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ARTICLE

Evaluation of a simple technique for recovering fish from capture stress: integrating physiology, biotelemetry, and social science to solve a conservation problem

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Abstract: We evaluate the utility of an inexpensive, portable recovery bag designed to facilitate recovery of fish from capture stress by combining physiological assays, biotelemetry, and social science surveys. Adult migrating Pacific salmon (*Oncorhynchus* spp.) were used as a model, since some of their populations are threatened. While catch-and-release is common, there is a need to ensure that it is sustainable. A social science survey revealed that anglers generally have positive attitudes towards recovery bag use, particularly if research identifies that such techniques could be effective. Physiological assays on pink salmon (*Oncorhynchus gorbuscha*) revealed benefits of both high- and low-velocity recovery, but high velocity was most effective with reduced plasma cortisol concentrations and similar plasma sodium and chloride concentrations as those found in controls at all recovery durations. A biotelemetry study on sockeye salmon (*Oncorhynchus nerka*) captured by anglers and stressed by air exposure then placed in recovery bags had 20% higher, but not significantly different, survival than no-recovery salmon. The integration of natural science and social science provides an important step forward in developing methods for promoting recovery of fish from capture.

Résumé : Nous évaluons l'utilité d'un sac de récupération portable et peu dispendieux pour ce qui est de favoriser la récupération de poissons après un stress de capture, en combinant des essais physiologiques, des données de biotélémétrie et des études sociologiques. Des saumons du Pacifique (*Oncorhynchus* spp.) adultes en migration ont été utilisés comme modèle étant donné que certaines de leurs populations sont menacées et que, bien que la pêche avec remise à l'eau soit répandue, il importe de vérifier qu'il s'agit d'une pratique durable. Une étude sociologique a révélé que les pêcheurs à la ligne voient généralement d'un bon œil l'utilisation d'un sac de récupération, en particulier si la recherche établit l'efficacité de telles méthodes. Des essais physiologiques sur des saumons roses (*Oncorhynchus gorbuscha*) ont révélé que la récupération tant à haute vitesse qu'à basse vitesse présentait des avantages, mais que la récupération à haute vitesse était plus efficace, se traduisant par une réduction des concentrations de cortisol plasmatique et des concentrations semblables de sodium et de chlorure, utilisées comme témoins, pour toutes les durées de récupération. Dans une étude biotélémétrique, des saumons sockeye (*Oncorhynchus nerka*) capturés par des pêcheurs à la ligne et soumis au stress de l'exposition à l'air, puis placés dans des sacs de récupération présentaient un taux de survie de 20 % supérieur à celui des saumons n'ayant pas récupéré, bien que cette différence ne soit pas significative. L'intégration des sciences naturelles et de la sociologie a donc permis une importante avancée dans la mise au point de méthodes favorisant la récupération de poissons suite à leur capture. [Traduit par la Rédaction]

Introduction

Conservation physiology has emerged as a field that uses physiological tools and knowledge to inform conservation and management initiatives (Wikelski and Cooke 2006). One of the current limitations of conservation physiology is that physiological research is often disconnected from conservation practitioners and managers (Cooke and O'Connor 2010), but positive examples of using physiological knowledge to improve fisheries management are beginning to emerge (e.g., Cooke et al. 2012). Here, we use a novel approach by combining natural science and social science research in the Pacific salmon (*Oncorhynchus* spp.) recreational angling fishery, a highly relevant system given the precarious status of some Pacific salmon populations (Jonsson et al. 1999; Irvine et al. 2005; Gustafson et al. 2007). We assess the utility of facilitated recovery techniques, i.e., methods of expediting physiological recovery and promoting survival following fisheries capture stress, by combining a social science survey, an assessment of physiological condition, and a determination of survival to reach spawning areas. Given the applied nature of this research and the importance of stakeholder opinion, we begin by conducting a social science survey of recreational anglers, then follow up this work with a laboratory-based physiology study and a field-based telemetry survival study.

