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Can smartphones kill Trout? Mortality of memorable-sized Bull Trout (*Salvelinus confluentus*) after photo-releases

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ABSTRACT

Mortality associated with catch-and-release (C&R) fisheries is typically estimated as a single value associated with fish that are immediately released after capture. However, with the widespread use of smartphones by anglers, memorable or rare fish may be subjected to prolonged handling time for photographs and measurements, resulting in increased air exposure and subsequent increased potential for post-release mortality. In situations of overfishing, large fish become rarer and their memorable status may increase. This may create a depensatory cycle of additional handling and mortality. The combination of mortality from prolonged handling, immediate release, and illegal harvest is a cumulative C&R-related cryptic mortality that may have population-level effects in high-effort sport fisheries. We investigated the potential post-release mortality of memorable-sized (average length of 60 cm) bull trout after simulating prolonged handling (involving photographing and measuring) and immediate release in a controlled angling study at a remote Albertan lake during summer. We found that handling time and air exposure of large bull trout subjected to photography and measurement was long (112 s) and associated post-release mortality was high (10 dead / 30 fish; 33 % after 24 h observation). Immediate release mortality was also high (3 dead / 20 fish; 15 %). These levels of mortality, combined with high angler effort, can potentially lead to population-scale declines at C&R fisheries. The complexity and difficulty of population-scale and field-level measurements of cryptic mortality suggest that adaptive management experiments in reductions in angling effort and improved fish handling may be effective in increasing understanding of sustainable angling.

1. Introduction

Catch and release (C&R) regulations for recreational angling are a common conservation management practice across many jurisdictions and for multiple species (Muoneke and Childress, 1994; Arlinghaus and Cooke, 2009; Isermann and Paukert, 2010; Lamansky and Meyer, 2016), with a history that dates back to the 1950′s (Hazzard, 1952; Lennon and Parker, 1960). The basic premise of C&R is that recreational angling opportunities can be sustained with minimal impacts to fish stocks, and the ability to re-capture an individual fish (Wydoski, 1977; Arlinghaus et al., 2007; Gutowsky et al., 2011). Typically, a single value of estimated release mortality is applied to C&R fisheries (e.g., Post et al., 2003; Coggins et al., 2007) usually described as immediate release, where fish are simply unhooked and released within seconds of capture.

Fisheries managed under C&R regulations, however, can incur mortality from anglers under three broad and cumulative categories; a) immediate release, as defined above, b) prolonged handling, where fish are photographed, measured or otherwise handled for a brief time prior to release, and c) illegal harvest, where fish are intentionally or mistakenly killed in violation of the C&R regulations. These three categories of cryptic mortality (Pollock and Pine, 2007; Gilman et al., 2013) are cumulative in the sense that the sum of the dead fish relates to the overall fishing mortality in the C&R fishery, and must necessarily result in a higher mortality rate than the single estimated value for immediate release. This cumulative C&R mortality must be considered when assessing population-level effects of C&R (Kerns et al., 2012).

When analyzed as a part of the cumulative C&R effect, delayed mortality associated with prolonged handling may be the most important parameter. Delayed mortality implies death of the fish after it has been released (Cooke and Wilde, 2007) and it is challenging to observe and asses in the field. Smartphones used as cameras have

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become nearly ubiquitous, and photos of memorable fish are a normative behaviour on social media. It could be hypothesized that mortality from immediate release may involve the majority of fish, but has such a low mortality rate that it results in few dead fish. Illegal harvest is implicitly fatal, but likely involves very few anglers, so results in few dead fish. Prolonged handling, however, has the potential to have a moderate mortality rate, may involve a moderate number of released fish and, consequently (and counter-intuitively), may therefore produce the largest proportion of dead fish in the cumulative C&R effect.

Prolonged handling, in the context of this study, is defined as holding the fish for photographs and measurements, and thereby subjecting it to a period of air exposure. Air exposure and handling stress has been found to cause declines in swimming vigour (Schreer et al., 2005), inability to cope with thermal stress (Gingerich et al., 2007), delayed righting reflex and increased downstream fall back (Twardek et al., 2018), and extracellular acidosis amongst other lethal physiological effects (Ferguson and Tufts, 1992). Roth et al. (2018), however, demonstrate that C&R practices involving immediate release and photographs from a range of fish sizes likely result in air exposure well below these laboratory-deduced thresholds for mortality.

