 and may be attributed to a PIT-tag antenna malfunction (approximately 3 weeks) that likely allowed a substantial portion of the study fish to out-migrate without being detected. Although many studies have reported short-term survival of fishes exposed to air (e.g., Davis and Parker 2004; Thompson et al. 2008; Gagne et al. 2017), our study is the first study to evaluate the relative effects of air exposure on fish over the long term. Similar to short-term survival, air exposure had no effect on relative survival after a year.

Another potential effect of air exposure on fishes is reduced fitness through altered reproductive success. Only two studies have attempted to address this question and the results are contradictory. Richard et al. (2013) used Atlantic Salmon captured via angling as they traveled upstream to spawn. Once a fish was captured, a tissue sample was taken and the angler recorded how long the fish was exposed to air during release. After spawning, backpack electrofishing was used to capture age-0 fish that were then assigned back to adult fish to evaluate the relationship between air exposure and production of progeny. The authors reported that Atlantic Salmon exposed to air for more than 10 s had two to three times lower reproductive success than fish not exposed to air. Based solely on their study, a "10 s rule" has been proposed for implementation in all C&R fisheries where anglers would not be allowed to remove fish from the water for more than 10 s (Cook et al. 2015). Unfortunately, this recommendation fails to acknowledge the limitations of Richard et al. (2013). First, Richard et al. (2013) suffers from small sample sizes. Only 40 adult Atlantic Salmon were caught-and-released and only 24 were exposed to air. By comparison, the present study included nearly 2,300 adult fish. Additionally, the authors' analysis indicated that longer exposure to air resulted in increased reproductive success when the water was warm (> 17ºC) compared to a decline in reproductive success when the water was colder. This observation is contrary to nearly all other studies on the relationship between production of salmonids and water temperature (Strange et al. 1977; Dotson 1982; Beacham and Murray 1985; Vladic and Jarvi 1996). In the only other study that has evaluated reproduction and air exposure, no decline in spawning success was observed after simulated capture and up to 60 s of air exposure for Chum Salmon and Pink Salmon (Raby et al. 2013).

Our results, along with Raby et al. (2013), indicate that air exposure experienced during a typical C&R angling event (i.e., < 30 s; Lamansky and Meyer 2016; Chiaramonte et al. 2017; Roth et al. 2018) does not significantly influence reproductive success. The proportion of fish that produced progeny was equal across treatments and the number of progeny produced was unrelated to air exposure treatment. The analysis of marginal effects highlights this argument in that the actual difference in offspring produced between treatment groups was trivial.

The most obvious pattern in our study was that larger Yellowstone Cutthroat Trout produced more offspring than smaller individuals. Similar patterns have been reported extensively in the literature for a variety of taxa including salmonids (Bulkley 1967; Riebe 2014). Larger fish produce more and larger eggs than small fish (Bulkely 1967). Larger fish also reportedly produce offspring that are more likely to survive due to factors such as better energy resources (yolk) or better habitat conditions selected by larger parents (e.g., larger substrates; Palumbi 2004; Marshall et al. 2011; Riebe 2014).

Overall progeny production was seemingly lower in 2017 than in 2016, but lower production of progeny in 2017 can likely be attributed to differences in streamflow. The 2017 water year was a record year across the basin. For example, discharge in the SFSR averaged 375.1 m^3/s in 2016 during the study period. In 2017, average discharge was nearly 40% higher (520.6 m^3/s). Lower assignment rates of fry to two parents in 2017 is also likely attributed to the high water year because fish were able to pass the velocity-barrier weir on Burns Creek without being captured.

Results of our study are limited by the fact that the study was conducted using only one species in one location. However, when considering that the majority of the literature and the current study report little to no effect of air exposure on mortality and reproductive success, it seems unlikely that exposing fish to air during C&R angling is truly a problem. Nevertheless, additional studies are warranted to address air exposure concerns in other novel catch-and-release fisheries (e.g., anadromous salmonid fisheries in Idaho). Given the growing body of evidence, regulations or even voluntarily limiting the amount of time that anglers expose fish to air during C&R angling (Cook et al. 2015) seem unnecessary. The majority of anglers in a variety of fisheries including coldwater, coolwater, and warmwater fisheries release their fish within 30 s (Lamanysky and Meyer 2016; Chiaramonte et al. 2017; Roth et al. 2018). Given the lack of evidence that air exposure causes negative effects at the individual level, it seems, highly unlikely that air exposure would have negative effects at a population level.

Acknowledgements

We thank N. Birmingham, T. Brauer, G. Briley, J. Dupont, K. Estep, D. Garren, D. McCarrick, C. McClure, J. Rosales, E. Roth, C. Rudfelt, D. Skidmore, S. Smith, T. Smouse, C. Traughber, and J. Wu for their assistance with field work. Funding for this project was provided by the Idaho Department of Fish and Game through the Federal Aid in Sport Fish Restoration Act and by Idaho anglers via license fees. Additional support was provided by the U.S. Geological Survey, Idaho Cooperative Fish and Wildlife Research Unit. The Unit is jointly sponsored by the University of Idaho, U.S. Geological Survey, Idaho Department of Fish and Game, and Wildlife Management Institute. The use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. government. This project was conducted under the University of Idaho Institutional Animal Care and Use Committee Protocol 2015-48.

References

Anderson, R. M., and R. B. Nehring. 1984. Effects of catch-and-release regulation on a wild trout population in Colorado and its acceptance by anglers. North American Journal of Fisheries Management 4:257–265.

Beacham, T. B., and C. B. Murray. 1985. Effect of female size, egg size, and water temperature on the developmental biology of Chum Salmon (Oncorhynchus keta) from the Nitinat River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 42:1755–1765.

Brownscombe, J. W., T. P. Parmar, J. Almeida, E. Giesbrecht, J. Batson, X. Chen, S. Wesch, T. D. Ward, C. M. O'Connor, and S. J. Cooke. 2017. The efficacy of assisted ventilation techniques for facilitating the recovery of fish that are exhausted from simulated angling stress. Fisheries Research 186:619–624.

Bulkley, R. V. 1967. Fecundity of steelhead trout, Salmo gairdneri, from Alsea River, Oregon. Journal of the Fisheries Board of Canada 25:917–926.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd edition. Springer-Verlag, New York.

Chiaramonte, L. V., D. W. Whitney, J. L. McCormick, and K. A. Meyer. 2017. Air exposure and fight times for anadromous fisheries in Idaho. Pages 335-341 in R.F. Carline and C. LoSapio, editors. Wild Trout XII: who's driving and where are we going? Wild Trout Symposium, Bozeman, Montana.