Pacific salmon are targeted by recreational fisheries during the marine and freshwater phases of their spawning migrations. As an example, the Canadian sockeye salmon (*Oncorhynchus nerka*) recreational fishery in Fraser River, British Columbia, has grown in recent years (Kristianson and Strongitharm 2006) despite some

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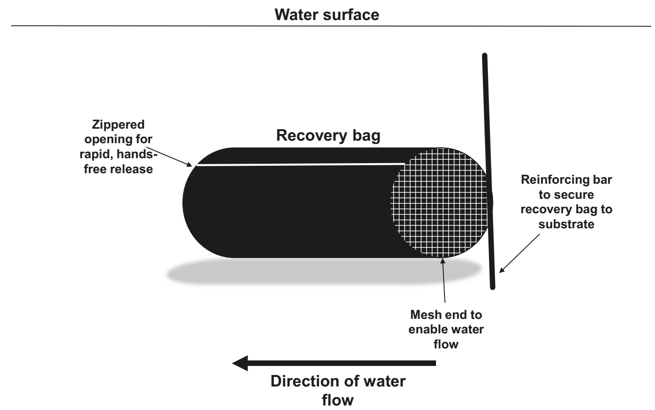
populations being considered endangered, owing in part to mixed-population fishing (e.g., Cultus Lake sockeye salmon; Rand 2008). This fishery is traditionally catch-and-keep, but anglers may choose to voluntarily release fish if they are over their quota or if the fish is undesirable. The release-to-keep ratio can be as high as 1:2 for Fraser River sockeye salmon, which translates to high numbers when fish are in high abundance (e.g., 100 000 released versus 200 000 harvested in 2010; Fisheries and Oceans Canada 2010) and postrelease mortality is known to occur (Donaldson et al. 2011). While released fish may resume their migrations without delay, individuals showing signs of exhaustion at the time of release (e.g., loss of equilibrium, inability to swim against current, and (or) physiologically compromised) may potentially drift downriver and be prone to capture by predators or secondary fisheries (e.g., subsequent capture by a gill net). In such cases, specially designed recovery gear that ram ventilates the gills could assist physiological recovery and allow fish to more quickly and effectively resume migration. However, recovery techniques would require acceptance from stakeholders and scientific evidence of their effectiveness before they could be considered for implementation.

Human dimensions research and conservation social science (e.g., Mascia et al. 2003) are increasingly being used to inform policy and management actions, in particular to help in understanding the factors that influence compliance with conservation regulations (Rudd et al. 2011*a*). While understanding socio-ecological dynamics has been suggested as an important part of ensuring sustainable recreational fisheries management (Post et al. 2008; Hunt et al. 2011), and important examples of collaborations between the angling community and scientists have occurred (e.g., Tufts and Morlock 2004; Danylchuk et al. 2011), the viability of facilitated recovery methods has not been examined interactively from the dual perspectives of the social and natural sciences. In fact, few management agencies throughout North America have considered facilitated recovery methods in freshwater recreational fisheries (Pelletier et al. 2007), likely owing to the limited data available on their effectiveness. If facilitated recovery were to be considered for implementation, an understanding of recreational angler perspectives on the issue of facilitated recovery gear would help fisheries managers to determine whether such gear could be readily adopted by anglers.

The physiological response of fish to capture stress is generally considered analogous to exercise stress and has been well characterized in the fish physiology literature (Milligan 1996; Kieffer 2000). The time required to clear metabolites from the blood and restore muscle energy stores may limit subsequent performance, since this recovery rate will determine the frequency of maximal performance (Milligan 1996). Prolonged recovery may lead to tertiary consequences, including delayed mortality (Black 1957; Wood et al. 1983). Prior to the work of Milligan (1996) and Milligan et al. (2000), the physiological time course of recovery from exercise stress was thought to be long, requiring ~4 h for recovery of oxygen consumption (Brett 1964) and even longer for metabolites to return to prestress conditions (Black 1957; Turner et al. 1983). Most early studies measured recovery in static (i.e., no velocity) water, but Milligan et al. (2000) found that when rainbow trout (*Oncorhynchus mykiss*) recovered in flowing water with a constant low-velocity current (i.e., 0.9 body lengths per second), complete metabolic recovery was much quicker (~2 h) relative to static water recovery. Subsequent work suggests that low-speed swimming during recovery from exhaustive exercise can improve swim performance in subsequent swimming tests in juvenile salmonids (Kieffer et al. 2011).

The results of Milligan et al. (2000) have been adapted to facilitate physiological recovery and improve survival of coho salmon (*Oncorhynchus kisutch*) captured by various marine fisheries (Farrell et al. 2000; Farrell et al. 2001*a*, 2001*b*). Farrell et al. (2001*b*) found that placing troll-captured coho salmon in a cage towed alongside the fishing vessel promoted accelerated physiological recovery. A revival box (i.e., Fraser Box) used on board a commercial gill net boat that jetted seawater towards confined individual fish promoted rapid physiological recovery within 1–2 h, restored swimming ability, and improved survival even for fish that appeared moribund at capture (Farrell et al. 2001*a*). The general physiological principle involved in these studies is that recovery is facilitated by assisted gill ventilation by ramming water velocity into the mouth and across the gills of recovering fish and (or) maintaining steady swimming during the recovery process, although recent work by Kieffer et al. (2011) suggests that the former may be the more likely mechanism. The marine studies by Farrell et al. (2001*a*, 2001*b*) involved large vessel-based apparatus, and survival was determined by observing fish in net pens for 24 h. There have been no investigations of this kind in freshwater environments or with recovery gear that is more portable and thus could be used by recreational salmon fishers, despite recent findings for delayed mortality of fish released following angling capture (Donaldson et al. 2011). Biotelemetry is a useful tool to track long-term survival of individuals caught and released from fisheries (Donaldson et al. 2008).

