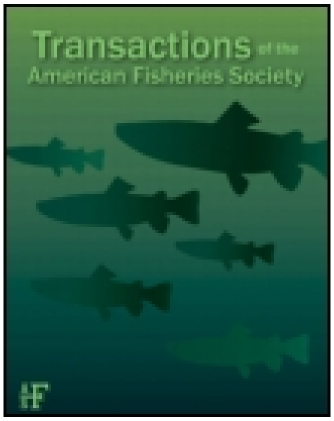

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Influence of Postcapture Ventilation Assistance on Migration Success of Adult Sockeye Salmon following Capture and Release

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ARTICLE

Influence of Postcapture Ventilation Assistance on Migration Success of Adult Sockeye Salmon following Capture and Release

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Abstract

Catch and release is a tactic employed in recreational fisheries to help conserve and sustain fish populations, but postrelease mortality can occur when fish fail to recover from the stress and exhaustion of capture. Depending on factors like the duration of the stressor and whether air exposure occurs, fish can be lethargic or have negative equilibrium upon release; some anglers are motivated to attempt to manually revive fish upon release by assisting with water flow across the gills. Indeed, some management agencies and angling groups recommend different recovery techniques, but very little scientifically defensible evidence exists about the utility of assisted ventilation. We conducted two separate field experiments on Sockeye Salmon *Oncorhynchus nerka* in the lower Fraser River basin in which fish were (1) exposed to a standardized exercise stressor with air exposure or (2) angled by volunteer anglers and air exposed, with a subset of fish in each experiment then being provided with 1 min of assisted ventilation before release with a radio transmitter. Assisted ventilation took the form of simply holding the fish below the water surface, facing into a flow of ~0.5 m/s. Postrelease behavior and migration success were examined in both experiments by radio-tracking fish, using a combination of fixed stations and manual tracking. Our results

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from both experiments provide no support for the utility of this revival technique in benefiting the migration success of Sockeye Salmon exhausted from a capture-and-release event. Future experiments should test the survival and physiological benefits of different revival techniques and durations for fish at different levels of postcapture impairment.

Releasing captured fish back to the wild is a practice commonly employed in recreational fisheries (Arlinghaus et al. 2007). The motivations for releasing fish include conservation ethic, fisher's preference, lack of economic value of the catch, or mandatory release regulation set by fisheries managers (Cowx 2002; Arlinghaus et al. 2007). Mandated live release is used by managers to minimize fishing mortality for a fish population or segment of a population (e.g., all fish of a certain size; Policansky 2002; Cooke and Schramm 2007). However, the success of this conservation and management tactic is contingent on the assumption that the released fish survive and experience negligible fitness effects (Cooke and Schramm 2007) or that the survival rate is known such that it can be incorporated into management models (Coggins et al. 2007). In recreational fisheries in which catch and release occurs, capture can result in delayed mortality of released fish (i.e., mortality that occurs hours or days after fish are released by anglers) and, in some cases, mortality following release can be extremely high (range = 0–95%; mean = 18%; Bartholomew and Bohnsack 2005). Globally, it is estimated that 60% of the total recreational catch is released, representing billions of fish annually (Cooke and Cowx 2004). Clearly, approaches that can reduce delayed mortality in recreational capture and release would contribute to the sustainable management of such fisheries.

The delayed mortality of fish released by anglers ultimately arises from physical injury or the inability of the fish to regain physiological homeostasis (Wood et al. 1983; Chopin and Arimoto 1995; Arlinghaus et al. 2007). The physiological changes that result from capture stressors can partly be described in the context of the exhaustive burst swimming that is provoked in fish during the capture process (Kieffer 2000; Cooke and Suski 2005; Cooke et al. 2013). Burst swimming events are fueled by the anaerobic metabolism of glycogen resulting in the accumulation of metabolites (e.g., lactate and protons) in white muscle and plasma, which will ultimately alter the acid–base status and cause ion-osmoregulatory imbalance (Wood 1991; Kieffer 2000). These metabolic changes are further exacerbated by the air exposure that commonly occurs during landing, hook removal, and photography of the catch (Ferguson and Tufts 1992). The depletion of glycogen reserves and accumulation of lactate during anaerobic breakdown will temporarily inhibit repeat burst swimming (Milligan 1996). Inhibiting the burst swimming capacity in fish can leave them vulnerable to predation (Cooke and Philipp 2004; Danylchuk et al. 2007; Campbell et al. 2010). In fluvial systems, this reduced capacity can cause them to delay or move downstream (Mäkinen et al. 2000; Thorstad et al. 2007) and increase the potential for recapture during reascension. Therefore, should fish recover rapidly from the capture-and-release event, they would have a lower risk of negative capture-related fitness effects.

The resynthesis of energy stores and the removal of anaerobic metabolites occurs during metabolic recovery from a fisheries capture (Wood 1991), and this recovery process requires oxygen uptake that exceeds the basal metabolic rate (termed excess postexercise oxygen consumption; Gaesser and Brooks 1984). Thus, facilitating ventilation and oxygen uptake for a fish following capture would be a potential approach to improve postrelease survival. Indeed, as part of best-practice recommendations, a number of North American natural resource agencies currently advise that anglers use manual recovery techniques prior to release. Examples of these techniques include orienting the fish into a water flow (e.g., in a fluvial system) or moving the fish back and forth in the water (Pelletier et al. 2007), both of which attempt to facilitate the flow of water over gill surfaces. This underlying recovery foundation seems intuitive given that the metabolic changes caused by capture events are rectified using excess oxygen consumption (Wood 1991); however, an adequate evaluation of this manual recovery technique is lacking. Few field studies have evaluated the benefits of commonly used or recommended (Pelletier et al. 2007) postangling revival practices in any fishery (but see Brownscombe et al. 2013; Donaldson et al. 2013), despite it being recognized as a research need for some time (Arlinghaus et al. 2007).