Cook, K. V., R. J. Lennox, S. G. Hinch, and S. J. Cooke. 2015. Fish out of water: how much air is too much? Fisheries 40:452–461.

Davis, M. W., and S. J. Parker. 2004. Fish size and exposure to air: potential effects on behavioral impairment and mortality rates in discarded Sablefish. North American Journal of Fisheries Management 24:518–524.

Dotson, T. 1982. Mortalities in trout caused by gear type and angler-induced stress. North American Journal of Fisheries Management 2:60–65.

Doudoroff, P., and D. L. Shumway. 1970. Dissolved oxygen requirements of freshwater fishes. FAO (Food and Agricultural Organization of the United Nations) Fisheries Technical Paper 86, Rome.

Ferguson, R. A., and B. L. Tufts. 1992. Physiological effects of brief air exposure in exhaustively exercised Rainbow Trout (Oncorhynchus mykiss): Implications for "catch and release" fisheries. Canadian Journal of Fisheries and Aquatic Sciences 49:1157–1162.

Fleiss, J. L. 1981. Statistical methods for rates and proportions, 2nd edition. Wiley, New York.

Gale, M. K., S. G. Hinch, E. J. Eliason, S. J. Cooke, and D. A. Patterson. 2011. Physiological impairment of adult Sockeye Salmon in fresh water after simulated capture-and-release across a range of temperatures. Fisheries Research 112:85–95.

Gingerich, A. J., S. J. Cooke, K. C. Hanson, M. R. Donaldson, C. T. Hasler, C. D. Suski, and R. Arlinghaus. 2007. Evaluation of the interactive effects of air exposure duration and water temperature on the condition and survival of angled and released fish. Fisheries Research 86:169–178.

Goeman, T. J., P. D. Spencer, and R. B. Pierce. 1993. Effectiveness of liberalize bag limits as management tools for altering Northern Pike population size structure. North American Journal of Fisheries Management 13:621–624.

Graves, J. E., and A. Z. Hordoysky. 2008. Does hook choice matter? Effects of three circle hook models on postrelease survival of White Marlin. North American Journal of Fisheries Management 28:471–480.

Graves, J. E., B. J. Marcek, and W. M. Goldsmith. 2016. Effects of air exposure on postrelease mortality rates of White Marlin caught in the U.S. offshore recreational fishery. North American Journal of Fisheries Management 36:1121–1228.

Hosmer, Jr. D., and S. Lemeshow. 1989. Applied logistic regression. Wiley, New York.

Isermann, D. A., and C. P. Paukert. 2010. Regulating harvest. Pages 185-212 in W. A. Hubert, and M. C. Quist, editors. Inland fisheries management in North America, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Johnson, T. H., and T. C. Bjornn. 1978. Evaluation of angling regulations in management of Cutthroat Trout. Cooperative Fishery Research Unit, University of Idaho, Federal Aid in Fish Restoration, Project F-59-R-7, Job Completion Report, Moscow.

Johnson, T. J. 2018. Trtools: Teaching tools for regression modeling and survey sampling. R package version 0.1.0. https://github.com/trobinj/trtools.

Lamansky, J. A., and K. A. Meyer. 2016. Air exposure time of trout released by anglers during catch and release. North American Journal of Fisheries Management 36:1018–1023.

Long, J. S. 1997. Regression models for categorical and limited dependent variables. Sage Publications. Thousand Oaks, California.

Louison, M. J., C. T. Hasler, M. M. Fenske, C. D. Suski, and J. A. Stein. 2017. Physiological effects of ice-angling capture and handling of Northern Pike, Esox Lucius. Fisheries Management and Ecology 24:10–18.

Marshall, D. J., S. S. Heppell, S. B. Munch, and R. R. Warner. 2010. The relationship between maternal phenotype and offspring quality: Do older mothers really produce the best offspring? Ecology 91:2862–2873.

McFadden, D. 1974. Conditional logit analysis of qualitative choice behavior. Pages 105-142 in P. Zarembka, editor. Frontiers of Economics. Academic Press, New York.

Moore, V. K., and D. J. Schill. 1984. Fish distributions and abundance in the South Fork Snake River. Idaho Department of Fish and Game, Federal aid in Sport Fish Restoration, Project F-73-R-5, Job Completion Report, Boise.

Palumbi, S. R. 2004. Why mothers matter. Nature 430:621–622.

Pelzman, R. J. 1978. Hooking mortality of juvenile Largemouth Bass, Micropterus salmoides. California Fish and Game 64:185–188.

Philipp, D. P., C. A. Toline, M. F. Kubacki, D. B. F. Philipp, and F. J. S. Phelan. 1997. The impact of catch-and-release angling on the reproductive success of Smallmouth Bass and Largemouth Bass. North American Journal of Fisheries Management 17:557–567.

Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. American Fisheries Society Symposium 7:317–322.

Quist, M. C., and W. A. Hubert. 2004. Bioinvasive species and the preservation of Cutthroat Trout in the western United States: ecological, social, and economic issues. Environmental Science and Policy 7:303–313.

R Core Team. 2017. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available: www.R-project.org.

Raby, G. D., S. J. Cooke, K. V. Cooke, S. H. McConnachie, M. R. Donaldson, S. G. Hinch, C. K. Whitney, S. M. Dreener, D. A. Patterson, T. D. Clark, and A. P. Farrell. 2013. Resilience of Pink Salmon and Chum Salmon to simulated fisheries capture stress incurred upon arrival at spawning grounds. Transactions of the American Fisheries Society 142:524–539.

Rapp, T., J. Hallermann, S. J. Cooke, S. K. Hetz, S. Wuertz, and R. Arlinghaus. 2014. Consequences of air exposure on the physiology and behavior of caught-and-released Common Carp in the laboratory and under natural conditions. North American Journal of Fisheries Management 34:232–246.

Reynolds, J. D., and M. R. Gross. 1992. Female mate preference enhances offspring growth and reproduction in a fish, Poecilia reticulate. Proceedings of the Royal Society of London B: Biological Sciences 250:57–62.

Richard, A., M. Dionne, J. Wang, and L. Bernatchez. 2013. Does catch and release affect the mating system and individual reproductive success of wild Atlantic Salmon (Salmo salar L.)? Molecular Ecology 22:187–200.

Riebe, C. S., L. S. Sklar, B. T. Overstreet, and J. K. Wooster. 2014. Optimal reproduction in salmon spawning substrates linked to grain size and fish length. Water Resources Research 50:898–918.

