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Consequences of catch-and-release angling on the physiology, behaviour and survival of wild steelhead *Oncorhynchus mykiss* in the Bulkley River, British Columbia

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ABSTRACT

Steelhead, the anadromous form of rainbow trout (*Oncorhynchus mykiss*), is one of the most coveted recreationally targeted salmonids worldwide, and catch-and-release (C&R) is commonly used as a conservation strategy to protect wild stocks. Nevertheless, little research has examined how wild steelhead respond to capture and handling. During a summer-run recreational fishery on the Bulkley River in British Columbia, we used non-lethal blood sampling and radio telemetry to assess the physiological stress response, post-release behaviour, and survival of wild steelhead exposed to either 0 s, 10 s, or 30 s of air exposure, over a range of water temperatures, fight times, and landing methods. Steelhead that were air exposed following landing had greater reflex impairment and moved further downstream immediately following release than fish kept in the water, though there was no observed difference in movement two weeks after capture. Overall, angled fish had significantly greater blood lactate levels than baseline levels (obtained from a subsample of fish dip netted from the river) suggesting a general stress response to angling and handling. Regardless of air exposure treatment, water temperature was positively associated with blood lactate and negatively associated with blood pH. Other variables such as fish body size (mm) and fight time (s) had little influence on any of the physiological or behavioural variables. Estimated 3-day survival of steelhead was 95.5%, with deep-hooking as the primary source of mortality. Overwinter mortality of caught-and-released fish was estimated at 10.5%, with an estimated total pre-spawn mortality of 15.0%. This study is the first to evaluate the factors that influence C&R outcomes in wild steelhead in a recreational fishery. Findings suggest that steelhead anglers should limit air exposure to less than 10 s, and that anglers should be cautious (minimize handling and air exposure) when water temperatures are warmer.

1. Introduction

Oncorhynchus mykiss are an iteroparous fish species that maintain populations with a range of life-history strategies (Moore et al., 2014). These life-history strategies are typically described in terms of the freshwater resident forms (rainbow trout) and the anadromous forms (steelhead). Unlike other iteroparous salmonids with anadromy (e.g. Atlantic salmon; *Salmo salar*), steelhead over-winter in freshwater and spawn in tributaries during the spring, prior to emigrating back to the ocean as kelts (Quinn, 2005). Their spawning migrations often span hundreds of kilometres resulting in considerable energy expenditure (94% loss in lipid content of white muscle tissue; Penney and Moffitt, 2014). This severe energy depletion coupled with down-regulation of feeding hormones during their reproductive cycle may make steelhead particularly susceptible to anthropogenic stressors that result in additional energetic costs (Fenkes et al., 2016). Previous research has highlighted the negative influences of warm water temperatures (Wade et al., 2013), habitat degradation (National Research Center (NRC, 1996), water pollution (Suttle et al., 2004) and fisheries interactions (Andrews and McSheffrey, 1976; Stewart and Lewynsky, 1988) on steelhead populations. Given the multifaceted stressors steelhead face during their upstream migration, Kendall et al. (2015) suggested the need to further evaluate the role of anthropogenic impacts (including fisheries) on steelhead.

Capture by fisheries can be one of the most severe acute stressors imposed on fish throughout their lives (Davis, 2002). Previous work

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investigating commercial net fisheries for salmon has shown significant by-catch mortality of wild steelhead following discard (Thomas and Associates LTD., 2010). Discard may also occur in recreational fisheries (typically termed catch-and-release; herein, C&R) either voluntarily or to comply with regulations (Arlinghaus et al., 2007). Comparatively little is known about recreational fisheries discard mortality (Cooke and Suski, 2005), and even less is known about the impacts of recreational angling practices on steelhead physiology, behaviour, and survival (but see Nelson et al., 2005 for the general effects of angling). Given the widespread decline and conservation status of wild steelhead populations (Gayeski et al., 2011; Good et al., 2005; Smith et al., 2000), recreational fisheries for steelhead have been established as primarily C&R in hopes of conserving wild populations. The efficacy of C&R as a conservation tool, however, is contingent on released fish surviving and incurring negligible fitness consequences (Cooke and Schramm, 2007; Wydoski, 1977).

Fish may be subject to considerable stress and even mortality during a capture event, and this may be related to environmental variables, intrinsic biotic factors (fish condition, disease presence, size, age, sex), and angler behaviour (gear choice, fight time, and air exposure; reviewed by Cooke and Suski, 2005). Prolonged fight times, air exposure, and hooking injury can lead to blood acidosis, hypercapnia, and injury, respectively (Ferguson and Tufts, 1992; Meka, 2004; Wood et al., 1983). Previous work has suggested general guidelines for anglers to adhere to including the minimization of fight times, air exposures, and proper gear choice (Brownscombe et al., 2017). Although generalities can be made, differences exist in species morphology, life-history, and surrounding environments creating the need for species- and context-specific evaluations (Cooke and Suski, 2005). Salmonid species are considered some of the most valuable and coveted species to recreational anglers, and have been subject to numerous studies assessing the extent of sublethal consequences and mortality following recreational fisheries encounters (Boyd et al., 2010; Gjernes et al., 1993; Lennox et al., 2015; Pope et al., 2007; Schreer et al., 2005). Albeit, even amongst salmonids the response to fisheries capture is consistently context- and fishery-specific (Patterson et al., 2017; Raby et al., 2015). As anglers have a considerable role on the outcome of an angling event (Cooke et al., 2017), it is relevant for recreational fisheries to have scientifically based best practices for anglers to follow to minimize harm on released fish. Despite the popularity of steelhead as a recreational fish species (Kelch et al., 2006), little to no research has evaluated the response of wild steelhead to various C&R angling practices. An exception is a study on the Chilliwack River of British Columbia which investigated the movement and survival of winter-run steelhead following catch-and-release, but focused primarily on the differences between fish of hatchery and wild origin (Nelson et al., 2005).