Each fall, the Fraser River (in British Columbia) and its tributaries are home to millions of adult Sockeye Salmon *Oncorhynchus nerka* returning from the ocean for their freshwater migration to natal spawning streams (Hinch et al. 2006). The predictable nature of this life history event and the economic, social, and cultural value that these fish have for British Columbians make them targets for fishers during their approach and upon entry into the Fraser River. In the freshwater phase of the spawning migration, Sockeye Salmon are targeted by a growing number of recreational fishers (Kristianson and Strongitharm 2006; English et al. 2011). Fisheries and Oceans Canada (DFO) manages this growing fishing pressure by implementing harvest restrictions (i.e., no retention mandates or daily catch limits) in an effort to achieve Sockeye Salmon spawning escapement targets or to reduce the fishing pressure on a comigrating Pacific salmon population of concern. In 2011 alone, freshwater recreational anglers released approximately 62,642 of the estimated 145,291 Sockeye Salmon captured (43% released; for data, see DFO 2012a).

Recent studies of Fraser River Sockeye Salmon have shed light onto the delayed mortality associated with recreational fisheries events (Donaldson et al. 2011). Using biotelemetry to evaluate postrelease survival, Donaldson et al. (2011) estimated that catch and release can reduce survival to natal tributaries by approximately 35%. One of the first published examples of facilitating recovery to enhance postrelease survival comes from the marine commercial realm using Fraser River Coho Salmon *Oncorhynchus kisutch* (Farrell et al. 2001). That research paper demonstrated that providing forced ventilation in a specially designed revival box could be used to revive moribund Coho Salmon, promote physiological recovery, and improve 24-h survival. More recently, in the freshwater phase of migration, research has indicated that the postrelease survival of Sockeye Salmon can be enhanced under certain circumstances by facilitating recovery with a flow-through recovery bag (Donaldson et al. 2013). The recovery bag allows for the fish to be oriented into the river current, providing flow of water over the gills, while isolating the fish in a safe, dark environment. A manual recovery technique designed to assist ventilation by physically orienting the fish into a high-flow water source was recently evaluated in a laboratory environment (Robinson et al. 2013). This technique mimicked the methods of facilitating recovery that many recreational anglers use, based on the recommendation of fisheries management agencies (Pelletier et al. 2007); however, the study found no benefit of this technique. In fact, the authors observed a relative increase in delayed mortality for female Sockeye Salmon provided with assisted ventilation, which was partially attributed to the increased sensitivity of females to the stress of long-term laboratory confinement. This manual recovery approach has yet to be tested in the field to determine if assisted ventilation can improve postrelease survival for fish released to resume their migrations.

The purpose of our study was to determine whether postcapture ventilation assistance has any effect on the migration behavior or success of Fraser River Sockeye Salmon released to resume their freshwater spawning migration. To address this objective, two telemetry-based field experiments were conducted. The first experiment, experiment 1, was a field study that sought to examine the utility of assisted ventilation following a controlled capture event. The controlled capture event was designed as an extension of the previously published laboratory study that demonstrated that this approach can cause physiological exhaustion in adult Sockeye Salmon (Robinson et al. 2013). Controlling the capture event but releasing fish into a realistic environment eliminated the potential limitations associated with extending results from laboratory experiments (e.g., captivity effects; Donaldson et al. 2011). The second experiment, experiment 2, examined the utility of assisted ventilation following catch and release by volunteer anglers using standard capture methods. This experiment was designed to test a specific capture event (i.e., angling) within a natural environment. Experiment 1 evaluated migration behavior and successful arrival to natal spawning grounds for two populations in the Harrison River system (a tributary of the Fraser River), whereas experiment 2 evaluated migration behavior and success to reach an upriver radio receiver station located downstream of the natal spawning grounds for several Fraser River Sockeye Salmon populations.

METHODS

Experiment 1: Harrison River

Experimental site and fish capture.—This experiment was conducted using Weaver Creek and Harrison Rapids Sockeye Salmon that were captured during their migration up the Harrison River (British Columbia) to reach natal spawning areas (Figure 1). Weaver Creek Sockeye Salmon spawn in Weaver Creek and a connecting artificial spawning channel. Harrison Rapids Sockeye Salmon spawn in the nearshore gravel lining the Harrison Rapids channel in the middle reaches of the Harrison River (Schaefer et al. 1951). Both populations spawn within 5–10 km of the capture site but spend a substantial period holding in the Harrison River or Harrison Lake before spawning (Donaldson et al. 2012). The peak spawning periods for Weaver Creek and Harrison Rapids Sockeye Salmon are approximately October 20 and November 15, respectively (Gilhousen 1990).

Fish capture and treatment were conducted on the west bank of the Harrison River (Harrison release site in Figure 1) approximately 10 km upstream of the confluence with the Fraser River over 5 d in 2011: August 23 and 29 and September 1, 20, and 21. Fish were captured using a beach seine, with one end anchored on shore and the other end pulled to the center of the river then arced closed with a power boat, forming a circular area of containment. The seine was drawn in from both ends to concentrate fish close enough to shore to allow for dipnetting and removal of fish, while maintaining sufficient water depth to minimize crowding and injury (Donaldson et al. 2011). The average river temperature during the hours of capture and experimental treatments was 15.0°C (range = 13.2–15.9°C), measured using a temperature logger (TidbiT v2; Onset Computer Corporation, Bourne, Massachusetts) deployed across from the capture site by the DFO Environmental Watch Program.