Roth, C. J., D. J. Schill, and M. C. Quist. 2018. Fight and air exposure times of caught and released salmonids from the South Fork Snake River. Fisheries Research 201:38–43.

Schill, D. J., J. S. Griffith, and R. E. Gresswell. 1986. Hooking mortality of Cutthroat Trout in a catch-and-release segment of the Yellowstone River, Yellowstone National Park. North American Journal of Fisheries Management 6:226–232.

Schill, D. J., and R. L. Scarpella. 1997. Barbed hook restrictions in catch-and-release trout fisheries: A social issue. North American Journal of Fisheries Management 17:873–881.

Schill, D. J., J. A. Heindel, M. R. Campbell, K. A. Meyer, and E. R. J. M. Mamer. 2016. Production of a YY male Brook Trout broodstock for potential eradication of undesired Brook Trout populations. North American Journal of Aquaculture 78:72–83.

Schisler, G. J., and E. P. Bergersen. 1996. Postrelease hooking mortality of Rainbow Trout caught on scented artificial baits. North American Journal of Fisheries Management 16:570–578.

Schneider, J. C., and R. N. Lockwood. 2002. Use of Walleye stocking, antimycin treatments, and catch-and-release angling regulations to increase growth and length of stunted Bluegill populations in Michigan lakes. North American Journal of Fisheries Management 22:1041–1052.

Schreer, J. F., D. M. Resch, M. L. Gately, and S. J. Cooke. 2005. Swimming performance of Brook Trout after simulated catch-and-release angling: looking for air exposure thresholds. North American Journal of Fisheries Management 25:1513–1517.

Steele, C. A., E. C. Anderson, M. W. Ackerman, M. A. Hess, N. R. Campbell, S. R. Narum, and M. R. Campbell. 2013. A validation of parentage-based tagging using hatchery steelhead in the Snake River basin. Canadian Journal of Fisheries and Aquatic Sciences 70:1046–1054.

Strange, J. R., C. B. Schreck, and J. T. Golden. 1977. Corticoid stess response to handling and temperature in salmonids. Transactions of the American Fisheries Society 106 213–218.

Suski, C. D., S. J. Cooke, A. J. Danylchuk, C. M. O'Connor, M. Gravel, T. Redpath, K. C. Hanson, A. J. Gingerich, K. J. Murchie, S. E. Danylchuk, J. B. Koppelman, and T. L. Goldberg. 2007. Physiological disturbance and recovery dynamics of Bonefish (Albula vulpes), a tropical marine fish, in response to variable exercise and exposure to air. Comparative Biochemistry and Physiology 148:664–673.

Svardson, G. 1949. Natural selection and egg number in fish. Report of the Institute of Freshwater Research, Drottningholm 29:115–122.

Thompson L. A., S. J. Cooke, M. R. Donaldson, K. C. Hanson, A. Gingerich, T. Klefoth, and R. Arlinghaus. 2008. Physiology, behavior, and survival of angled and air-exposed largemouth bass. North American Journal of Fisheries Management 28:1059–1068.

Thompson, P. E. 1958. Fishing is fun. Sports Afield (May):19–23.

Thurow, R. F., C. E. Corsi, and V. K. Moore. 1988. Status, ecology, and management of Yellowstone Cutthroat Trout in the upper Snake River drainage, Idaho. Pages 25-36 in R. E. Gresswell, editor. Status and management of interior stocks of Cutthroat Trout. American Fisheries Society, Symposium 4, Bethesda, Maryland.

Vladic, T., and T. Jatrvi. 1997. Sperm motility and fertilization time span in Atlantic Salmon and Brown Trout–the effect of water temperature. Journal of Fish Biology 50:1088–1093.

Table 4.1. Top regression models predicting the number of offspring produced by Yellowstone Cutthroat Trout in Burns Creek, Idaho (May – October 2016; May – September 2017). Models were put into two categories (i.e., models using only male fish and models using only female fish). Covariates include what year the fish was sampled, the fish's length (mm), and what air exposure treatment (i.e., 0 s, 30 s, or 60 s) the fish had been given. Models were evaluated using Akaike's information criterion corrected for small sample size (AIC_c), the change in Akaike's information criterion between models (ΔAIC_c), and the number of parameters in the model (K). McFadden's pseudo R^2 was used to evaluate model fit.

Model	K	AIC_c	ΔAIC_c	w_i	pseudo-R^2
Male models					
Treatment + Length + Year	6	3796.9	0.00	0.87	0.06
Female models					
Treatment + Length + Year	6	4164.3	0.00	0.41	0.02
Treatment + Length	5	4165.0	0.62	0.30	0.02
Treatment + Length + Treatment × Length + Year	8	4166.1	1.77	0.17	0.02

Table 4.2. Marginal effects analysis showing the difference in the predicted number of offspring produced by adult Yellowstone Cutthroat Trout at a given length based on comparisons between air exposure treatments air exposure treatment (i.e., 0 s. 30 s, or 60 s). Positive values indicated that the shorter air exposure treatment produced more offspring, on average, than the longer air exposure treatment. Fish were sampled via velocity-barrier weir on Burns Creek, Idaho (May – October 2016; May – September 2017).

Year	Comparison	200 mm	300 mm	400 mm	500 mm
		Males			
2016	0 - 30	-0.010	-0.055	-0.290	-1.542
	0 - 60	-0.002	-0.010	-0.048	-0.257
	30 - 60	0.009	0.045	0.242	1.286
2017	0 - 30	-0.005	-0.026	-0.139	-0.740
	0 - 60	-0.001	-0.004	-0.023	-0.123
	30 - 60	0.004	0.022	0.116	0.617
		Females			
2016	0 - 30	0.009	0.033	0.122	0.448
	0 - 60	0.127	0.046	0.170	0.625
	30 - 60	0.004	0.013	0.048	0.177
2017	0 - 30	0.007	0.027	0.100	0.367
	0 - 60	0.010	0.038	0.140	0.512
	30 - 60	0.003	0.011	0.040	0.145