Studies on C&R physiology in salmonids often either include discreet field observation of air exposure (Lamansky and Meyer, 2016; Roth et al., 2018) which are then correlated to air exposure effects from laboratory experiments, or experiments that observe mortality under simulated ex-situ conditions that attempt to mimic field conditions (Ferguson and Tufts, 1992; Schreer et al., 2005). Additionally, there is limited information on how long anglers typically expose fish with C&R practices (Roth et al., 2018) and the effects of air exposure warrant additional research to determine if they could contribute significantly to cumulative impacts (Cooke et al., 2013; Cook et al., 2015). We know of no study to date that has observed post-release recovery of in-situ angled mature bull trout (*Salvelinus confluentus*). Gutowsky et al. (2011) did observe immediate injury and mortality in bull trout from recreational angling methods in British Columbia, but did not observe delayed mortality estimates due to the logistical challenges of catching experimental and control populations for field observation. It is both important and difficult to study C&R-related mortality on large Bull Trout because of their rarity at most fisheries.

'Memorable fish' (Gabelhouse, 1984), either of a memorable size or a remarkable species, are potentially photographed and measured at higher rates than more common sizes or species of fish. Large-sized, memorable fish have a disproportionate value to the fish population (e.g., higher gonadal production, improved survival of offspring, portfolio-effect of prolonged spawning; Chambers and Leggett, 1996; Berkeley et al., 2004a; and b; Frances et al., 2007). As well, memorable-sized fish may have a disproportionate value to the anglers' perception of the quality of the fishery (Beardmore et al., 2015). Rates of mortality on these memorable fish therefore needs to be estimated to understand the effects of C&R. In Alberta, bull trout are classified as a species-at-risk (ASRD, 2012; DFO, 2017) and angler catches appear to be becoming rarer, with recent angler reported catch rates of under 2 fish per 100 h angling (Hurkett and Fitzsimmons, 2019). However, the popularity of bull trout as a desirable sport fish has increased, with magazine and internet articles focussing attention not on its species-at-risk status, but on its size and uniqueness as a catch (McLennen, 2010; Roy, 2015; Schlachter, 2016; Alberta Tourism, 2018). Recovery of these fish requires that all sources of mortality are minimized (Post et al., 2003; Hagen and Decker, 2011; Pollard et al., 2015). The rarity and large-size of mature bull trout may have the potential to result in a depensatory cycle of increasingly memorable fish being subjected to increased rates of prolonged handling, due to photographing and measuring them, thereby compounding the effects of mortality.

Our objective in this study was to measure handling time, air exposure, and associated post-release mortality of memorable-sized bull trout subjected to two angling treatments; prolonged handling (photograph-measure-photograph-then release), and immediate release. This study was conducted at a remote unnamed mountain lake (1905 m ASL), on the southern boundary of the Willmore Wilderness Park in the Rocky Mountains of west-central Alberta, during mid-summer, and under relatively typical angling conditions. The lake was naturally fishless, with an 8 m vertical drop waterfall downstream preventing native bull trout from colonizing the lake. Bull trout caught during the study were transplanted into the lake in 1987 and this transplanted status makes them an appropriate population for this kind of potentially lethal experiment. The findings are used to inform potential scenarios of C&R-related mortality for recovery planning of bull trout in Alberta.

2. Methods

Our methodology was designed to mimic the potential actions of casual anglers who may catch a memorable bull trout and be excited about catching 'the trout of the summer'. Our protocol was for the angler's companion to take two photographs of the angler holding the fish, then the angler would measure the length of the fish, and then the angler would take two more photographs of the companion holding the fish (i.e., two photographs, length measurement, two more photographs). This protocol was influenced by field and media observations of anglers, and aimed to mimic how a typical angler may react to the very unusual event of catching a memorable-sized bull trout. The intent was not to emulate handling by a highly experienced angler who might have developed the skills and knowledge to minimize air exposure (e.g., https://www.keepemwet.org/).

Our team of four anglers used spin casting and fly fishing techniques. The minimum line strength was 5 kg. We used only single barbless hooks (or barbs pinched) with a maximum hook length of 50 mm and maximum hook gape of 20 mm. Terminal tackle consisted of streamer flies, or weighted jigs with artificial soft baits (curly tail grubs). As it has been found that landing nets cause an insignificant increase in time for anglers to release fish (Roth et al., 2018), they were not used in this study. No attempt was made to prolong the fight time of any fish; all fish were landed as quickly as possible to minimise exercise stress.

The study was conducted over 4 days, during 24–27, July 2018. The photo-release treatment was conducted on Day 1, with fish held in a net pen for 24 h, and released on Day 2. The control (immediate release) treatment was conducted on Day 2, with fish held in the same net pen for 24 h and released on Day 3. Research was conducted in late July to ensure that water temperatures were typical of mid-summer conditions (i.e., the most popular season for angling in bull trout waters in Alberta; Spiegl and Hurkett, 2005).