Experimental design.—Sockeye Salmon were assigned to one of three treatment groups: (1) immediate release (25 females [14 Harrison, 11 Weaver] and 18 males [14 Harrison, 4 Weaver]), (2) simulated capture without assisted ventilation (25 females [20 Harrison, 5 Weaver] and 27 males [20 Harrison, 7 Weaver]), and (3) simulated capture with assisted ventilation (24 females [15 Harrison, 9 Weaver]

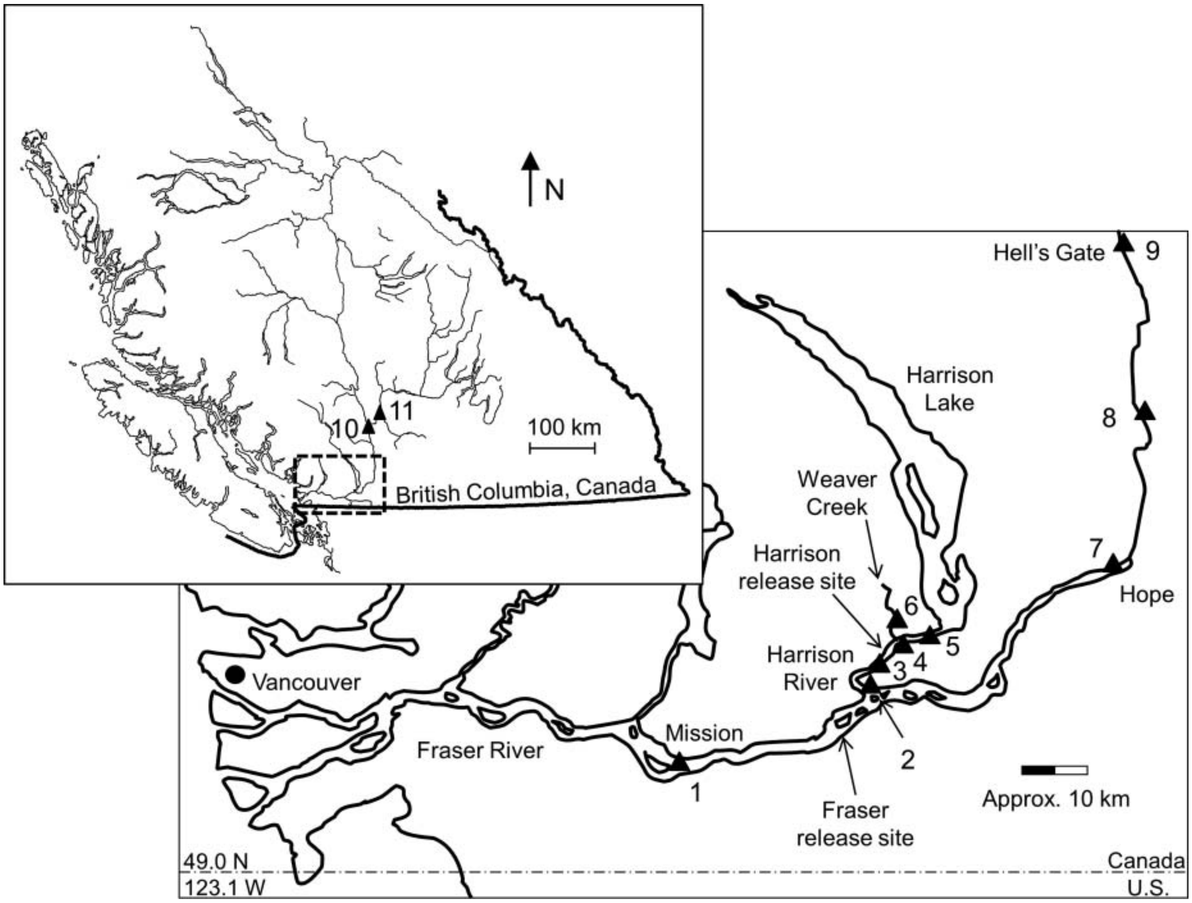

FIGURE 1. Map of the Fraser River system in British Columbia. The enlarged map shows the Harrison River and Fraser River release sites where Sockeye Salmon were captured, treated, and released. The numbered triangles represent the radio receiver stations. The Sockeye Salmon that were tagged in the Fraser River experiment were identified as populations with natal spawning grounds located upstream of the area covered by the receiver array. For the Harrison River experiment, the Weaver Creek Sockeye Salmon spawn upstream (north) of station 6 in Weaver Creek or the Weaver Creek artificial spawning channel and the Harrison Rapids Sockeye Salmon spawn in the Harrison River, typically between stations 3 and 4.

and 26 males [22 Harrison, 4 Weaver]). Fish assigned to immediate release were quickly placed inside a black cylindrical fish holding bag with mesh ends (100 cm long × 20 cm in diameter; see Donaldson et al. 2011) for processing. The immediate release fish were released directly from these bags following the sampling and tagging procedures described below. At the same time, additional fish were dipnetted from the seine and transferred to an in-river holding pen (1.0 m × 2.5 m × 1.0 m deep) with mesh ends providing a constant flow of river water. A maximum of 11 fish were used per seine set to ensure no fish was held in the pen for >45 min. Fish in the net pen were individually dipnetted from the pen and placed in a flow-through, foam-lined, V-shaped trough for sampling and tagging (see the section below) before being transferred to an adjacent circular tank for experimental treatments.