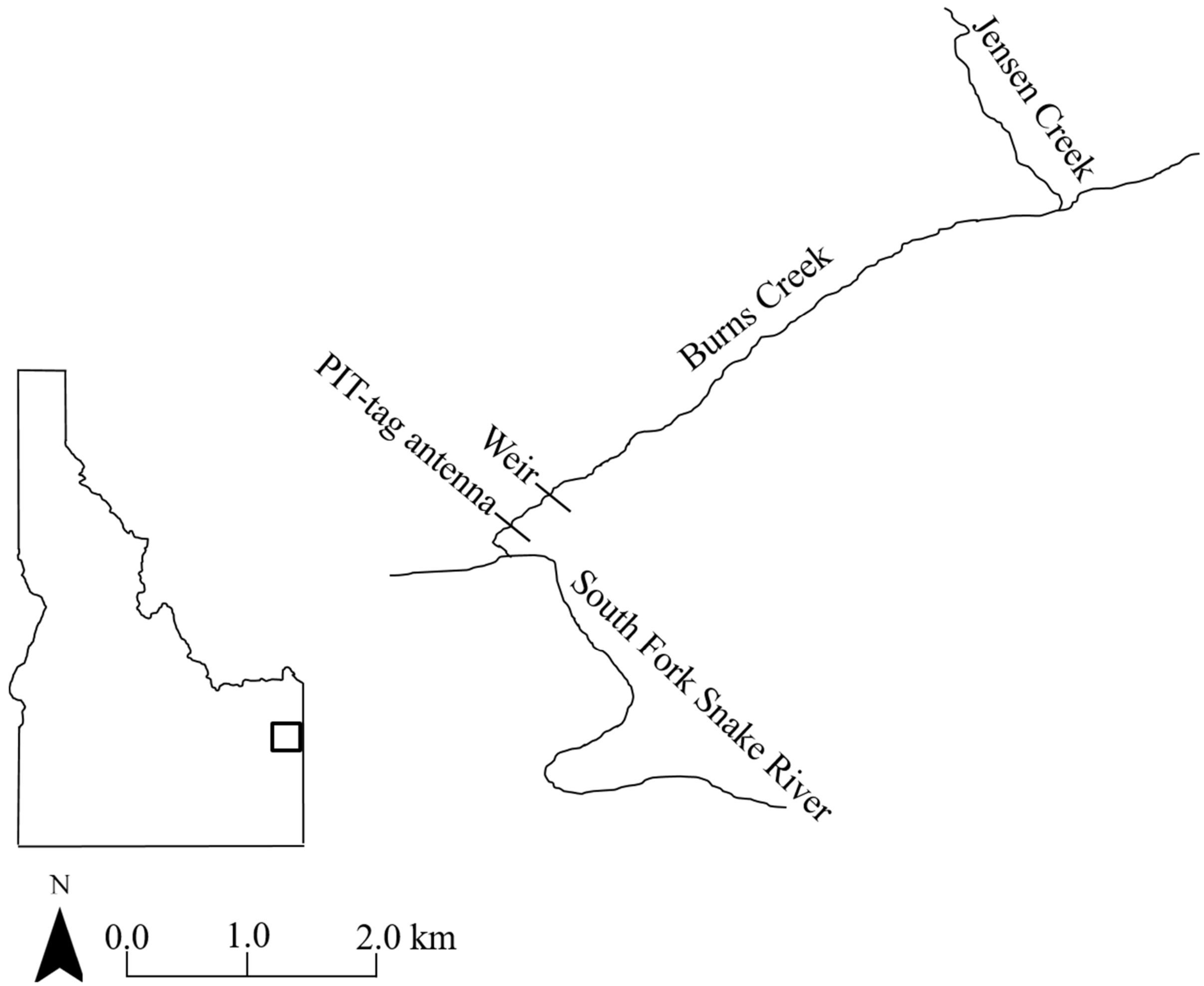

Figure 4.1. Burns Creek, Idaho, from its confluence with the South Fork Snake River to its confluence with Jensen Creek, Idaho.