Fig. 1. A schematic of a facilitated recovery bag attached to a reinforcing bar to secure the bag to the substrate. Fish are placed into the bag and oriented into the water flow. Wide mesh ends of the bag enable sufficient water velocity to pass through the fish's mouth and gills. The zippered opening enables fish exit the bag with minimal disturbance and without additional handling.



The objective of the present study was to test the utility of a simple, inexpensive, and portable example of facilitated recovery gear, herein referred to as a recovery bag (Fig. 1). Recovery bags are structured cylindrical hypolon bags with mesh ends that are submerged in high-velocity water to enable flow through the bag and over the fish's mouth and gills, resulting in ram ventilation akin to the Fraser box tested by Farrell et al. (2001*a*). The purpose of the recovery bags is to provide an environment where the exhausted fish can be oriented into the flow of water without risk of drifting downriver and being susceptible to injury, predation, or fisheries capture. Recovery gear in general requires relatively high water velocities to be effective, but recovery bags have the added benefit of being portable and not requiring an external power source, which is ideal for recreational anglers and shore-based net fisheries, such as Native fisheries.

We aimed to test the utility of recovery bags for facilitating the recovery of Pacific salmon following capture in freshwater using a three-pronged approach. First, we surveyed salmon anglers to assess the potential for implementing recovery techniques in a Pacific salmon recreational fishery. Second, we assessed the effectiveness of recovery bags on the physiological response of adult pink salmon (*Oncorhynchus gorbuscha*) following a catch-and-release simulation. Third, we used biotelemetry to determine whether recovery bags influenced the survival of sockeye salmon

Table 1. Latent class membership profile for two-class recovery bag support model.

Latent-class cluster	Supporters (%)	Nonsupporters (%)
Overall cluster size	53.8	46.2
Indicator variables		
1. What do you think about the idea of a revival bag to help incidental [salmon] catches?		
(*a*) Negative (protest, legitimate)	13.1	78.6
(*b*) Neutral	0.1	10.7
(*c*) Positive (conditional, fully)	86.8	0.3
2. Is there a need for a recovery bag to revive incidentally caught salmon?		
(*a*) No	39.8	98.0
(*b*) Neutral	9.1	0.3
(*c*) Yes	51.1	1.8
3. If the bag was shown to improve survival of released salmon, would you use it on a voluntary basis?		
(*a*) No	15.5	54.1
(*b*) Yes	84.5	45.9
4. Suppose using a recovery bag was mandatory for reviving fish before releasing it. What are your thoughts on that?		
(*a*) Negative (protest, legitimate, conditional)	0.6	35.4
(*b*) Other/Neutral	0.1	7.2
(*c*) Supportive (compliant, conditional, fully)	96.3	57.4

released by recreational anglers. These three components were integrated to discuss the application of portable recovery gear in the management and conservation of Pacific salmon in the context of freshwater recreational salmon fisheries.

Materials and methods

Angler social science survey

Experimental design

The purpose of the angler survey was to determine whether recreational anglers participating in a fishery for Pacific salmon would be willing to consider the use of facilitated recovery gear for fish that are caught with the intention of being released. We surveyed anglers participating in the Fraser River sockeye salmon recreational fishery. Face-to-face interviews with anglers were conducted at fishing sites and boat launches of the lower Fraser River between 30 July and 27 August 2010. Sixty-seven anglers participated in our survey. Our mixed-method research approach (i.e., both quantitative ratings data and open-end responses were collected) used semistructured interviews lasting 10–50 min (Creswell 2009) in which key questions prompted structured conversations between interviewer and interviewee (Table 1). During the interview period, anglers were targeting sockeye salmon, but the survey was designed to ask questions in general about facilitated recovery for Pacific salmon and did not focus on one specific species.