The fisheries capture simulation consisted of 3 min of strenuous exercise and 1 min of air exposure (following Donaldson et al. 2010; Robinson et al. 2013) for two fish at a time. The fish were forced to exercise in a ring-shaped tank (~800 L; 2-m diameter) by three experimenters touching the tail or splashing behind the fish to elicit burst swimming. The fish were then dipnetted from the tank and exposed to 1 min of air in wetted knotless nylon dip nets. There was no imposition of physical injury for this fisheries simulation, though some injury always occurs in recreational angling as a result of hooking. Following air exposure, one of the two fish was released to the river to resume its migration, while the other was provided ventilation assistance. For ventilation assistance, an experimenter held the fish in the river with its mouth oriented into a jet of river water (held ~20 cm from the jet nozzle) supplied by a submersible pump. The flow speed was ~0.50 m/s, as measured at the mouth. The fish was supported with one hand around the caudal peduncle and the other on the ventral surface, just posterior to the pectoral fins. Ventilation was assisted for a maximum of 1 min; if the fish became vigorous and attempted to struggle free, it was released early to minimize additional stress (this occurred seven times).

Although the prior laboratory experiment (Robinson et al. 2013) could not demonstrate a benefit from the same revival technique, the present field-based investigation was warranted given the potential differences between the field and laboratory, particularly for Pacific salmon *Oncorhynchus* spp., who can be severely stressed by confinement during the spawning migration stage (Patterson et al. 2004; Donaldson et al. 2011).

Blood sampling, stock identification, and tagging procedures.—To determine the sex of the study fish via analysis of reproductive hormones, blood samples (~2 mL) were drawn from the fish via caudal puncture using a 21-gauge needle and a heparinised Vacutainer (detailed in Cooke et al. 2005). Whole blood was centrifuged (7,000 × *g*) for 5 min, and plasma samples were stored in 1.5-mL cryogenic vials in liquid nitrogen prior to storage at −80°C. Plasma was analyzed for testosterone and 17β-estradiol (Neogen enzyme-linked immunosorbent assay with Molecular Devices Spectramax 240pc plate reader). A scale sample was obtained from each fish for post hoc identification of stock origin (Gable and Cox-Rogers 1993): 105 of the tagged fish were identified as Harrison Rapids Sockeye Salmon and 40 were identified as Weaver Creek Sockeye Salmon. Finally, all the fish had an individually coded radio transmitter (Pisces, Sigma Eight, Newmarket, Ontario) gastrically inserted by holding the fish supine with its head just out of the water and pushing the transmitter down the esophagus using a smooth plastic plunger (Ramstad and Woody 2003; Cooke et al. 2005). The transmitters were cylindrical (16 mm diameter × 46 mm long) with a 460-mm-long antenna and transmitted on the 150-MHz band on one of six frequencies (320, 360, 440, 460, 600, or 800 KHz) with pulse intervals of 5.5 s. Previous work on gastrically tagged adult Fraser River Sockeye Salmon did not find an adverse effect of blood sampling on migration behavior and success (Cooke et al. 2005).

Radio-tracking and determination of fate.—The coded radio transmitters were detected using five fixed radiotelemetry receiver stations (SRX400; Lotek Wireless, Newmarket, Ontario) with 3-, 4-, or 5-element Yagi antennas. Four stations were set up on the Harrison River, two downstream of the release site and two upstream of the release site (Figure 1). The downstream receiver nearest the release site was 2.5 km away, and the nearest upstream receiver was 1.5 km away. The fifth station was set up on Weaver Creek, ~250 m upstream of the mouth. In addition, manual tracking by boat occurred throughout the study to supplement the fixed-station array.

Migration success was assessed as arrival to natal spawning areas. Telemetry receivers were distributed throughout the study system to provide broad coverage for the detection of tagged individuals as they approached known spawning locations. Thus, we used the term "natal spawning areas" to describe the general location where fish return to spawn; a fish was considered to have "migration success" if it was detected in this location. For Weaver Creek Sockeye Salmon, that meant detection at the Weaver Creek receiver (station 6 in Figure 1). For Harrison Rapids Sockeye Salmon, the nearest downstream receiver (station 3) and the nearest upstream receiver (station 4), relative to the release site, flank their natal spawning area. Harrison Rapids Sockeye Salmon assemble and exhibit spawning activity from October 20 through the end of November (Donaldson et al. 2012). Thus, Harrison Rapids fish were assessed as successful migrants if they exhibited movement within the spawning area on or after October 20, 2011 (following Donaldson et al. 2012), based on a combination of fixed receiver detections and manual tracking.

There are a variety of regulated fishery openings for Pacific salmon in the Harrison River each year, creating the potential for recaptures of tagged study fish in those fisheries. During the course of the experiment, the First Nation fishery sector harvested Sockeye Salmon during openings in August and September (for dates, see DFO 2012b, 2012c, 2012d). Recreational angling for Sockeye Salmon in the lower reaches of the Harrison River (downstream of the capture site) was open August 18 to September 18, 2011 (for data, see DFO 2011a, 2011b). The reward program for returning a radio tag is well known in the recreational fishing community of the lower Fraser River basin, resulting from a 10-year ongoing tagging program that involved extensive advertising (online, in fishing shops, etc.) to encourage reporting of recaptures to our research group. Two of the study fish were captured in the Harrison River First Nation Sockeye Salmon economic opportunity fishery on August 24, 2011, and reported to researchers—they were not included in estimates of survival.

Eight tags were not detected at a fixed-station receiver. Five of these tags were picked up near the release site using manual tracking, and they were confirmed to be mortalities. The three tags that were not detected by fixed stations or manual tracking were considered to be tag malfunctions and were removed from the data set.