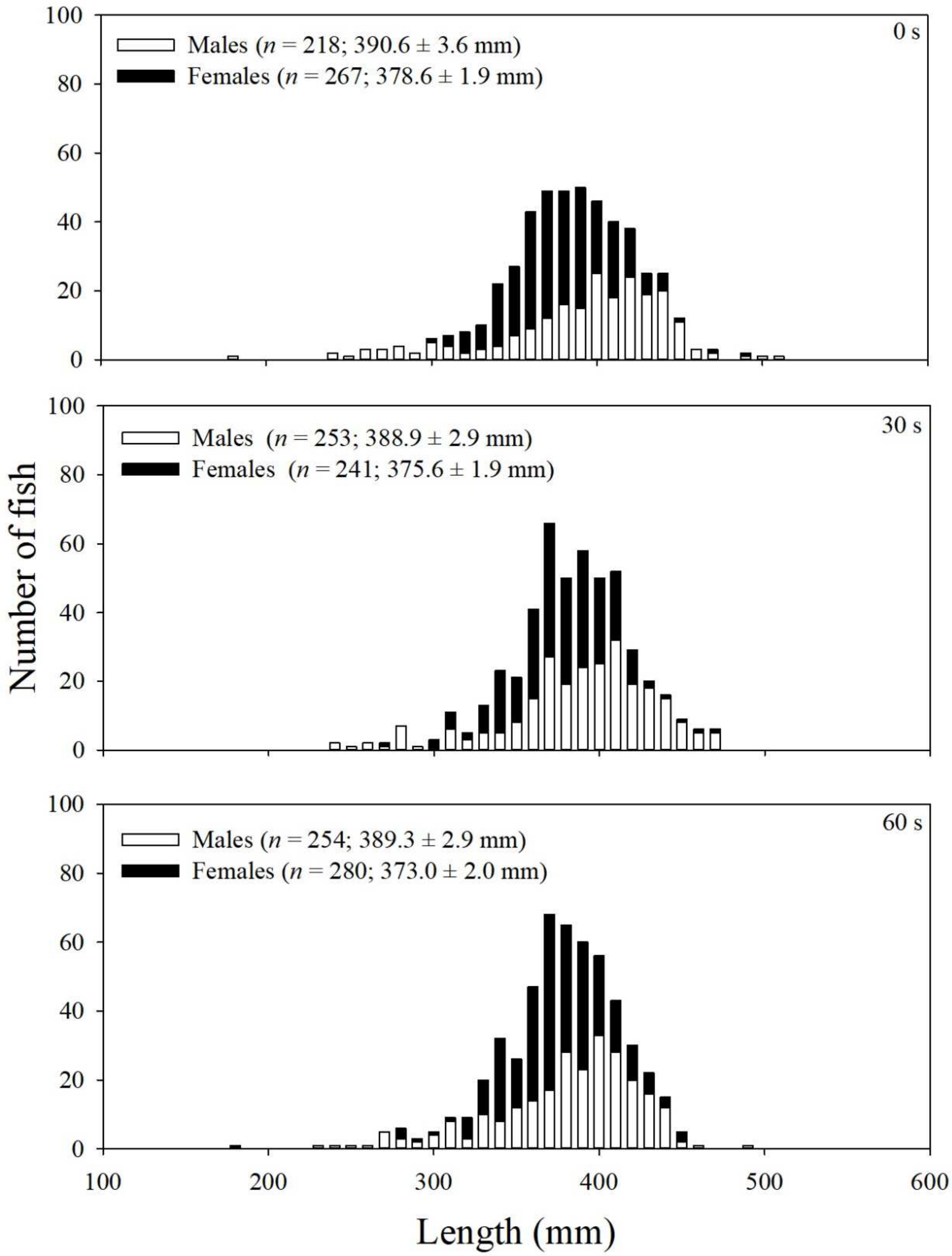

Figure 4.2. Length frequency distributions of Yellowstone Cutthroat Trout sampled at a velocity-barrier weir by sex and air exposure treatment group sampled in Burns Creek, Idaho (May – July, 2016). Average length by sex is included in each treatment along with one SE.

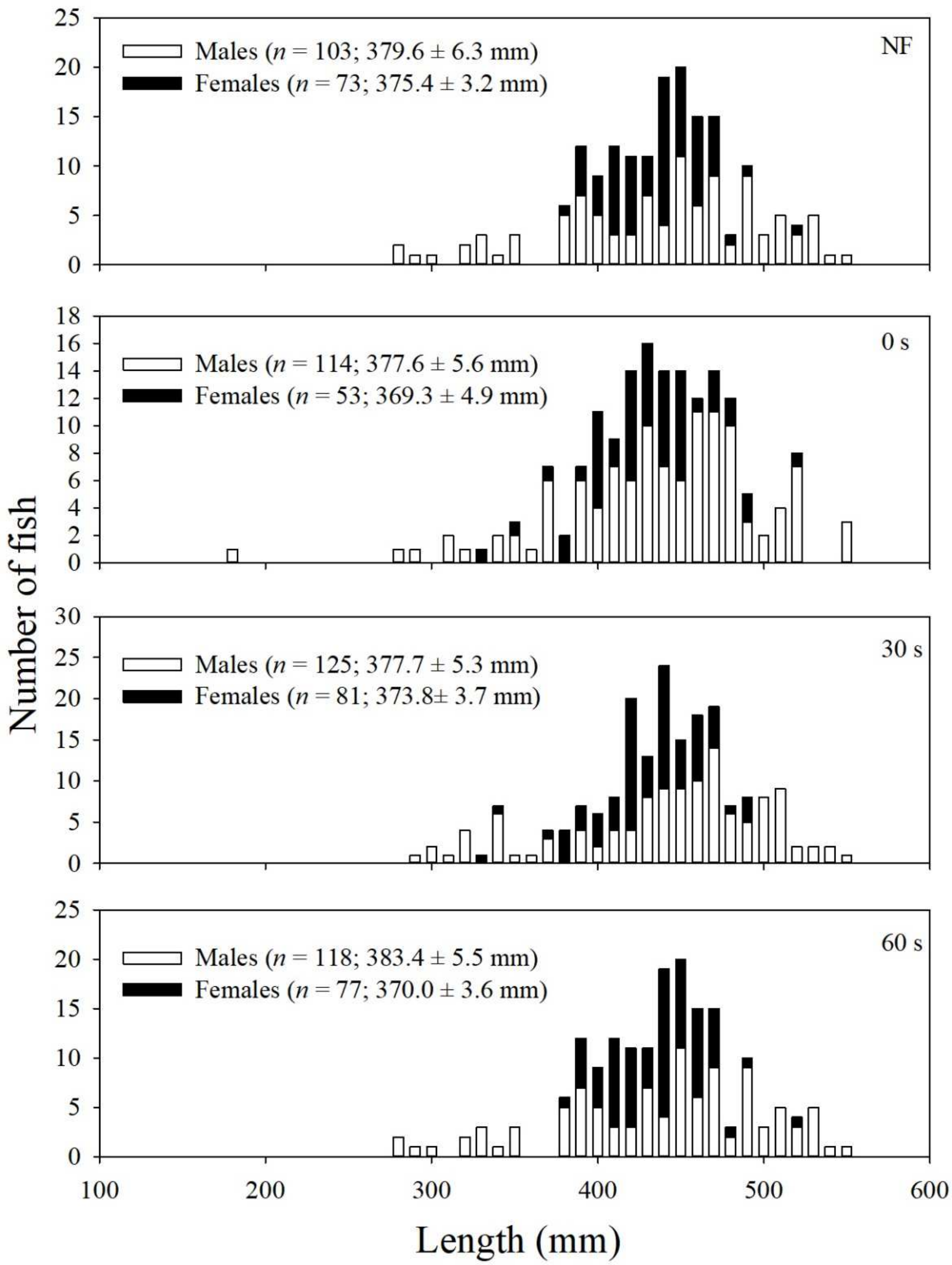

Figure 4.3. Length frequency distributions of Yellowstone Cutthroat Trout sampled via velocity-barrier weir by sex and air exposure treatment group sampled in Burns Creek, Idaho (May – June, 2017). In addition to the three air exposure treatment groups, a fourth treatment group was included where the fish were not played or air exposed (NF). Average length by sex is included in each treatment along with one SE.