Statistical analysis

Latent-class (LC) cluster analysis (Magidson and Vermunt 2004) can be used to statistically identify LC membership using information from a set of observed variables (indicators) that imperfectly measure underlying true class membership (e.g., Rudd et al. 2011*b*). In our LC models, indicator variables, based on our categorization of qualitative responses to four sets of questions about recovery bag use, were used to estimate a latent variable, "supporters of recovery bag program implementation". The LC models based on qualitative attitudinal data allowed us to characterize LC clusters whose members have statistically homogeneous beliefs or preferences regarding recovery bag use within clusters, but maximal difference between clusters. We used the Akaike information criterion (AIC) to identify the most parsimonious LC model by choosing a final LC model with the number of clusters that minimized AIC. We also tested for local independence between indicators using bivariate residual statistics (e.g., Rudd et al. 2011*b*). Significant bivariate residuals ($\chi^2 > 3.84$, df = 1, $P < 0.05$) signify local dependence between variables and functionally mean that two or more indicators provide redundant information for the clustering process. We used Latent GOLD 4.0 (Vermunt and Magidson 2005) for all analyses.

Facilitated physiological recovery

Study site and animals

Experiments were conducted at Fisheries and Oceans Canada's Weaver Creek Spawning Channel (49°32′N, 121°88′W) in British Columbia, Canada, an artificial channel draining into the Harrison River, a lower Fraser River tributary. Water temperatures during the study ranged between 10 and 12 °C. Only females were used in this experiment because sex-specific differences are known to occur in certain physiological variables (e.g., plasma cortisol; Donaldson et al. 2010*a*). Fish were selected upon first arrival at the spawning channel. Fish were showing signs of secondary sexual characteristics but none were reproductively mature (i.e., not ripe). Pink salmon are targeted by fisheries and co-migrate with other Pacific salmon species that are of conservation concern in the Fraser River (e.g., interior coho and Cultus Lake sockeye salmon), but are not a species of concern themselves.

Experimental design

Individuals were randomly assigned to controls or no-, low-, or high-velocity treatments. Controls (n = 8) were immediately placed into individual holding boxes (length × width × depth of 93.7 cm × 54.0 cm × 47.3 cm) and held for 24 h before blood samples were taken. Each holding box was supplied with fresh water (0.63 $L \cdot s^{-1}$) pumped from the spawning channel. Fish from the no-, low-, or high-velocity treatments were individually transferred into a donut-shaped exercise tank (diameter 150 cm, water depth 40 cm) supplied with fresh water pumped from the spawning channel, where they were manually chased for a period of 3 min (coaxed by three experimenters positioned around the exercise tank to burst swim for 3 min (Black 1958; Wood 1991) to simulate an angling capture event), then given 1 min air exposure using previously described methods (Donaldson et al. 2010*a*), simulating gear removal in air or photography.

Recovery bags are particularly relevant where fish are exhausted to the point where they have lost equilibrium or are unable to swim to locations that are free from predators or locations of optimal flow conditions. Here, fish were visibly exhausted following the exercise and air exposure treatments, typically unable to engage in burst swimming and (or) having difficulty maintaining equilibrium. Fish assigned to the low-velocity (n = 75) or high-velocity (n = 75) group were transferred to one of three recovery bag types. The recovery bags were fine (1 cm mesh size) or coarse mesh (5 cm mesh size) made from Hypalon and cylindrical in shape (length of 100 cm, diameter of 20 cm) or were simple drawstring mesh sacks (length × width = 80 cm × 40 cm). Bags were positioned in the natural water current of the spawning channel and attached by rope to a structure at the side of the channel to ensure that the bag remained stationary and that the position of the bag did not change during the recovery period. The low-velocity group was placed in a location with a water current of 0.19 $m \cdot s^{-1}$, and the high-velocity group was placed in a location with a current of 0.43 $m \cdot s^{-1}$. Velocities inside the fine and coarse mesh bags in the low-velocity group were 0.15 and 0.17 $m \cdot s^{-1}$, respectively, and within the fine and coarse mesh bags in the high-velocity group 0.35 and 0.39 $m \cdot s^{-1}$, respectively (mean rates). For comparison, within the Weaver Creek Spawning Channel, mean current velocity has been measured at 0.4 $m \cdot s^{-1}$ (Hruska et al. 2011). During the present study, velocities measured in areas of the spawning channel where fish typically maintained position averaged 0.18 $m \cdot s^{-1}$. Fish assigned to the no-velocity group (n = 22) were transferred into individual holding boxes (as described above) for recovery and blood sampling.

We chose three time points of <60 min to provide a range of realistic times in which anglers might be willing to remain in the same location as the bag (i.e., enabling them to continue to fish) while the fish in the bag had time to recover.

