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Physiological impairment of adult sockeye salmon in fresh water after simulated capture-and-release across a range of temperatures

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ABSTRACT

Sockeye salmon abundance in the Fraser River has declined precipitously over the past two decades, reducing fishing opportunities for this ecologically, culturally and economically valuable species. Release of non-target species that are captured incidentally is a growing conservation measure used in managing mixed species fisheries. Fraser River sockeye salmon are released from commercial, First Nations, and recreational fisheries, however little research exists investigating the fitness and fate of released sockeye salmon, and none examine how the effect of ecologically relevant temperature ranges interact with capture stressors. We exposed adult migrating summer-run sockeye in freshwater to simulated capture and release stressors, including exhaustive exercise and air exposure, at temperatures spanning the range of historic, current and predicted future migration conditions in the Fraser River (13 °C, 19 °C, and 21 °C) to understand the physiological consequences of these stressors acting in synergy. Three minutes of exhaustive exercise significantly raised the plasma lactate, chloride, sodium, and osmolality, and lowered the plasma potassium of these fish, and one minute of air exposure following exercise elevated glucose (females only) and exacerbated high lactate levels. The inability of all air-exposed fish in the warmest temperatures to maintain equilibrium upon return to the water is evidence of the effects of warm temperatures. Fewer than half of the air-exposed fish in the coolest temperature demonstrated this impairment. Further, air exposure resulted in a marked depression of ventilation rates in the warmest temperatures. This is the first experiment investigating the physiological disturbance of capture and release at various temperatures on adult Pacific salmon, and the results suggest a need for better understanding of the potential fitness consequences to improve the management of this important resource.

1. Introduction

Fisheries management agencies frequently impose harvest regulations (e.g. gear selection, bag limits, closed seasons for some species) that require the release of non-target species (i.e., bycatch) in both commercial and recreational fisheries. In the recreational sector, some fish are also released voluntarily due to a conservation ethic among anglers (Arlinghaus et al., 2007). A major assumption involved with capture and release fishing, irrespective of the sector, is that released fish do not have significantly reduced survival or fitness relative to conspecifics that are not exposed to the same stressors (Cooke and Schramm, 2007; Wydoski et al., 1976). Although there are a number of inherent differences between commercial and recreational fisheries, fish are exposed to stress and injury in both sectors, with the potential for mortality during the process. Studies have examined the effects of capture and release on immediate, short-term, and delayed mortality of various species and they have found that the survival of released fish can range from zero to almost 100% (Alverson et al., 1994; Arlinghaus et al., 2007; Bartholomew and Bohnsack, 2005; Cooke and Suski, 2005; Davis, 2002; Muoneke and Childress, 1994). In these examples, survival was dependant upon species, anatomical hooking location, capture depth, hook, bait, gear types, air exposure, life history stage and/or size, and handling. Mortality arising from capture and release is often not incorporated into management models, which can impede the ability of management agencies to develop sustainable fishing practices (Coggins et al., 2007). In addition, considerable research has examined the specific influence of water temperature on post-release survival of fish (Cooke and Suski, 2005; Davis, 2002; Wilkie et al., 1997, e.g. Wilkie

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et al., 1996). Results of this research have been used to develop some general guidelines adopted by management agencies, such as recommending avoiding catch-and-release fishing or reducing air exposure during high temperatures (e.g. Fisheries and Oceans Canada; DFO, 2010a, Atlantic Salmon Federation; ASF, 2010). However, these guidelines often provide vague or even contradictory advice when it comes to catch-and-release best practices (for example with regard to air exposure and resuscitation; Pelletier et al., 2007). It is known that fish have adapted to and depend upon the thermal environment in which they live (Pörtner, 2002), and that temperatures exceeding an optimal range can cause impairment of physiological processes and decreased survival (Brett et al., 1958; Eliason et al., 2011; Elliot, 1981). The degree to which the optimal thermal range may narrow when fish experience capture and thermal stress simultaneously remains to be understood.

In British Columbia, sockeye salmon (*Oncorhynchus nerka*) are the most commercially valuable Pacific salmon species (BCMOE, 2008) and are highly valued by anglers and First Nations (aboriginal) fishers. Owing to an abundant return in 2010, approximately 13 million Fraser River sockeye salmon were caught in commercial seine, troll, and gill-net fisheries, and an additional 1.4 million were caught in First Nations gill-net and seine fisheries (DFO, 2010b). Both sectors fish primarily where sockeye salmon are approaching, and then transitioning to, fresh water from the Pacific Ocean. The recreational fishery for sockeye salmon in the Fraser River is focused mainly in the lower Fraser River and has grown from being almost non-existent a decade ago (between 1984 and 1990, a total of 370 sockeye were caught by anglers) to a catch of 190,000 (2002), 155,000 (2006) and 300,000 (2010) in dominant cycle years (DFO, 2010c). Temporal closures of the sockeye fisheries and catch limits are implemented to protect threatened stocks and ensure adequate escapement to spawning grounds, forcing the periodic release of captured sockeye salmon. For example, anglers released one third of captured sockeye salmon (100,000 fish) in 2010 in the Fraser River, and on average released 21,000 fish per year in the previous four years (DFO, 2010c). There are no direct estimates of how many sockeye salmon escape from different gear types but fail to complete their migration. However, a recent study in Alaska (Baker and Schindler, 2009) and a report on Fraser River sockeye salmon (Clarke et al., 1994) demonstrate up to 50% of spawning adults had characteristic net mark scars on their bodies. The authors also found that Alaskan sockeye salmon with moderate to severe gillnet injuries were far less likely to successfully enter natal streams than non-injured fish (Baker and Schindler, 2009).