2.1. Photo-release treatment

The procedure for the photo-release treatment population was as follows: fishing in pairs, the companion angler would start a stopwatch once a hooked fish was landed (i.e. removed from the water). The angler holding the fish would then ask their companion to take two smartphone photographs while they supported the fish horizontally with both hands (i.e., no gill holds). The angler would then lay the fish on green vegetated ground (not silt or gravel) and quickly measure the fish with a tape measure (fork length to nearest mm). The companion angler then picked up the fish and was photographed twice by the angler, resulting in a handling protocol of four photographs and one measurement, in total.

The photographed and measured fish was then released (and stopwatch stopped) into a net pen in the lake made from soft nylon netting. All angling occurred within 100 m of the net pen. Fish that were not caught adjacent to the pen were released (and stopwatch stopped) into an inflatable raft that was filled with enough freshwater to completely cover the fish, and immediately transported to the pen. Maximum transport time was approximately 30 s. All fish caught in the treatment population had their adipose fin clipped to prevent subsequent observations as part of the control population (fin clipping occurred during length measurements).

The net pen for both the treatment and control was a rectangle approximately 20 m x 2 m large, positioned along the lakeshore. Water depth in the pen was up to 1 m in depth. A large net pen is advantageous to observe recovery as it enables the fish to swim normally during recovery (Milligan et al., 2000). Cover and shade was provided for the fish in the enclosure with several floating mats of willow branches. Water and air temperatures were recorded with four Onset HOBO® Pendent temperature loggers.

2.2. Control treatment

A control group of fish was treated to an ‘immediate release’ protocol that involved the same attempts to minimise fight times but without the handling and air exposure associated with the photo-release and measurement treatment. Angled fish were immediately released into the holding pen, either directly into the pen or into the partially submerged transport raft to the pen (the same pen as photo-release group). Air exposure of these immediately-released fish was negligible and limited to the few seconds of lifting the fish into the pen or transport raft (< 5 s). Hooks were removed while fish were held submerged in water.

2.3. Fish health assessment

All fish were observed after 24 h in the holding pen. The two sample groups were observed independently (i.e. photo release treatment (July 24^{th} to 25^{th}) and control (July 25^{th} to 26^{th}). Fish were classified as dead or alive after 24 h in the net pen. Fish that were unable to swim or right themselves were classified as dead. After being assessed as dead or alive after 24 h, all control treatment fish were measured (fork length to nearest mm) prior to being released.

Dead fish were necropsied and sampled for biological information including otoliths, gonadal development and genetic samples via fin clips and scales. Relationship between fork length and mortality, and between fork length and the length of air exposure for photography was analysed by bivariate regression using JMP 13 (SAS Institute Inc.). Proportions of dead vs. live fish were visualized as binomial frequency distributions with 10,000 simulations (Haddon, 2011) and compared using Chi-square statistics in JMP 13 software (SAS Institute Inc.). All fish handling followed Alberta’s Ethical Use of Fishes protocols (AESRD, 2013).

3. Results

In total, 50 mature bull trout were angled, 30 in the photo-release group (treatment) and 20 in the immediate release group (control). All angled bull trout were ‘Preferred’ or ‘Memorable size’ (larger than 50 cm, Gabelhouse, 1984). The unusual large size of these fish was particularly notable when compared to bull trout sampled via backpack electrofishing in the Oldman River (Blackburn, 2008a, b), a popular and accessible bull trout sport fishery in Alberta (Fig. 1).

The average air-exposure time for bull trout from the photo-release group was 112 s (SD = 20.1 s, (Fig. 2) range = 75 − 162 s, Fig. 3). Within the ranges of large sizes of these bull trout, there was no significant relationship between fork length and air-exposure time ($p = 0.56$, $r2 = 0.014$, Fig. 4). Because photo-release fish were not individually marked, we were unable to determine whether survival of individuals was related to specific air exposure times. All anglers found that handling these large fish was difficult. Most photographs showed mud and debris on the fish, evidence that the fish had been either dropped, or had struggled on the shoreline prior to being photographed. Obtaining two satisfactory photographs was also difficult, as fish moved or anglers shifted position.

Of the 30 fish in the photo-release group, 10 (33 %) were dead within 24 h. Of the 20 fish in the immediate release group, 3 (15 %) were dead within 24 h. These proportions were not statistically different (Table 1. Chi-square = 2.206, $df = 1$, $p = 0.14$). Two additional fish from the photo-release group were observed for more than 4 h near the pen, resting, immobile but upright on the lakebed. They were maintaining equilibrium but appeared weak and moribund, but were not be classified as dead at the 24 h mark based on our standards. They would be vulnerable to predation by Bald Eagles that were observed frequenting this lake during this study. Post-release predation is a concern in other fisheries (Raby et al., 2014). Adding these two fish to the “dead” group increases the observed photo-release mortality to 40 % (Chi-square = 3.571, $df = 1$, $p = 0.059$). The “dead” fish generally died quickly after being placed in the pen; showing inability to swim upright, or no body movement and very slow gill movements. At least two fish appeared to die during initial handling.