Single blood samples were taken after 15, 30, or 60 min of recovery. For blood sampling, individuals were collected from bags, placed supine in a water-filled, V-shaped foam-padded sampling trough (Cooke et al. 2005), and blood sampled immediately. Individuals were only blood sampled once. The duration of the entire procedure was <2 min. Fork length (FL) was also measured. Each blood sample collected 2.5 mL blood by caudal puncture using a 3.8 cm, 21-gauge needle and a heparinised vacutainer (3 mL lithium heparin, Becton-Dickinson, Franklin Lakes, New Jersey), and then stored in ice-chilled water for ~1 h until subsequent processing.

Physiological assays

The chilled ~2.5 mL blood samples were centrifuged at 7000g for 3 min, and plasma was stored in liquid nitrogen prior to being frozen at –80 °C until analysis. Plasma was subsequently analysed for cortisol (Neogen ELISA with Molecular Devices Spectramax 240pc plate reader), lactate, glucose (YSI 2300 STAT Plus analyser), osmolality (Advanced Instruments 3320 freezing point osmometer), chloride (Haake Buchler digital chloridometer), and sodium and potassium (Cole-Parmer, model 410 single channel flame photometer; Farrell et al. 2001*b*).

Statistical analysis

Normality was assessed using Shapiro–Wilk tests, homogeneity of variance was assessed using Levene's test, and variables were $\log_{10}$-transformed to reduce heteroscedasticity where necessary, but all data are presented as nontransformed values. Three-way multivariate analysis of variance (MANOVA) was used to test for relationships among each of the physiological variables with recovery period (15, 30, or 60 min), water velocity (no, low, or high), and bag type (fine mesh, coarse mesh, or mesh sack), as well as their interactions. Subsequent one-way ANOVA was used to test for differences among groups at each recovery period, and Bonferroni adjustments were made, resulting in α = 0.007. Tukey's post hoc tests were conducted on one-way ANOVA results (α = 0.05). Statistical analyses were performed in JMP version 9.0 (SAS Institute 2011).

Facilitated recovery and survival to reach spawning areas

Study site and experimental design

Experimental procedures were conducted on sockeye salmon at the Fraser River at Grassy Bar, near Chilliwack, British Columbia, Canada, between 9 and 26 August 2010 (Fig. 2). Treatment groups were established as follows: (1) angling; (2) angling plus 1 min of air exposure; (3) angling plus recovery; (4) angling plus 1 min of air exposure plus recovery; and (5) beach seine. Volunteer anglers captured sockeye salmon using standard bottom-bouncing gear from either the shore or boats anchored near the shore (Donaldson et al. 2011). Capture durations ranged between 1 and 5 min. Once landed, hooks were removed and individuals were randomly assigned to a treatment. Fish in the angling-only treatment were tagged for radio telemetry and released immediately, while those in the angling and air exposure treatment were given a 1 min air exposure by holding the fish by hand out of the water, then being tagged for radio telemetry and released to resume their migrations.

For the angling recovery groups, fish were likewise either assigned to no air exposure or air exposure. Individuals were then tagged for radio telemetry and placed in mesh-ended Hypalon bags for a 15 min recovery period. The mean velocity in this area was 0.11 $m \cdot s^{-1}$, which is closer to our "low-velocity" treatment from the pink salmon study rather than the "high-velocity" treatment. However, this was the highest and most consistent water velocity available at the study site. Bags were positioned to ensure that the current was directed through the bag and that fish were oriented in the bag anteriorly to direct the flow of river water over the fish's mouth and gills. Following the recovery period, individuals were guided out of the bag, with minimal physical touching by technicians, and back into the river to resume their migrations. For the beach seine capture group, fish were captured using a 64 m × 7.5 m × 5 cm mesh beach seine net. Technicians continually monitored the catches from both capture methods and recorded qualitative information about angling durations, air exposure durations, injuries (e.g., hooking location and degree of bleeding), and general condition descriptions.