A recent review of 83 studies, involving an examination of capture-release and thermal stress (Gale et al., in press), found that the majority detected deleterious physiological and survival consequences of warm temperatures on released fish. However, more than half failed to put the study temperatures into an ecologically or biologically meaningful context. For most species, there exists little or no data on the consequences of capture and release at ecologically relevant high temperatures. This is true for all Pacific salmon species (*Oncorhynchus* spp.), and perhaps most notably for sockeye salmon, which are well-studied in regards to temperature tolerance (Brett, 1971; Cooke et al., 2004; Crossin et al., 2008; Eliason et al., 2011; Farrell et al., 2008) yet there is little known about how temperature affects survival of released sockeye following capture.

Summer water temperatures in the Fraser River have increased by ∼2 °C over the last 60 years (Patterson et al., 2007) with 13 of the past 20 years being the warmest on record. Extremely high levels of migration mortality (>90% in some populations) have been attributed to high temperatures in Fraser River sockeye salmon (Cooke et al., 2004; Farrell et al., 2008; Martins et al., 2011), and are presumed to result from factors including energy exhaustion, collapse of aerobic and cardiac scope, physiological stress, diseases and parasites (Eliason et al., 2011; Farrell et al., 2008; Mathes et al., 2010; Rand and Hinch, 1998). Fisheries gear interactions occur as a stressor overlaid on the inherent migration challenges, and consist of burst swimming behaviour in attempt to escape, injury from gear entanglement/hooking, and often air exposure during handling and release. Given that Fraser River sockeye salmon are experiencing temperatures in freshwater that can affect migration survivorship, and that capture and release (or capture and escape) is frequently occurring, there is a pressing need to examine the how temperature and capture-related stressors may interact to influence the survival and physiological responses of fish, particularly Pacific salmon.

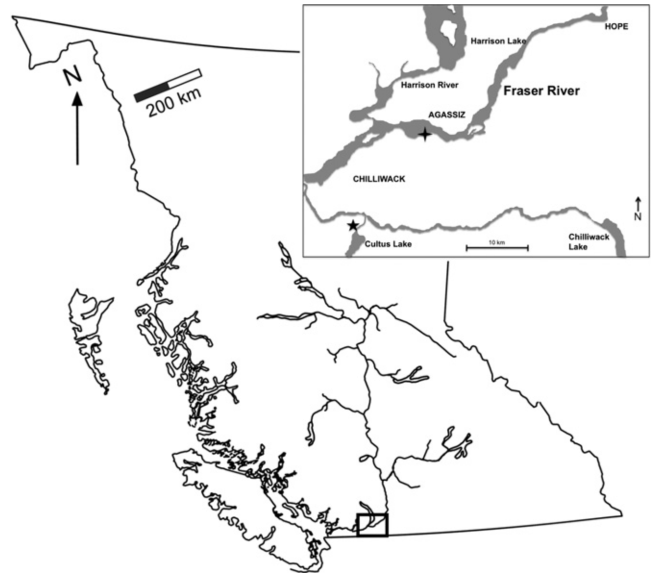

Fig. 1. British Columbia and the Fraser River, which drains almost one-third of the province. Inset is the study area, with the cross marking the fish capture site on the Fraser River in Chilliwack, and the star marking the Cultus Lake Salmon Research Laboratory, where experiments took place.

The objective of this study was to use sockeye salmon to investigate the interactions between temperature and capture-related stressors and their consequences for post-release blood physiology and survival. To that end, Fraser River sockeye were exposed to three different simulated capture-related stressors – no applied capture stressor, simulated capture, or simulated capture including air exposure – under a range of water temperatures. They were then assessed for the magnitude of physiological impairments using plasma metabolite, ion, and hormone concentrations. Water temperatures reflected a natural range that this run has historically encountered, including temperatures both cooler (13 °C) and warmer (19 °C) than the window for maximum aerobic scope (Farrell et al., 2008; Fry, 1971), as well as a high temperature (21 °C) that is approaching the critical thermal limit for this group of fish (Eliason et al., 2011; Farrell et al., 2008). Capture stressors were intended to simulate the flight response and exhaustive exercise, with or without air exposure, that might be experienced by a sockeye salmon caught in a net or on a hook. We hypothesized that the capture stressor coupling exhaustive exercise with air exposure would cause the highest physiological impairments, and that these effects would be most severe at the highest temperature.

2. Methods

2.1. Study site and animals

Capture of study animals took place on August 11–12, 2009 in the main-stem of the Fraser River in Chilliwack, British Columbia (Fig. 1). Fraser River sockeye salmon are managed as four consecutive "run-timing" groups based on the timing of entry to the Fraser River: early Stuart, early summer, summer-run, and late-run.