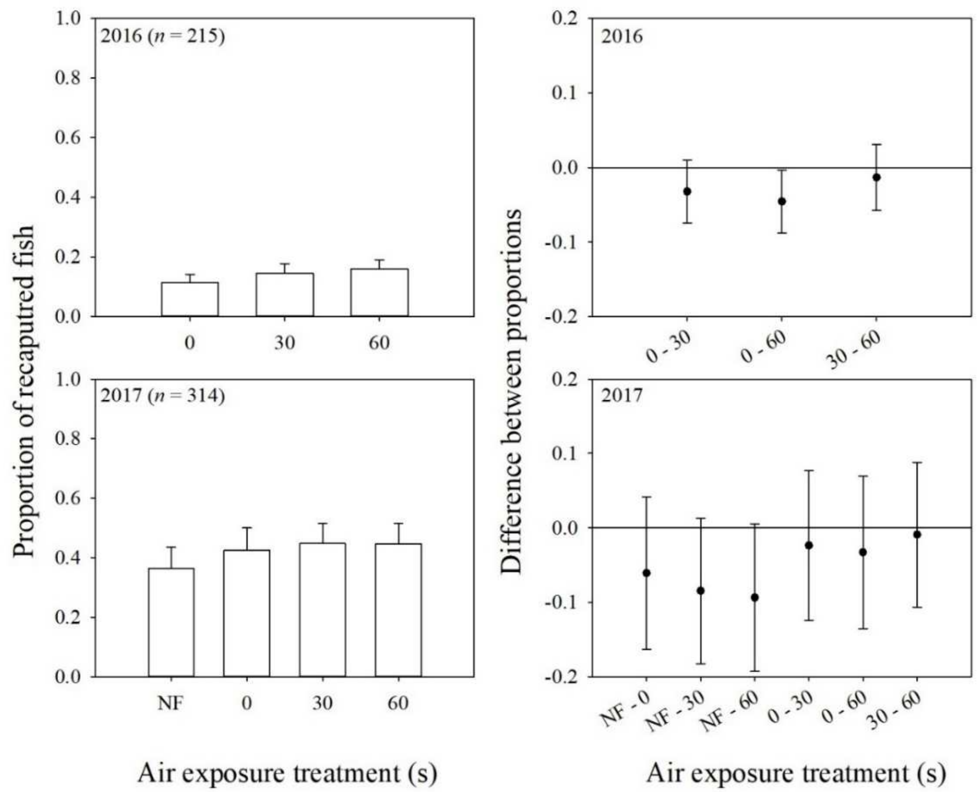

Figure 4.4. Proportions and one SE of adult Yellowstone Cutthroat Trout (Left panels) out-migrating from Burns Creek, Idaho, within 60 days of air exposure treatment (May – August, 2016; May – August 2017). Differences between the proportions (Right panels) were calculated as the treatment group with the least amount of air exposure minus the treatment group that had the most air exposure. Values below the zero line indicate that fish in the treatment group with less air exposure had lower relative survival than the fish in the treatment group with a longer air exposure duration. A treatment group was added in 2017 where fish were not played or air exposed (NF). Error bars report 95% confidence intervals for the difference between proportions. Results were only statistically different if the 95% confidence interval did not overlap the zero line.

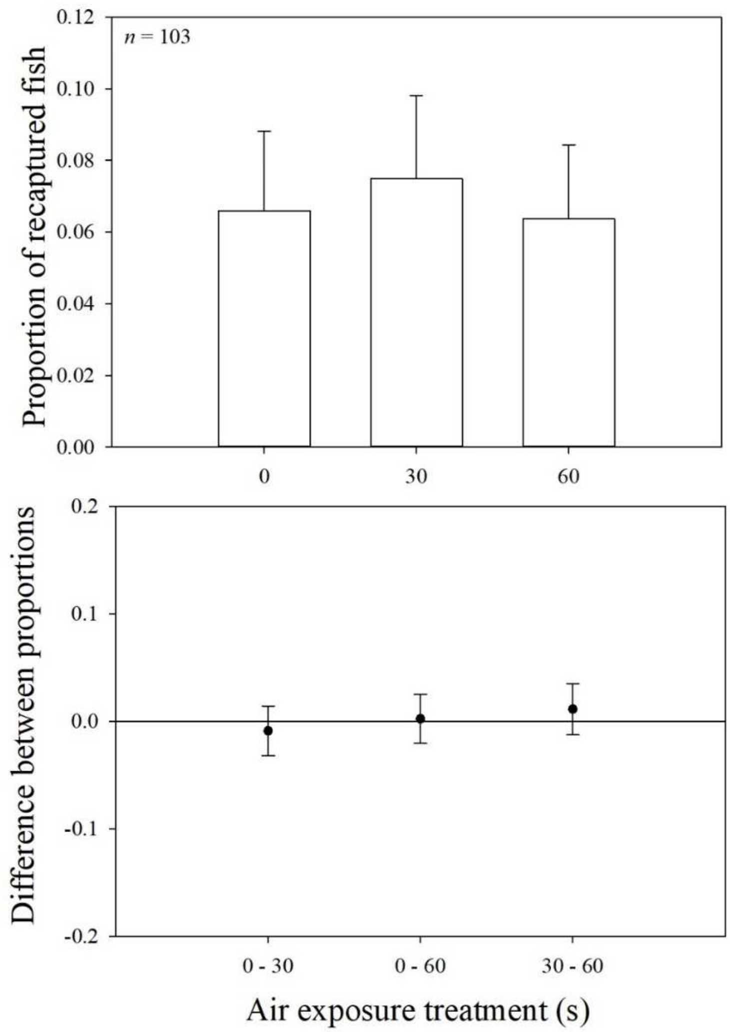

Figure 4.5. Proportions of Yellowstone Cutthroat Trout and one SE (Top panel) that were sampled and given an air exposure treatment in 2016 that were subsequently recaptured a year later in 2017. Difference between proportions (Bottom panel) were calculated as the treatment group with the least air exposure minus the treatment group with the most air exposure. Values above the line indicate that relative survival was higher for the treatment group with less air exposure, with values below the line indicating the opposite. Fish were sampled (May – July, 2016) and recaptured (May – June, 2017) in Burns Creek, Idaho. Error bars report 95% confidence intervals for the difference between proportions. Results were only statistically different if the 95% confidence interval did not overlap the zero line.