Water temperatures at the pen location for the sampling period of 24^{th} to 27^{th} July 2018 averaged 13.7 °C for the two temperature loggers (± 0.9 °C SD, range 12.6–15.8 °C). Air temperature adjacent to the enclosure averaged 10.0 °C (± 5.7 °C SD, range 2.1–21.9 °C). Diurnal shifts in both air and water temperatures were similar among all days sampled. These temperatures are typical for Alberta bull trout habitat during mid-summer (Post and Johnson, 2002), and within the thermal preferences of bull trout (Jones et al., 2014).

4. Discussion

The novelty of this study is that large salmonids can suffer moderately high catch-and-release (C&R) related mortality (15%–33% or higher based on our findings), and prolonged handling caused by handling and photography of these memorable fish could result in increased mortality. If the rarity of fish (size or species) increase the chance of a memorable fish being photographed it will increase handling time and likely air exposure, potentially perpetuating or accelerating a depensatory cycle of fisheries declines. This potential depensatory response of increasing C&R mortality with declining fishery status could produce a run-away cycle of collapsing fisheries in spite of stringent regulations. Popularizing fishes memorable status, through photographs and magazine articles, risks feeding this depensatory cycle of loss.

As a fishery declines, the population-level importance of each fish and especially each large memorable-sized fish increases (Berkeley et al., 2004b; Birkeland and Dayton, 2005; Frances et al., 2007). Bull trout are a late maturing species that typically spawns in low productivity streams in the fall, and produces comparatively few eggs. Larger specimens are more likely to spawn, and Thorley and Andrusak (2017) found the probability of spawning for bull trout increased from 0.4 for a 500 mm fish, to 0.94 for an 800 mm specimen. Given this low fecundity, larger fish are valuable for recovering populations (Post et al., 2003). Cryptic mortality on these large fish is consequently of disproportionate importance.

The cumulative cryptic mortality associated with C&R fisheries may be calculated as the product of three types of mortality; immediate release, prolonged handling, and illegal harvest. The cumulative effect of these three sources of C&R-related cryptic mortality is not intuitive. Consider a theoretical catch-and-release fishery with 1000 anglers catching 1000 fish. Assume that most anglers (e.g., 80 %) immediately release fish with very low mortality (e.g., 2 %), causing deaths of 16 fish. A minor proportion of anglers catch memorable fish (perhaps of a large size or a rare species), and delay the fishes’ release for photos, e.g., 18 % of anglers, and observe 33 % incidental C&R mortality, causing the deaths of 59 fish. Illegal harvest (including unintentional harvest) might be extremely rare, e.g., 2 % of anglers, but with 100 % mortality, causes the deaths of 20 fish. The overall C&R-related cryptic mortality is therefore not the 2 % that the majority of anglers would experience as immediate release, but 9.5 % (i.e., 95 fish out of 1000). This cumulative effect is over 4x higher than the vast majority of anglers may experience as immediate release. In this theoretical example, the largest proportion

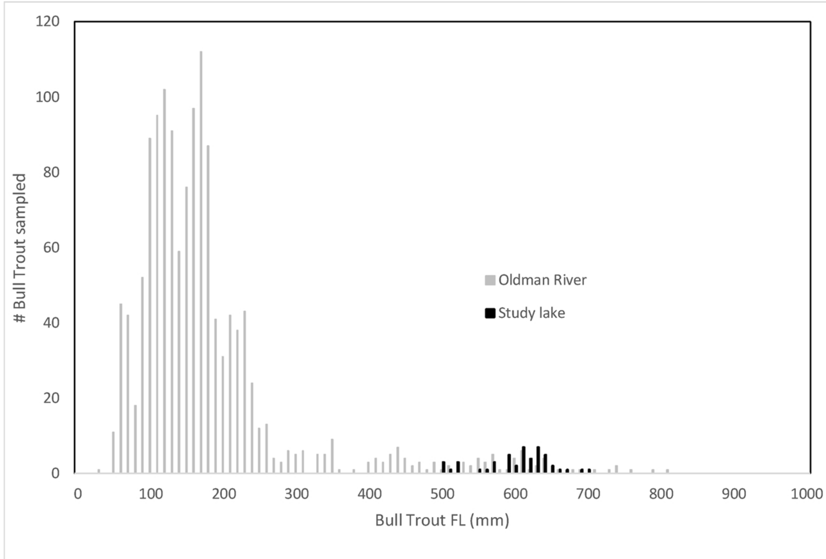

Fig. 1. Fork length frequency distribution of bull trout, showing large size of fish used in this study compared to the sizes of bull trout sampled by electrofishing at a popular catch-and-release fishery on the Oldman River, Alberta (Blackburn, 2008a, b).