Data analysis and statistics.—Significance levels were set at 0.05. Pearson's chi-square analysis was used to test for differences in the overall and population-specific postrelease survival to reach spawning grounds among the three treatment groups. Where significant differences were detected among treatments, Bonferroni multiple comparisons tests were used.

Experiment 2: Fraser River

Experimental site and fish capture.—Both the experimental site and angling method used were identical to those in Donaldson et al. (2011, 2013). All capture and tagging occurred at Grassy Bar (49°10′0.20″N, 122°1′9.14″W) on the Fraser River main stem (Fraser release site in Figure 1) from August 15 to September 2, 2011. During the angling and tagging period, the daily mean water temperature and discharge for the lower Fraser River ranged from 17.44°C to 19.07°C and from 3,978 to 4,917 m^3/s, respectively. For late August, the water temperatures were normal but discharge was

~35–40% above normal (Patterson et al. 2007); these values did not represent an increased risk of mortality (Macdonald et al. 2010). Hourly water temperature and discharge data for the Fraser River were obtained from measurements by the DFO Environmental Watch Program and Environment Canada Water Survey of Canada using monitoring stations on the main stem of the Fraser River at Qualark (49°31′58.13″N, 121°25′20.67″W) and Hope (Figure 1), respectively.

Adult Sockeye Salmon ($n = 70$) were caught by volunteer anglers using standard "bottom-bouncing" gear designed to target this species. This angling method uses long (>3-m) leaders with barbless J-shaped hooks sized 1–3/0 (without bait) and a heavy metal weight. The weight bounces along the riverbed and suspends the hook in the water column (for more details, see Donaldson et al. 2011). Duration from hooking to landing ranged from 1–5 min but was ≤2 min in 82% of the cases. Fish were landed using a knotless nylon landing net in which the fish were dehooked and then transferred into cylindrical fish bags (see description above in experiment 1) for processing. The dehooking and transfer to fish bags resulted in 15–45 s of air exposure.

Postangling treatment, tagging, reflex assessment, and release.—Once in the fish bag, each fish was randomly assigned to one of three treatment groups: (1) tagged and released, (2) 1 min of additional air exposure, tagged, and released, or (3) 1 min of additional air exposure, tagged, 1 min of ventilation assistance (see below), and released. Tagging consisted of gastrically inserting radio transmitters as described in experiment 1. Air exposure (when applicable) occurred immediately after capture by lifting the fish bag completely out of the water and allowing the water in the bag to quickly drain through the mesh ends. After transmitter insertion, a small clip of tissue was removed from the adipose fin using a hole punch and was stored in 95% ethanol for population identification via laboratory analysis (see Beacham et al. 2005). Each fish was measured (FL, nearest cm) and rapidly assessed for reflex impairment immediately following tagging.

We used reflex action mortality predictors (RAMPs; Davis 2010) to assess the effects of the angling capture treatments on fish condition. More specifically, we evaluated whether fish became sufficiently impaired, relative to the tagged-and-released fish (group 1), such that ventilation assistance could have a beneficial effect. This technique has previously been validated with multiple species of Pacific salmon for monitoring fish condition in association with gear encounters and, in some cases, predicting migration failure (Donaldson et al. 2012; Raby et al. 2012; Donaldson et al. 2013; Raby et al. 2013; Nguyen et al. 2014). The RAMP assessment involves rapidly checking (<20 s to complete) the presence or absence of five reflexes. If the technician had any doubt about the presence of a reflex it was assigned an impaired status. The reflexes assessed were "tail grab" and "body flex," two assessments of bursting response, followed by "head complex," an assessment of whether the animal had a regular ventilation pattern. "Vestibular-ocular" response involved checking whether the fish's eye maintained a level pitch when the fish was rolled on its side, while "orientation," a righting reflex, was tested to see whether the fish could right itself from the side position within 3 s. The presence or absence of the five reflexes was combined into a RAMP score of 0–1, which represented the proportion of reflexes that were impaired (i.e., absent).

Once tagging and processing were complete, fish were either released (groups 1 and 2) or provided with the ventilation assistance treatment (group 3). This ventilation assistance was carried out as detailed in experiment 1. The fish was oriented to face into the river flow (~0.5 m/s water speed) and gently held by the experimenter in this position for 1 min (no fish struggled free of the handler during the 1 min). Once the time elapsed, the experimenter simply let go of the animal and in every instance the fish swam away in the upstream direction. All fish exposed to the revival technique were ventilating while being held into the river flow.

Radio-tracking and determination of fate.—Transmitters were individually coded and seven frequencies (320, 360, 440, 460, 500, 600, and 800 KHz) were used on the 150-MHz band to reduce signal collisions as fish passed receiving stations (see below). All fish were tracked using an array of seven receiver stations on the main stem of the Fraser River (see Raby et al. 2014 for station details) and an additional four in the Harrison River system (including the station on Weaver Creek; Figure 1). The downstream receiver nearest to the release site was 22 km away at Mission (station 1); the nearest upstream receiver was 9 km away at the junction of the Harrison and Fraser rivers (station 2). Short-term survival was estimated for each fish based on whether the fish stopped migrating upstream within 72 h of release. Fish were assessed as successful migrants (i.e., survivors to the upmost receiver station) if they were detected at the most upstream receiver station on the migration pathway towards their DNA-identified natal spawning area (except for one fish of unknown origin, see below). Based on this information, the receiver at the junction of the Thompson and Fraser rivers (station 10) was the terminal detection station for 58 of the 70 fish tagged. For 10 fish, the receiver at the junction of the Nicola and Thompson rivers (station 11) was the terminal receiver. One fish was identified as belonging to a Harrison River system population (i.e., Birkenhead). To compare migration behavior among treatment groups, we used the time from release to the first detection at the upstream receivers (in hours), with the assumption that more severely impaired fish would require longer to recover from capture stress, thus leading to longer migration times. For analyses, we focused on the time to reach five upstream receivers for which sufficient sample sizes were attained: Harrison River, Hope, Sawmill Creek, Hell's Gate, and Thompson River (stations 2 and 7–10, respectively; Figure 1).