Telemetry methods and determination of survival

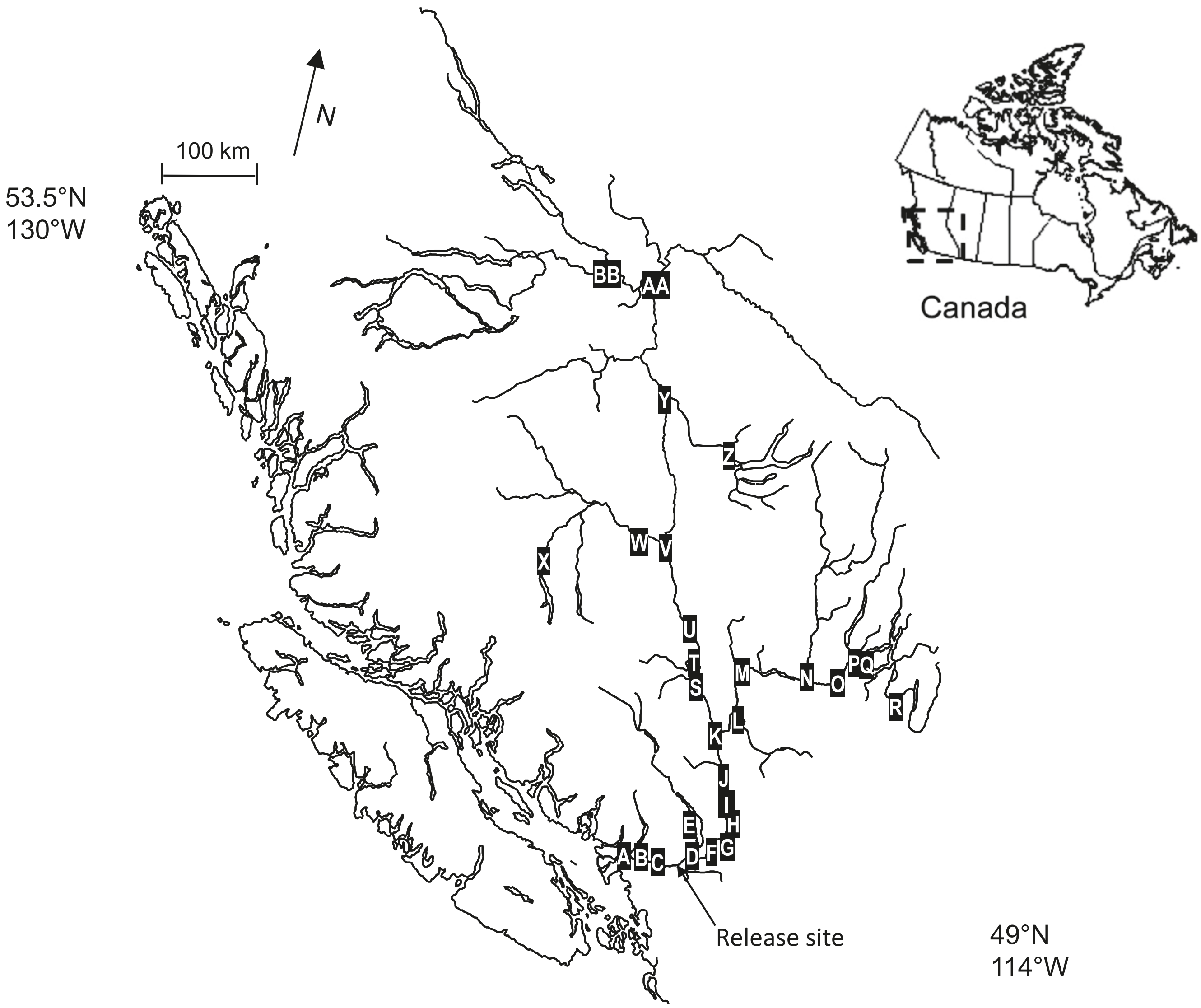
A total of 173 sockeye salmon were radio telemetry tagged for this study. Individuals from each treatment were tagged and released in equal proportions during the study period. Established protocols for the gastric tagging of sockeye salmon were used, where tags were inserted through the mouth and into the stomach of each individual, since they do not feed during their migrations and their stomachs close around and secure the tag following placement (Cooke et al. 2005). Coded radio transmitters (MCFT-3A-3 V, Lotek Wireless Inc., Newmarket, Ont., or Pisces 5, Sigma-Eight Inc., Newmarket, Ontario) were used. Coded transmitters enabled the identification of individual fish as they were detected at receiver stations. For all fish, a scale sample and a 0.5 g adipose fin clip were taken for identification of population complexes, and FL measurements were made and a numbered cinch marker tag (Floy Tag and Mfg., Inc., Seattle, Washington, USA) was attached through the dorsal musculature. Procedures were always completed in ≤2.5 min.

Twenty-eight radio telemetry receiver stations (SRX400 or SRX400A, Lotek Wireless Inc.) with three- or four-element Yagi antennas (Maxrad Inc., Hanover Park, Illinois, USA, or Grant Systems Engineering Inc., King City, Ontario) were strategically positioned throughout the Fraser River watershed (Donaldson et al. 2010*b*; Donaldson et al. 2011). Owing to their high fidelity to natal spawning areas, DNA stock identification enabled us to determine the natal subwatershed that each individual was migrating to. Arrival at natal subwatershed was determined by detection with fixed station telemetry receivers located in tributaries en route to spawning grounds. Failure of an individual to be detected at subsequent receiver locations was termed en route mortality (Donaldson et al. 2011). Individuals that were reported as fisheries harvest were excluded from this study.