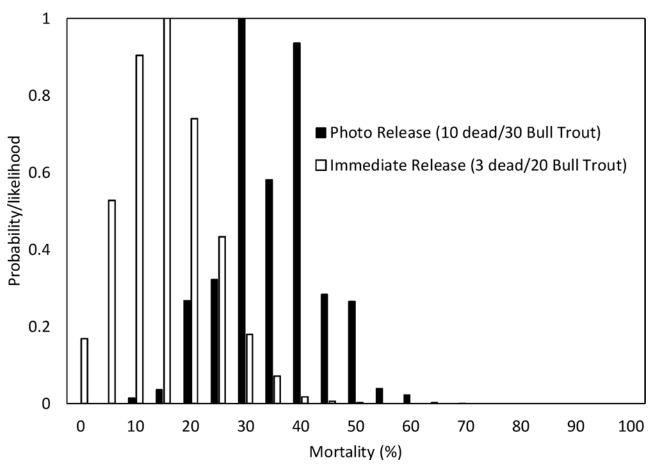

Fig. 2. Probability/likelihood distributions of mortality rates of angled bull trout after 24 h in net pens, from an unnamed Albertan Lake, 2018. Photo-released group was subjected to photograph-measurement-photograph, while the immediate release group was immediately released into net pens. All bull trout were of preferred/memorable size (> 500 mm FL). Distributions are neither smooth nor symmetrical as binomial simulations use specific bin sizes.

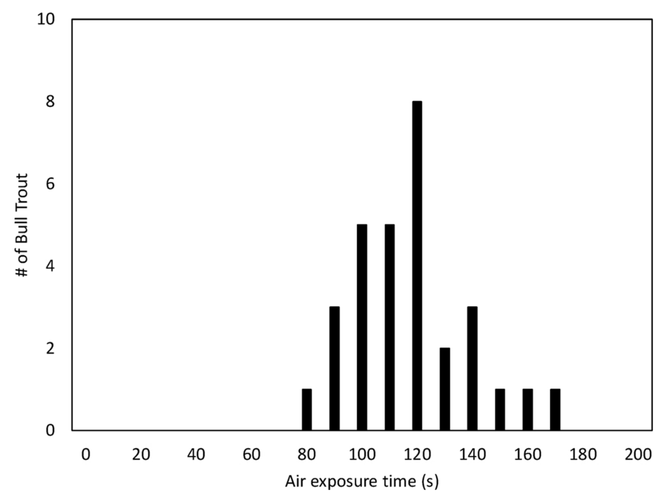

Fig. 3. Air exposure times of bull trout subjected to photograph - measurement-photograph prior to release. Average duration of air-exposure in simulated handling of memorable fish was 112 s (range of 75 s to 162 s).

of dead fish (nearly triple the other two) is unexpectedly from the prolonged handling category. To demonstrate the complexity of this relationship, theoretical values of proportions of anglers and mortality from the three sources of cryptic mortality (i.e., immediate release, photo-release, and illegal harvest) are combined and results shown in Fig. 5. Total mortality is considerably higher than most anglers would initially assume, especially (and counter-intuitively) when immediate-release mortality is low. Accurately quantifying each parameter (i.e. proportion of anglers and associated mortality rate in each category) under field conditions and over the seasonal duration of a fishery would, however, be impractical, if not impossible.

The cumulative cryptic mortality in the above-described example is large enough to have significant population-level effects if fish were vulnerable and pressure was high (i.e., if most of the fish were caught at least once). Blackburn (2008a,b) estimated that at a popular Alberta C&R trout fishery, on average, each cutthroat trout (*Oncorhynchus clarkii*) was caught at least twice per season. In his study, over 50 % of large (> 30 cm) cutthroat trout showed hook scarring. At these Alberta streams, modelling suggests that fishing mortality rates in excess of 15 % can lead to declining fisheries (Post et al., 2003 and see Fredenberg, 2014). Therefore, cumulative cryptic mortality of 7 % or higher, with trout caught twice per season, could result in declining fisheries. At Alberta stream fisheries, all three native trout species (bull trout, Athabasca rainbow trout *O. mykiss*, and westslope cutthroat trout *O. clarkii lewisi*) have shown severe declines and are now each listed as species-at-risk. The potential of C&R-related mortality as a factor in this decline is a theoretical possibility and should be investigated in order to confirm its effect.