The DNA analysis was not completed for one fish so it was assumed that its population identification was reflected in its migration pathway; this fish moved through the Harrison River system within 2 d and was last detected at the upmost Harrison River receiver (station 5 in Figure 1). That fish was assessed as having ultimately survived with the assumption that it was from a Harrison River system population. One fish was not tracked because its tag information was not recorded prior to release.

Fish that were recaptured and reported by anglers (reporting discussed in experiment 1) between the release site and the most upstream receiver were omitted from the calculation of survival estimates. Three other fish were recaptured and reported near spawning areas in the upper watershed beyond the terminal receivers and were assessed as successful migrants.

Data analysis and statistics.—We compared short-term (72-h) survival and survival to the upmost receiver station among the three treatment groups using Pearson's chi-square test. There was no significant correlation between fish size (FL) and migration times ($P > 0.05$ for all five receivers) so migration times were simply analyzed as the number of hours from release to each of the five upstream receivers. A Kruskal–Wallis test was then used to compare migration times (in hours) among the three treatment groups to each of the five upstream receivers. We used Kruskal–Wallis analysis of variance to compare RAMP scores among the three treatment groups. In addition, we used logistic regression to assess the effect of RAMP score on survival. Where needed, post hoc comparisons among treatment groups were accomplished using multiple comparisons of mean ranks.

RESULTS

Experiment 1: Harrison River

Postrelease migration behavior was associated with migration success for Harrison Rapids Sockeye Salmon. Sixty-six of the Harrison Rapids Sockeye Salmon (21 of 27 [77.8%] immediate release, 26 of 39 [66.7%] without assisted ventilation, 19 of 34 [55.9%] with assisted ventilation) and all Weaver Creek Sockeye Salmon (40 fish) swam upstream following release, based on detection at the most upstream receiver (station 5). Of those fish, 19 (28.8%) and 6 (15.0%) survived to reach spawning areas, respectively. The remaining Harrison Rapids fish were first detected at the downstream station nearest the release site ($n = 29$) or died close to the release site without fixed-station detection ($n = 5$). None of the 29 fish that were detected downstream survived to reach natal spawning areas, including 9 fish that later reascended to the most upstream receiver station but did not return to their natal spawning area during the documented spawning period. A high percentage of the fish that fell back in the system had been exposed to the fisheries capture simulation (without assisted ventilation: 41.4%; with assisted ventilation: 41.4%).

In total, 25 of 140 (17.9%) Sockeye Salmon survived to reach their natal spawning areas, and the overall migration success was comparable between Harrison Rapids and Weaver Creek populations (19.0% and 15.0%, respectively; Table 1). There was no significant effect of ventilation assistance; the percent survival did not differ significantly between the group that received assisted ventilation (4.3%, 2 of 47 fish) and the group that did not (9.8%, 5 of 51 fish; $P = 0.439$). The same statistical result held when tested within each population ($P > 0.05$ in both cases).

TABLE 1. Percentage and number of adult Harrison Rapids and Weaver Creek Sockeye Salmon that survived to reach their natal spawning areas after capture and release in the Harrison River, British Columbia. Upon capture, fish were assigned to one of three treatment groups. Fish assigned to the first group were released immediately after processing. Fish of the second group were subjected to the fisheries capture simulation, consisting of 3 min of strenuous exercise and 1 min of air exposure. Fish of the third group were subjected to the fisheries capture simulation plus 1 min of assisted ventilation that was accomplished by orienting the fish's mouth into a jet of river water.

Population, treatment group, and total	n	% Survival to spawning area (number survived)
Harrison Rapids		
Immediate release	27	48.1 (13)
Capture simulation	39	10.3 (4)
Capture simulation + assisted ventilation	34	5.9 (2)
Total	100	19.0 (19)
Weaver Creek		
Immediate release	15	33.3 (5)
Capture simulation	12	8.3 (1)
Capture simulation + assisted ventilation	13	0.0 (0)
Total	40	15.0 (6)
Grand total	140	17.9 (25)

TABLE 2. Sample sizes, study fish characteristics, and postrelease survival for the three treatment groups in the Fraser River experiment. Angling duration (presented in minutes : seconds as mean ± SE) refers to the time from hooking to landing. "Air" refers to 1 min of air exposure that was completed immediately after landing, and "assisted ventilation" was accomplished by holding the fish by hand and orienting its mouth into the river flow (~0.5 m/s). All fish were gastrically tagged with radio transmitters for monitoring postrelease survival. The stock composition and thus natal spawning areas were determined using DNA analysis of adipose tissue taken during processing (Beacham et al. 2005). The number recaptured refers to tagged fish that were recaptured, killed, and reported by recreational fishers. Survival differences among groups were not significant for 72-h survival (Pearson's Chi Square: $\chi^2 = 0.10$, df = 2, $P = 0.95$) or survival to the most upstream receiver station ($\chi^2 = 0.18$, df = 2, $P = 0.91$).