Statistical analyses

One-way ANOVA was used to test for differences in FL among treatment groups. Pearson χ^2 analysis was used to test for differ-

Fig. 2. A map of the Fraser River, British Columbia, Canada, showing locations of fixed station radio telemetry receivers. Receiver locations are denoted as follows: A, Crescent Island; B, Mission North; C, Mission South; D, Harrison Confluence; E, Weaver; F, Rosedale; G, Hope; H, Qualark; I, Sawmill; J, Hells Gate; K, Thompson Confluence; L, Spences Bridge; M, Ashcroft; N, North Thompson; O, Timbers House; P, Little River; Q, Adams River; R, Lower Shushwap; S, Seton Confluence; T, Bridge River; U, Kelly Creek; V, Chilcotin Confluence; W, Farwell Canyon; X, Chilko; Y, Quesnel Confluence; Z, Likely; AA, Nechako Confluence; BB, Stuart Confluence.



ences in postrelease survivorship among treatment groups. Because sex could not be determined visually (i.e., fish were not showing secondary sexual characteristics), sex could not be reliably included as a factor in analysis. All values presented here represent means ± standard error (SE), unless otherwise noted. Statistical analyses were performed in JMP version 9.0 (SAS Institute Inc., Cary, North Carolina, USA).

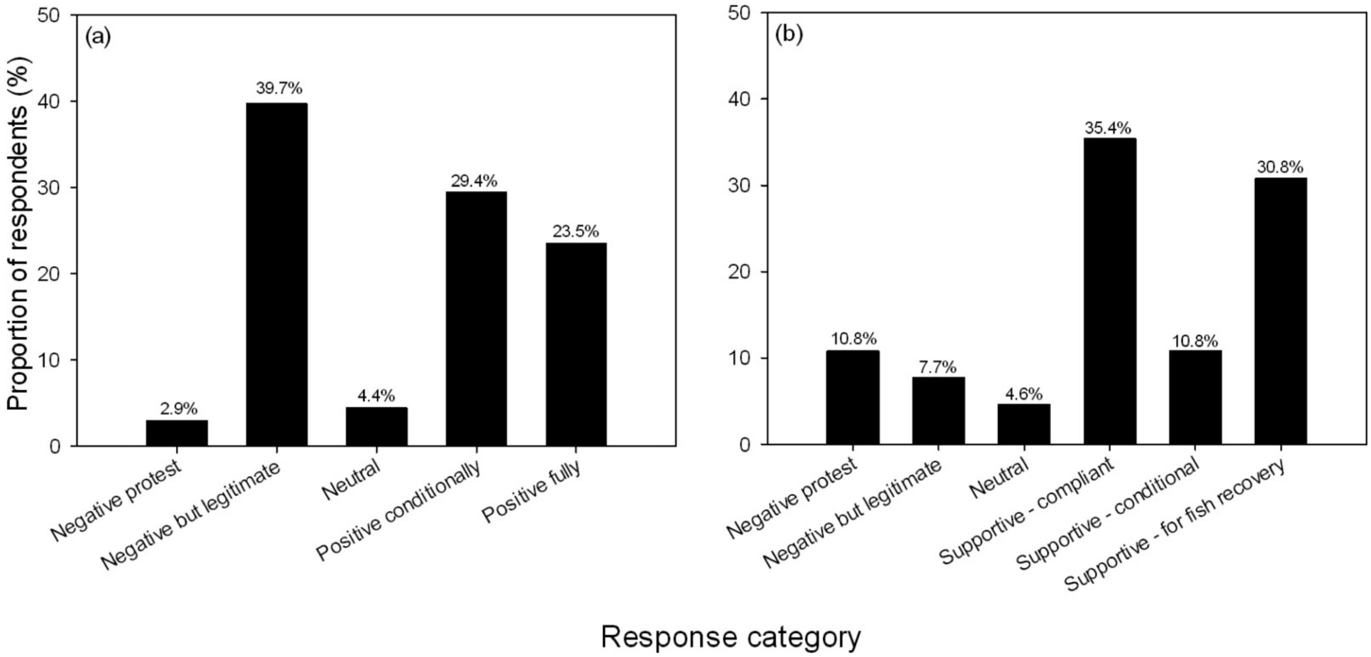
Results

Angler social science survey

Responses to the question "What do you think about the idea of a revival bag to help incidental [salmon] catches?" are shown in Fig. 3*a*. We found that 39.7% provided negative but legitimate responses: they were unsupportive of recovery bags as a catch-and-release tool, but for potentially legitimate reasons (e.g., they questioned their effectiveness or thought they were unnecessary when fish were handled properly). Interestingly, 29.4% were conditionally supportive of the concept (e.g., recovery bags might be used if mandated, if they were shown to be useful, for beginners only). We found that 23.5% were fully supportive of the use of recovery bags as a tool to help reduce catch-and-release mortality of salmon. When asked explicitly, 66.7% of respondents did not think there was a need for recovery bags. A total of 66.2% responded "yes," that they would use a recovery bag voluntarily. When asked "Suppose using a recovery bag was mandatory for reviving fish before releasing it — what are your thoughts on that?", responses were split among negative protest responses (10.8%), negative but legitimate responses (7.7%), supportive owing to compliance (with mandatory use regulations) responses (35.4%), conditionally supportive responses (10.8%), and fully supportive responses owing to the benefits for released salmon (30.8%; Fig. 3*b*).

A two-class model of indicator questions minimized AIC and there were no significant bivariate residuals, suggesting that all anglers cleaved into two clusters with internally homogeneous perspectives regarding recovery bag use (Table 1). Wald tests indicated that the coefficients for only two indicator questions were jointly significantly different than zero: "angler thoughts on idea