The objectives of this study were to evaluate the sub-lethal impacts and survival of wild steelhead following C&R angling. Steelhead were assessed for the presence of the righting reflex (an effective and non-invasive proxy for stress and mortality following fisheries interactions; Danylchuk et al., 2007b; Davis, 2010) and for physiological indicators, specifically glucose, lactate, and pH (Barton et al., 1998). A separate group of steelhead was monitored for immediate post-release movement, long-term migration rate, and mortality. It was anticipated that air exposure would impair reflexes, increase physiological alterations, and promote downstream post-release movement of angled wild steelhead. Findings from this research will help refine management strategies and identify best handling practices for wild steelhead.

2. Methods

2.1. Study site and collection methods

Steelhead were sampled from the Bulkley River, British Columbia from September 17th to November 7th, 2016. The Bulkley River is located ~250 km inland, stretching an additional 141 km to the Bulkley-Morice confluence (Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD), 2013). The Bulkley River watershed drains an area of approximately 12,000 km^2, making it the largest tributary of the Skeena River. The river is considered relatively pristine with no manmade barriers (i.e. dams) to fish migration. As a result, the river has maintained an entirely wild summer-run steelhead population averaging 21,520 (9735 to 41,428) individuals from 1999 to 2016 (Witset [formerly Witset] Mark-Recapture, 2017) and contributes greatly to the world-renowned Skeena recreational fisheries that are estimated to be worth nearly $53 million CAD annually (Counterpoint Consulting, 2008). Recreational anglers can access the river by jet boats, pontoon boats, or walk-in sites and are permitted to use both fly fishing and spin-cast equipment. Starting in 1991, the mandatory C&R of wild steelhead has become part of the B.C. FLNRORD's fishing regulations for the entire Skeena Watershed; the rule was expanded to all of British Columbia in 1997.

Steelhead were captured by approximately 30 different recreational anglers using fly fishing (spey rods, flies size #8+), spin-cast fishing (various sizes of inline spinners and artificial worms), and by centre pin (a free spooling reel, various sizes of inline spinners and artificial worms) while wading from shore. Anglers represented all levels of experience, from first time steelhead anglers to anglers that fish every day for the entire steelhead season. Most fish were captured by experienced steelhead anglers, which is representative of the general angling public of the Bulkley River. All fish were captured upstream of Witset Falls from rkm 314 to 407 (Fig. 1), using single barbless hooks as per the recreational fishing guidelines in the Skeena region (FLNRORD, 2017). Fish were landed with the assistance of another angler, who either netted the fish using a rubber or nylon landing net or grabbed the caudal peduncle of the fish (tail-grab). These conditions allowed anglers to unhook steelhead without lifting them out of the water at any point. Steelhead were selected through random stratification to be measured for blood physiology parameters, or radio-tagged following capture, thus creating two separate groups from here on referred to as the 'physiology' group and the 'movement' group, respectively.

2.2. Quantification of the angling event

For each capture event, the fight duration (s), anatomical hooking location, hook removal difficulty, water temperature (°C), fork length (cm), and sex were recorded. The fight duration was considered the time from hooking to landing by either tail-grab or landing net. Hook removal difficulty was determined by a 1–5 ordinal ranking system that reflected the effort needed by the angler or guide to remove the hook from the fish. A score of '1' indicated the hook was removed with no effort (hook fell out once the fish was landed), while a score of '5' indicated that substantial effort was needed to remove the hook (pliers were required to remove the hook). Water temperatures at the time of capture were taken using a handheld digital thermometer (Taylor Precision Digital Thermometer, #9847, Taylor USA, Oak Brook, IL, USA). Water temperature throughout the season was taken using a data logger (HOBO Water Level Data Logger, #U20L-01, Bourne, MA, USA) that recorded every 15 min. Discharge rates were taken from the Bulkley River at Smithers using Environment and Climate Change Canada's Real Time Hydrometric Data search engine.

2.3. Reflex test

A righting reflex test (equilibrium) was used as an indication of reflex ability after angling and air exposure. To assess the righting reflex, fish were flipped ventral side up and monitored for their ability to return to normal orientation within 3 s (outlined in Raby et al., 2012). To minimize handling of captured steelhead, only the righting reflex test was evaluated. This reflex is typically the one that is most "responsive" when salmonids are exhausted (Raby et al., 2012). Reflex tests were completed immediately following capture for fish that would