The complexity and hidden nature of cumulative cryptic C&R-related mortality precludes conclusive field-level studies of each aspect of mortality (i.e. rates of immediate release, prolonged handling, and illegal harvest, in addition to the proportions of anglers associated with each mortality). Instead, manipulating the single potential cumulative effect of cryptic mortality through adaptive management experiments is more likely to provide useful understanding. For example, if the combinations of measured angling effort and approximations of C&R-related mortality suggest a potential population-level effect, the obvious hypothesis test is to significantly reduce angler pressure and observe

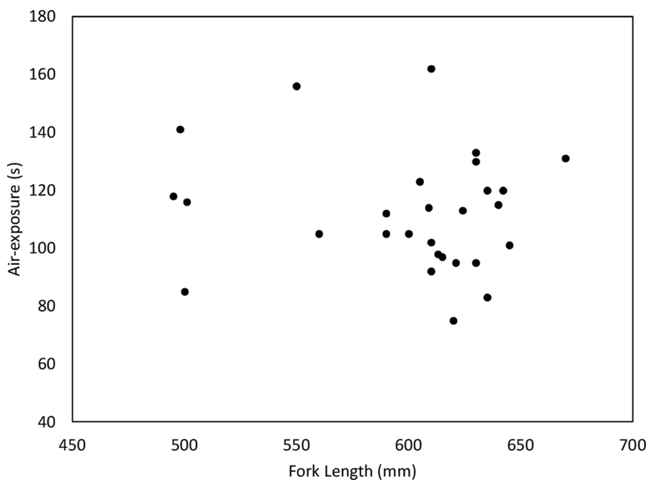

Fig. 4. Fork length and air-exposure of large, angled bull trout subjected to photograph-measurement-photograph prior to release. There was no relationship of fish size to air-exposure duration within the sizes of fish handled ($p = 0.56$, $r^2 = 0.014$).

Table 1
Chi-square contingency table with expected values for each (Chi-square = 2.206, df = 1, p = 0.14). Assuming no mortality for either treatment or control groups makes statistical significance compared to observed results. Assume no mortality (0:20) in quick release chi = 11.8, DF = 1, $p < .0006$. assume no mortality in photo release sample (0:30) chi = 5.7, DF = 1, $P < 0.01$.

Observed	Survive	Mortality
Control (Immediate Release)	17 (expected 14.8)	3 (expected 5.2)
Treatment (Photo Release)	20 (expected 22.2)	10 (expected 7.8)

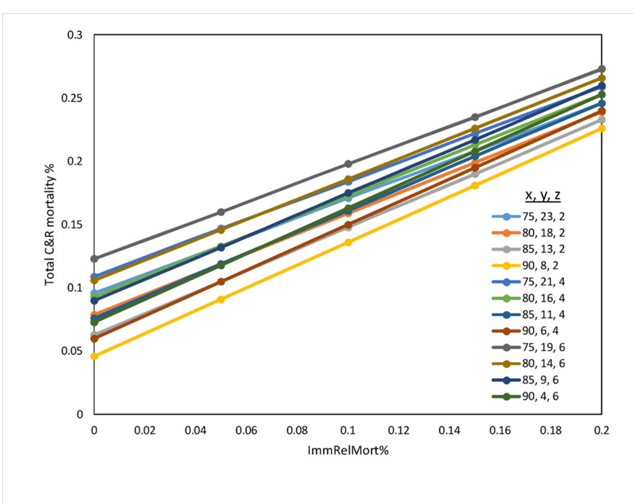

Fig. 5. Cumulative mortality resulting from combinations of immediate release mortality, photo-release mortality, and illegal harvest. Legend is X, Y, Z, where, X = proportion of fish caught immediately released, Y = proportion of fish caught photo-released, Z = proportion of fish caught illegally harvested. Immediate release mortality = 0%–20%. Photograph-release mortality = 33 % in all simulations. Illegal harvest mortality = 100 %. Proportion of immediate-release fish varied from 75 % to 90 %. Proportion of illegally harvest fish varied from 2 % to 6 %. Proportion of photo-released fish varied from 4 % to 23 %.

population-level responses. Regulations such as access-restrictions (e.g., foot-access only, limited entry fishing licences), season timing (e.g., closures during warm and low water summer months), or sanctuary zones may reduce effort while maintaining important fishing opportunities. Observations of population-level effects may be as simple as an increase in size (or age) of fish, or as complex as monitoring changes in recruitment, survival, and abundance. Adaptive management experiments of this scope are, however, socially and politically difficult to implement and may be subject to strong opposition (Schneider, 2019), requiring effective communications and stakeholder involvement.