Treatment group	*n*	Angling duration	Stock composition	Number recaptured	% 72-h survival (number survived)	% Survival to most upstream receiver (number survived)
Angling	24	1:43 ± 0:13	18 Chilko, 2 Thompson, 2 Stellako, 1 Quesnel, 1 unknown	3	87.0 (20 of 23)	69.6 (16 of 23)
Angling + air	22	1:39 ± 0:09	11 Chilko, 5 Thompson, 3 Stellako, 3 Quesnel	3	85.7 (18 of 21)	80.0 (16 of 20)
Angling + air + assisted ventilation	23	1:57 ± 0:15	18 Chilko, 2 Thompson, 2 Quesnel, 1 Birkenhead	6	94.4 (17 of 18)	70.6 (12 of 17)

The fisheries capture simulation had a significant effect on survival to natal spawning areas ($\chi^2 = 26.727$, df = 2, $P < 0.001$): fish that were immediately released following capture by beach seine were more likely to survive than those subjected to the simulated fisheries capture (with or without assisted ventilation; see Table 1). Overall, 18 of the 42 (42.9%) immediately released fish reached the spawning area, whereas 2 of 47 (4.3%) fish that received assisted ventilation and 5 of 51 (9.8%) fish that did not receive assisted ventilation were successful. Results were similar when tested within each of the populations separately (Harrison: $\chi^2 = 21.338$, df = 2, $P < 0.001$; Weaver: $\chi^2 = 6.667$, df = 2, $P = 0.036$).

A sex-specific pattern in survival to reach spawning areas was observed. Female fish that were subjected to the simulated capture event (with or without assisted ventilation) did not survive to reach their natal spawning areas (compared to an 8.3% and 19.2% survival of males, respectively), whereas 36.0% of females survived from the immediately released group (versus 52.9% survival of males).

Experiment 2: Fraser River

There were no significant differences among the three treatment groups for short-term survival ($\chi^2 = 0.10$, df = 2, $P = 0.95$) or for survival to the most upstream receiver station ($\chi^2 = 0.18$, df = 2, $P = 0.91$; Table 2). Across all treatment groups, short-term survival (72 h) was 88.7%, while the survival to the most upstream receiver station was 73.3%. Migration times (in hours) to reach the five upstream receivers were not significantly different among the three treatment groups ($P > 0.35$ in each case). Overall, the RAMP score was not a significant predictor of postrelease survival (odds ratio = 2.48, Wald statistic = 0.46, $P = 0.50$), with the mean RAMP scores of unsuccessful migrants (0.33, $n = 16$) and successful migrants (0.37, $n = 44$) being quite similar. Posttagging RAMP scores were statistically different among the three groups overall (Kruskal–Wallis: $H_{2,\ 70} = 30.88$, $P < 0.001$), with the "angling only" treatment fish having significantly lower impairment than the fish exposed to air (Figure 2).

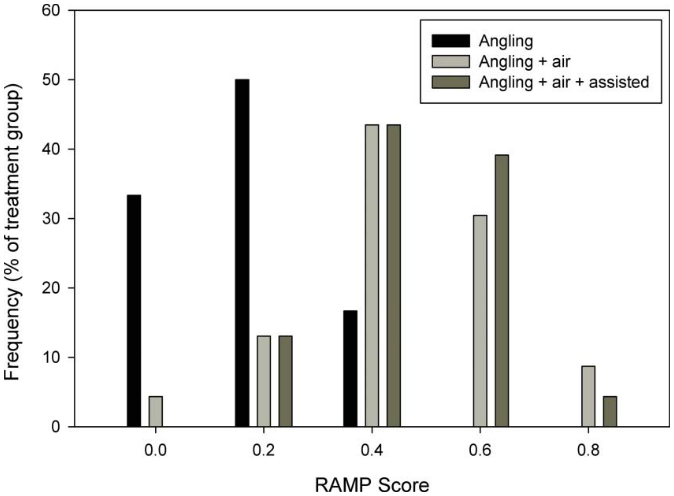

FIGURE 2. Histogram of the proportion of Sockeye Salmon at each reflex impairment level (RAMP Score) for each of the three treatment groups in the Fraser River experiment. Black bars refer to fish that were angled, tagged, RAMP-assessed, and released. The light and dark gray bars refer to fish that had added air exposure following capture, and the dark gray "assisted" group was provided with assisted ventilation, which occurred after the RAMP assessment. The two groups with air exposure were statistically similar and higher in mean RAMP impairment than the angling-only group ($H_{2,\ 70} = 30.88$, $P < 0.001$).

DISCUSSION

The ventilation assistance treatment applied in these two separate field experiments was intended to facilitate physiological recovery of the study fish prior to their release from capture by ensuring the strong flow of water over the gills of the fish. However, the data presented here provide no evidence of any benefit to migration success. In experiment 2, there was no significant effect of the assisted ventilation treatment on migration success for angled and air-exposed fish. In experiment 1, the forced exercise and air exposure treatment resulted in a clear reduction in survival to reach natal spawning grounds, regardless of whether the ventilation assistance technique was used before release. These findings are consistent with a laboratory holding experiment that also reported no survival benefit of the same revival technique for Sockeye Salmon (Robinson et al. 2013). To our knowledge, these are the first field experiments to use biotelemetry to evaluate this recovery technique, a method comparable to those commonly used by recreational anglers attempting to revive their catch before release.