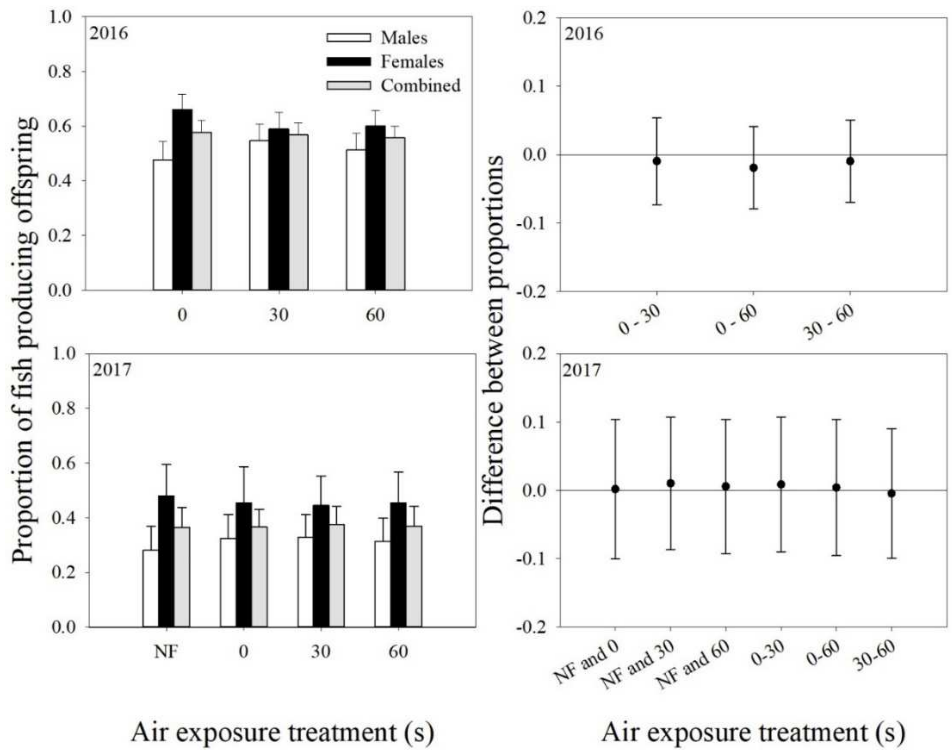

Figure 4.6. Proportions and one SE of male, female, and both sexes combined (combined; Left panels) Yellowstone Cutthroat Trout by treatment that successfully spawned in Burns Creek, Idaho (May – October, 2016; May – September, 2017). Differences between proportions (Right panels) were calculated as the treatment group with the least air exposure minus the treatment group with the most air exposure. Values above the line indicate a higher proportion of fish spawned in the air exposure treatment group with less air exposure, and values below the line indicate the opposite. A treatment group was added in 2017 where fish were not played or air exposed (NF). Error bars include 95% confidence intervals for the difference between proportions. Results were only statistically different if the 95% confidence interval did not overlap the zero line.

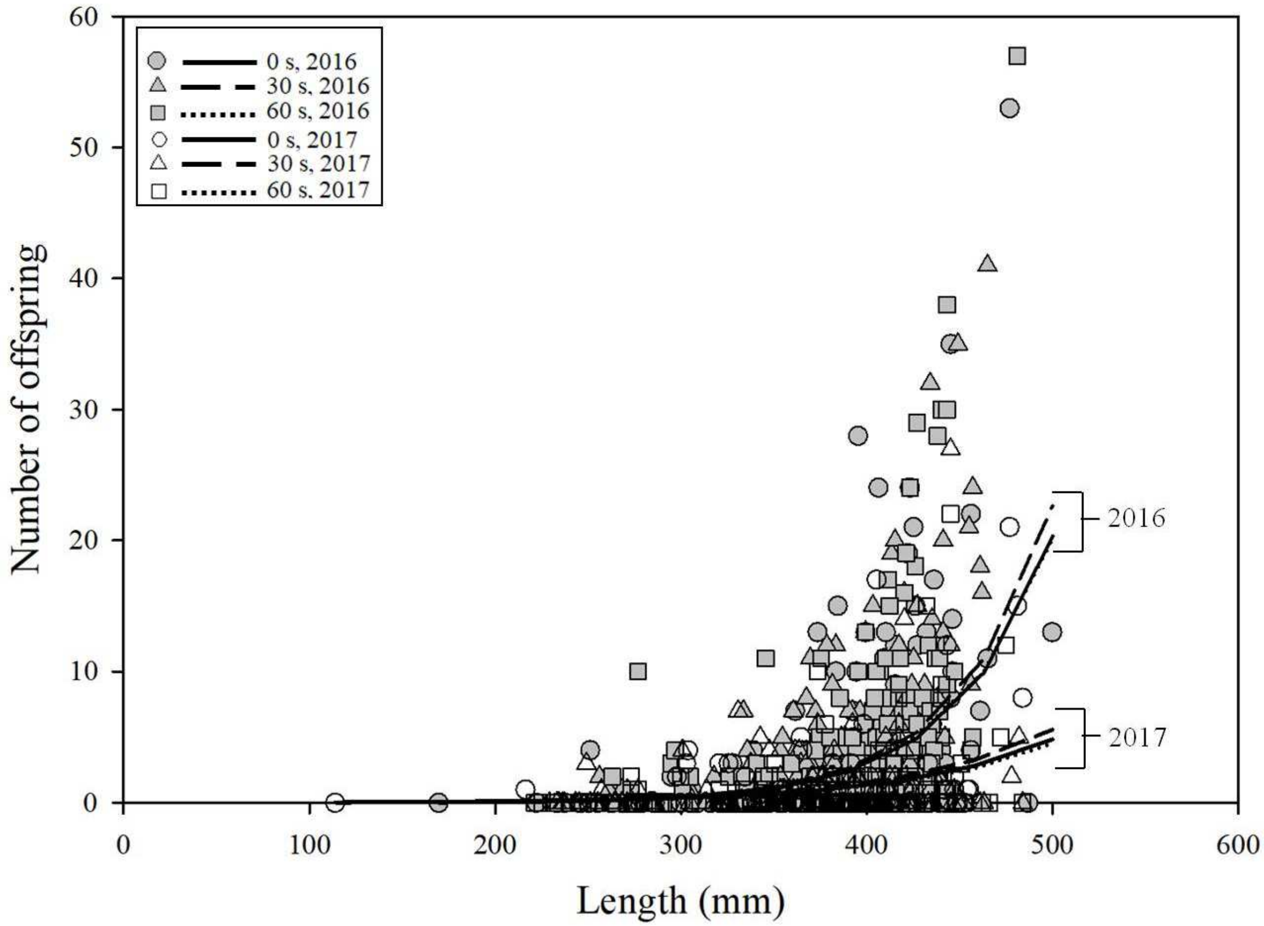

Figure 4.7. The number of offspring produced by adult male Yellowstone Cutthroat Trout in Burns Creek, Idaho (May – October 2016; May – September 2017). Lines represent predicted number of offspring by air exposure treatment group. A treatment group was added in 2017 where fish were not air exposed or played (NF).