Our findings of catch and release mortality on large bull trout are relatively high (i.e., control 15 % and photo treatment 33 %), compared to recent work on post-release angling mortality for bull trout (7 %; Thorley and Andrusak, 2017), but are within the ranges of salmonid C& R (Bartholomew and Bohnsack, 2005). While a range of C&R mortality estimates are observed in the literature (median 11 %, mean 18 %, range 0–95%, n = 274 studies, Bartholomew and Bohnsack, 2005), the values produced here plot close to the mean observed across a range of species and treatments (Bartholomew and Bohnsack, 2005). When considering the stress induced through both capture and air exposure (mean 111.9 s) these treatments were similar to those used a laboratory study on rainbow trout (chased to exhaustion and 60 s air exposure, 72 % mortality, Ferguson and Tufts, 1992), yet mortality values were lower likely linked to differences in study design (i.e., duration of exhaustion prior to air exposure). Regardless, these values are well within the spectrum of values observed in the field and laboratory for salmonids. Based on the values observed in the current study, mortality rates were greater than the values used in bull trout model simulations (≤ 10 %, Post et al., 2003 and < 7.5 % Fredenberg, 2014), suggesting the negative effects from C&R angling could be larger than those estimated in these studies. We believe that the results presented here are important for sustainable bull trout management and C&R guidelines, as different taxa present different responses to air exposure, and salmonids have been shown among the most sensitive to hypoxic stress (Doudoroff and Shumway, 1970).

Temperature can be an important factor in post-release mortality (Boyd et al., 2010; Gale et al., 2013). The summer-season water temperatures measured during this experiment are within normal ranges for adult bull trout presence across their range (McPhail and Baxter, 1996). The temperatures reported here were close to the upper end that favour bull trout occurrence (14-16^{0}C daily average max, Dunham et al., 2003) but are reflective of other systems in Alberta where bull trout are angled. For example, the Athabasca River near Jasper Alberta – within bull trout range – regularly sees summer water temperatures peak near 15^{0}C (Fiera, 2013). MacPherson et al. (2019) derived mean August water temperatures for Racehorse Creek (Oldman River watershed) that are in the 12-14^{0}C range, where bull trout are present and angling for them is popular.

Another interesting facet of this study is that the photograph treatment may have resulted in heightened mortality rates. While all fish were photographed in the photo treatment of this study, it may be argued that only the minority of angling events are photographed and that marginal time increases for fish photography are not that large. Lamansky and Meyer (2016) found 4.6 % of their field observed anglers (n = 280) took photographs which increased air exposure time by approximately 18–20 s on top of the average total exposure time of 29.4 s. In addition, Lamansky and Meyer (2016) found that larger fish (36.0 s) were exposed to air longer than small fish (22.5 s), indicating that our reported processing time in the photo treatment is higher but not unrealistic (56.0 s vs. 111.9 s). Similarly, Roth et al. (2018) report 7.4 % of their field observed angler sample (n = 312) took photographs which increased air exposure time by an additional 16 s on top of an average total air exposure time of 19.3 s (SD = 15.0, range 0–91.8 s). It is important to consider that Roth et al. (2018) and Lamansky and Meyer (2016) were observing a range of species and sizes of fish being caught, thus many medium to small size and non-target fish were likely released more quickly and without a picture. In the present study, all 30 fish photographed would be considered ‘large’ based on Lamansky and Meyer (2016) criteria, increasing both handling time and the likelihood of photography based on their observations. We hypothesize that a bull trout of the sizes that were observed here adds a rarity or novelty factor for many casual anglers, which would lead to them being more likely to be photographed by the anglers and their companions. Moreover, we also discovered that to measure and photograph a fish may take substantially longer for many anglers handling larger trout than was anticipated. This is noteworthy, considering that Twardek et al. (2018) recommend that steelhead (*Onchorynchus mykiss*) anglers should limit to air exposure to less than 10 s as they found air exposure of 10 s or more had significant effect on slowing the righting reflex of steelhead and resulted in greater downstream fallback post-release.

If bull trout do regularly suffer from high rates of mortality from photo releases like those reported here, then improving practices around releasing this species at risk should be a priority for fishery managers looking to recover suppressed populations that have not met recovery targets, perhaps with species-specific regulations (Cooke and Suski, 2005). This raises an interesting challenge in how to manage and recover bull trout within the current C&R regulations. If C&R is to be used as a conservation management strategy then incidental mortality needs redress, or at least more management consideration. While factors like accidental mortality from deep hooking is challenging to prevent without a reduction in overall angler effort on bull trout, changes to angler behavior and awareness of air exposure time and handling stress from C&R may be the next best approach. One option for C&R best practices is via regulated protocols (Arlinghaus and Cooke, 2009). For example, Washington State has made it "…unlawful to totally remove salmon, Steelhead, or Dolly Varden / Bull Trout from the water if it is unlawful to retain those fish, or if the angler subsequently releases the salmon, Steelhead, Dolly Varden / Bull Trout." (Washington Department of Fish and Wildlife, 2017).