The success of the facilitated recovery technique hinges on the excess oxygen requirements of metabolically impaired fish following the exhaustive exercise associated with fisheries capture. The controlled capture simulation protocol of experiment 1 has been previously demonstrated to metabolically impair Fraser River Sockeye Salmon in the laboratory environment (Gale et al. 2011; Robinson et al. 2013). The decreased survival in response to this simulation in our field experiment suggests that the study fish were sufficiently impaired and therefore might have benefited from an accelerated physiological recovery. In experiment 2, the RAMP scores demonstrated that these fish were behaviorally impaired after angling and air exposure and, therefore, may have benefited from the manual recovery treatment. The RAMP score was not a predictor of migration success, suggesting that the fish may not have been sufficiently impaired to see a clear relationship with survival. The extent to which fish are exhausted following fisheries capture may determine the potential effectiveness of recovery techniques (Donaldson et al. 2013). Previous research evaluating devices such as Fraser Boxes (Farrell et al. 2001; Nguyen et al. 2014) and recovery bags (Brownscombe et al. 2013; Donaldson et al. 2013; Raby et al. 2014) as methods of facilitating recovery have shown context-specific benefits in promoting physiological recovery (Farrell et al. 2001) and reducing delayed mortality (Donaldson et al. 2013). More vigorous fish may not benefit from recovery, whereas more impaired fish may reap the potential benefits of increasing the oxygen available for uptake during excess postexercise oxygen consumption (Farrell et al. 2001; Donaldson et al. 2013; Nguyen et al. 2014). For example, if a fish being released is unable to maintain equilibrium (i.e., has no swimming ability) and drifts downstream with negative orientation for an extended period, that animal is not receiving any significant flow over its gills other than what it can generate from opercular beats. Alternatively, if a fish is exhausted but able to maintain equilibrium and hold station in the river current, it would receive the same "benefit" as in our assisted ventilation treatment. In such cases, holding that animal in the river current may simply represent an unnecessary and additional handling stressor. Methods of evaluating fish vitality and predicting postrelease mortality could be valuable for informing decisions about whether fish can benefit from assisted ventilation.

The mortality patterns that can be inferred across the field experiments are likely a combination of differences in treatment protocol and variation in factors relating to natural mortality. Recent review papers on Fraser River Sockeye Salmon have highlighted key factors that drive variation in freshwater migration mortality among stocks and across years (Hinch et al. 2012; Johnson et al. 2012). These stock-specific factors include variation in physiological tolerance to temperature (Eliason et al. 2011), exposure risk to environmental conditions (Macdonald et al. 2010), migration behavior in freshwater (Hinch et al. 2012), and spatiotemporal pressure from fisheries. The early marine exit behavior of Harrison Rapids and Weaver Creek Sockeye Salmon stocks has been associated with very high in-river mortality estimates in recent years (Hinch et al. 2012), comparable to the mortality values of the immediate-release group reported herein. In fact, the mortality in both experiments is comparable to other telemetry studies using similar stocks (Donaldson et al. 2011, 2012). These factors extrinsic to the experimental protocols can together potentially explain some of the differences in migration success between experiment 1 and experiment 2. Further differences could be attributed to the experimental protocols. Most notable is the use of a much longer monitoring period for assessing the migration success in experiment 1 (3–10 weeks) than in experiment 2 (1–2 weeks). In addition, the capture and handling associated with using a beach seine to obtain fish in experiment 1 would have created additional stress. These experimental protocols and natural mortality factors will be present in field studies, but this should not impinge on the ability to examine treatment differences in the use of ventilation assistance within each experiment.

The data from experiment 1 corroborates evidence that adult female Sockeye Salmon are more sensitive to capture and release than males (see Martins et al. 2012; Robinson et al. 2013). None of the female Sockeye Salmon exposed to the chase and air exposure protocol survived to reach their spawning grounds, whereas 36% of "immediate release" females completed their migration. Sex-specific postrelease mortality remains a difficult consideration for those management systems, such as Fraser River Sockeye Salmon, which do not explicitly manage to female spawner escapement targets.

Experiment 2 presents managers with additional considerations by highlighting the importance of variable monitoring durations on determining postrelease mortality estimates. The mortality estimates derived from the 72-h and near-terminal migration success results are greater than the 3% mortality (based on 24-h holding studies) currently applied to the freshwater recreational fishery (DFO 2014). These higher delayed postrelease mortality results are consistent with estimates from a multiyear dataset on the migration success of Sockeye Salmon angled in the lower Fraser River (Donaldson et al. 2011, 2013). However, recommending direct estimates of release mortality regardless of monitoring duration for any fishery is difficult and ideally should consider the additional impacts introduced by tagging and handling (e.g., Halttunen et al. 2010; Baktoft et al. 2013; Ferter et al. 2015).

The current study provides no support to the claim that the simple revival methods commonly used by fishers always benefit fish survival. As one of the first scientifically defensible evaluations of these simple revival techniques, our results cast some doubt on the best-practice recommendations made by some fisheries managers and angling groups. Commonly recommended strategies to mitigate fishing impacts need to be field tested to ensure that the fisheries management objectives and fisher expectations are truly met. This is especially important considering the extent of recreational fishing for Sockeye Salmon in the Fraser River watershed. In 2010, an estimated 100,849 Sockeye Salmon were released by anglers in the lower Fraser River, and in 2011 that number was 62,642 (DFO 2010, 2012a). However, we cannot recommend the use of manual assisted ventilation for reviving migrating Sockeye Salmon captured in freshwater based on the techniques tested thus far. Future research on facilitating postcapture revival should use controlled experiments that compare different revival techniques and durations and determine at what level of impairment fish benefit—using both physiology and survival as endpoints. In the presence of predators (e.g., Cooke et al. 2014) or in the face of climate change (Gale et al. 2013), efforts that facilitate revival may be particularly beneficial.

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