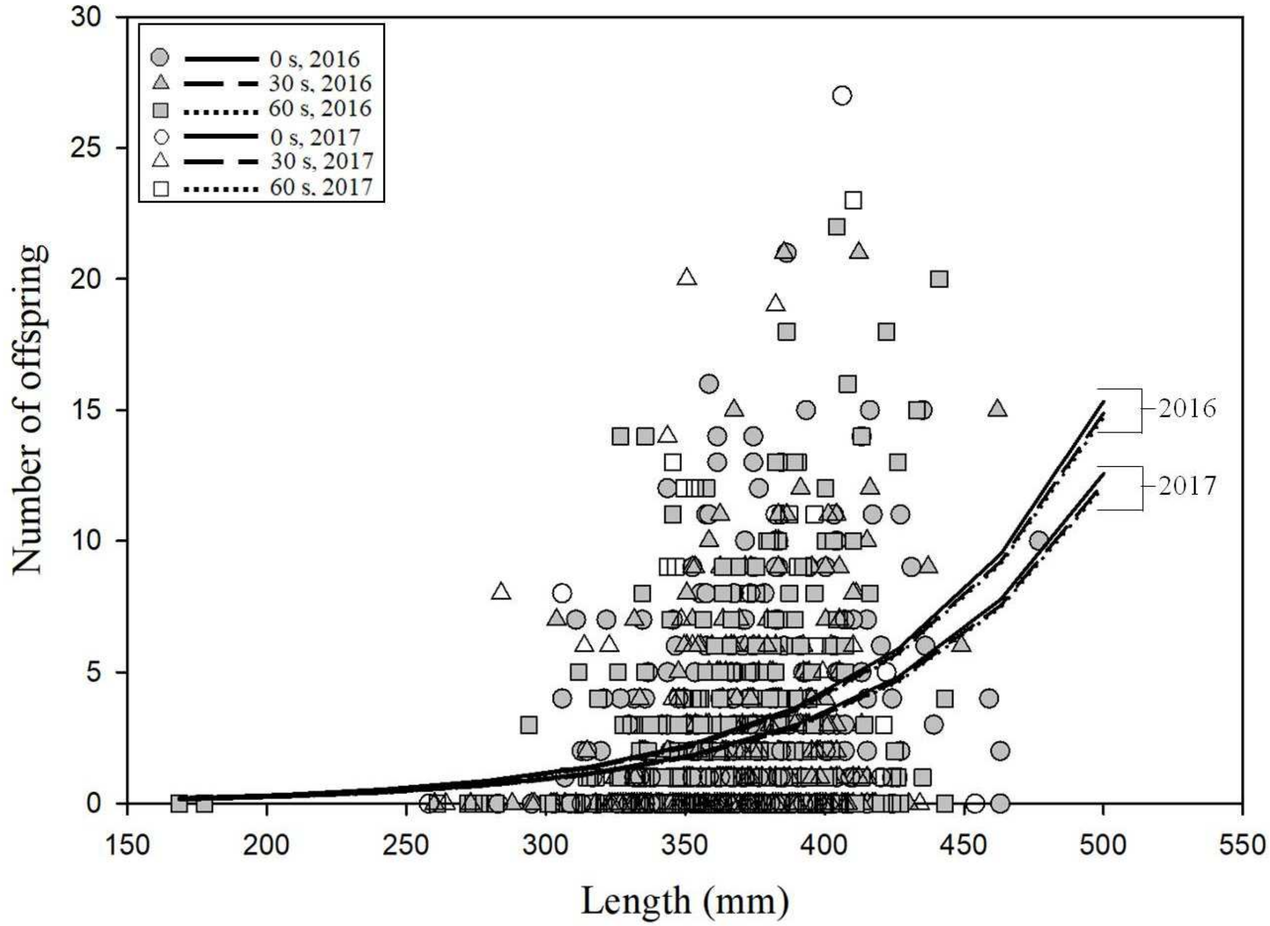

Figure 4.8. The number of offspring produced by adult female Yellowstone Cutthroat Trout in Burns Creek, Idaho (May – October 2016; May – September 2017). Lines represent predicted number of offspring by air exposure treatment group. A treatment group was added in 2017 where fish were not air exposed or played (NF).

Chapter 5: General Conclusions

This thesis contributes to the current understanding of the effects of air exposure due to catch-and-release angling on salmonids. The management goal in relation to this thesis was to determine if anglers exposing fish to air during catch-and-release angling negatively affected catch-and-release salmonid fisheries. Angler observations on the South Fork of the Snake River, Idaho, described how long anglers fought fish and how long they actually exposed fish to air during catch-and-release angling. Hook-and-line surveys added to the understanding of the effects of air exposure by evaluating how different air exposure durations affected the survival of three salmonid species during the summer when water temperatures were at their highest. Investigations on Burns Creek, Idaho, examined how air exposure and simulated angling influenced survival and production of progeny of Yellowstone Cutthroat Trout *Oncorhynchus clarkii bouvieri*.

Angler observations contributed to the contextualization of concerns with air exposure during catch-and-release angling by identifying how long catch-and-release anglers actually expose fish to air when angling. Fight time averaged 40.0 s (SD = 36.8) and 83.3% of anglers fought fish for less than 60 s. Observations revealed that average total air exposure duration for catch-and-release trout anglers was only 19.3s (SD = 15.0). Furthermore, the longest continuous interval of air exposure that anglers exposed fish to during catch-and-release angling averaged 18.8 s (SD = 14.2) and nearly all anglers (99.7%) exposed fish to air for < 60.0 s.

The effects of air exposure on the survival of salmonids during the summer was evaluated using three salmonid species (i.e., Yellowstone Cutthroat Trout, Bull Trout *Salvelinus confluentus*, and Rainbow Trout *Oncorhynchus mykiss*). Evaluation on the survival of Yellowstone Cutthroat Trout exposed to air revealed that air exposure of up to 60 s had no effect on survival. Similar results were observed with Bull Trout in that air exposure of up to 60 s had no effect on survival. Air exposure of up to 60 s also had no effect on survival for Rainbow Trout.

Investigations on Burns Creek were concordant with our other research. Air exposure of up to 60 s had no effect on the short-term (i.e., within 60 days of treatment) or long-term (i.e., one year after treatment) survival of Yellowstone Cutthroat at up to 60 s of air exposure. The act of simulated angling with no air exposure had no effect on survival of Yellowstone Cutthroat Trout. Furthermore, no decline in reproductive success was observed at up to 60 s of air exposure. Air exposure of up to 60 s and the act of simulated angling also had no effect on the proportion of fish that successfully spawned.

Collectively, my research provides valuable insight into concerns with air exposure from a management perspective. For example, these chapters indicate that air exposure durations commonly practiced in catch-and-release fisheries are not a management concern for two reasons. No increase in mortality was observed in any of the species evaluated under real-world conditions. No decrease in reproductive success was observed in Yellowstone Cutthroat Trout at up to 60 s of air exposure. From a management standpoint, it appears that concern with air exposure is largely a social issue given the lack of scientific evidence showing an effect under real-world air exposure times. Fisheries agencies should exercise caution and consider the repercussions of proposing air exposure regulation on catch-and-release fisheries.