However, it is unclear how effective detailed C&R handling regulations concerning air exposure thresholds and in-field angler conduct are, or what the levels of intentional or accidental non-compliance are. Fish handling regulations may be too coarse of an approach to detail specific in-field protocols to reduce air-exposure, or to outline specific handling procedures that address the myriad of angling contexts and species. Other regulatory options may include managed angler effort such as timing restrictions, limited access opportunities or location specific licencing, moratoriums on targeting bull trout in sanctuaries, prohibiting the inclusion of the species in awards or contests, etc. These may prove to be effective, but could be politically challenging for fisheries managers. Stronger education might offer a solution, for example, a mandatory angler education course to highlight the nature of cumulative effects of C&R variables, and how these are multiplied according to angler effort.

Another way to improve best practices may be to institutionalise voluntary conservation ethics that transcend the basic regulatory requirements on C&R (Fobert et al., 2009; Cooke et al., 2013). For example, in the 2019/2020 Alberta Fishing Regulations, anglers are encouraged to avoid targeting fish species-at-risk such as bull trout and native westslope cutthroat trout, and to voluntarily reduce their efficiency, i.e., "Practice this proven method to drop your release mortality by half; catch half as many fish." (Sullivan, 2019). Appeals to normative behavior or 'doing the right thing', accompanied by informal sanctioning systems (e.g., angling community appeals to appropriate behavior, and anglers confronting those who don't use best handling practices), can be powerful social institutions. Normative appeals have demonstrated their effectiveness among users of shared resources across various resources types and contexts (Ostrom et al., 1994; Platteau, 2008; Agrawal, 2001; Swim, 2013). Public access fisheries are good examples of shared resources yet there is little to no research on how collective action around best practices for fish handling (or other voluntary fish conservation practices) has or can be developed to reduce unintended C&R mortality. How does the desire and ability to photograph and share pictures of trophy fish by well-meaning anglers ultimately influence C&R handling practices, air exposure and subsequent mortality of fish like Bull Trout? This remains an under-investigated phenomenon in the human dimensions of fisheries management.

Chapman et al. (2018) identify that research into the social factors that underlie a collective willingness for interpersonal sanctioning, or the institutionalising of C&R best practice among recreational anglers, is an obvious gap in human dimensions research. As work on stress response and physiology of C&R expands for different taxa and in different contexts, there needs to be a concurrent focus on how the angling community can adopt and enforce more comprehensive and nuanced best practices beyond the overarching regulatory requirements for C&R. For example, there might be an increased availability in the information on how to release fish effectively but we likely do not understand the behavioral, psychological or attitudinal factors of how this may be mediated by the availability and rapid changes for photo sharing technology and other online community platforms. Evidence suggests that many of these 'informal' social institutions that drive shared rules and sanctioning systems are not explicit, but evolve through ongoing negotiations and adapt to context, rather than conforming to broad regulations or other statutory rules (Joubert and Summers, 2018; Nolan, 2013; Cleaver, 2002). Communal norms may be useful in not only normalizing improved C&R but also in 'shaming' anglers who share photos of large fish or who purposely target at-risk-species but it is unclear, without further investigation, if this is achievable or how voluntary compliance to social norms will manifest in practice.

There remains a need to expand the scientific literature on physiological responses of species under different angling C&R angling scenarios. However, we recommend that more attention needs to be given to social-institutional factors and alternative regulatory considerations that guide anglers C&R behaviours if species management and recovery are to be effective under regulatory regimes that aim to conserve fisheries and provide angling opportunities.

5. Conclusion

While C&R regulations provide excellent options to reduce mortality without necessarily limiting angling opportunities, we show that incidental C&R mortality is present in mature bull trout when observed under experimental conditions following two C&R fish handing practices. We also show that additional air exposure through additional fish handling, measuring, and photographing potentially increases incidental C&R mortality. We further suggest that a depensatory cycle of increasing rarity, resulting in increased handling and subsequent increased mortality may have population-level consequences at high-effort fisheries. Understanding the magnitude of this potential cycle requires adaptive management studies conducted at the scale of manipulating fish populations and angling fisheries.

We argue that beyond the contributions to the literature on physiological responses to certain C&R handling variables for this species, we need to better understand the social-psychological aspects of fish photography (and other C&R practices) to better facilitate the development of C&R regulations and best practices amongst anglers. Human motivations are critical factors in effective resource management (Sullivan, 2003) and the production of scientific evidence for varying levels of physiological responses to C&R variables needs to complement with the understanding of the human dimensions complexities before it is applied as regulations. Increasingly, scientific uncertainty and mixed research results have been used to cast doubt on wildlife management actions and regulations (Boan et al., 2018). The variability within air exposure as a stress or mortality covariate for other C&R handling variables can be argued as an example of how good science is used to cast doubt on the observed impacts of C&R practices, such as photographing fish. Regulating via statutory mechanisms the details and/or thresholds of fish photography or C&R handling practices is one approach. Institutionalizing best practices within a community of anglers who sanction each other and negotiate their norms of conduct might be an additional longer-term option if angling opportunities and population recovery are to be sustained.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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