Fig. 3. Fraser River salmon angler responses to social science surveys on the support for using facilitated recovery gear to promote recovery of caught-and-released salmon. Panel (*a*) shows responses to the question, "What do you think about the idea of a revival bag to help incidental [salmon] catches?" Panel (*b*) shows responses to the question, "Suppose using a recovery bag was mandatory for reviving fish before releasing it — what are your thoughts on that?"



of recovery bag" (Wald = 10.14, $P \leq 0.01$), and "voluntary use of bag," (Wald = 6.07, $P \leq 0.05$). The first cluster, which constituted 53.8% of the sample, included respondents who demonstrated positive attitudes towards recovery bags and greater support for mandatory implementation and use of bags. The remaining 46.2% did not see a need for a recovery bag, though almost half of respondents would use it on a voluntary basis if the recovery bag was shown to increase salmon survival.

Facilitated physiological recovery

MANOVA revealed a significant whole model for $\log_{10}$-transformed plasma physiological variables and recovery period, velocity, and bag type (Wilk's $\lambda = 0.124$; $F_{[119,785.87]} = 2.497$; $P < 0.001$). Significant effects were found for recovery period (Wilk's $\lambda = 0.581$; $F_{[14,238]} = 5.308$; $P < 0.001$) and velocity ($F_{[7,119]} = 11.163$; $P < 0.001$), but not for bag type (Wilk's $\lambda = 0.861$; $F_{[14,238]} = 1.323$; $P = 0.194$) or its interactions. Mean FL was 50.2 ± 1.9 cm and did not differ among treatments (two-way ANOVA with recovery period and water velocity as effects; whole model $F_{[8,209]} = 1.45$; $P = 0.179$).

High and low water velocity with a recovery bag was more effective than no water velocity in mitigating simulated capture stress and was influenced by recovery period. For the 15 min recovery period, one-way ANOVA testing for differences among velocity groups revealed significant differences for plasma lactate ($F_{[3,63]} = 242.600$; $P < 0.001$), sodium ($F_{[3,63]} = 6.309$; $P < 0.001$), chloride ($F_{[3,63]} = 7.173$; $P < 0.001$), potassium ($F_{[3,63]} = 16.304$; $P < 0.001$), osmolality ($F_{[3,63]} = 62.144$; $P < 0.001$) and cortisol ($F_{[3,63]} = 26.925$; $P < 0.001$), but not glucose ($P > 0.05$; Fig. 4). Similarly, for the 30 min recovery period there was a significant effect of velocity on plasma lactate ($F_{[3,61]} = 253.972$; $P < 0.001$), sodium ($F_{[3,61]} = 5.785$; $P < 0.001$), potassium ($F_{[3,61]} = 19.298$; $P < 0.001$), osmolality ($F_{[3,61]} = 35.759$; $P < 0.001$) and cortisol ($F_{[3,61]} = 22.514$; $P < 0.001$), but not for either glucose or chloride (both $P > 0.05$). For the 60 min recovery period, there were significant differences among no-, low-, and high-velocity types in plasma lactate ($F_{[3,62]} = 258.412$; $P < 0.001$), potassium ($F_{[3,62]} = 6.944$; $P < 0.001$), osmolality ($F_{[3,62]} = 17.105$; $P < 0.001$), and cortisol ($F_{[3,62]} = 27.385$; $P < 0.001$), but not for either glucose, sodium, or potassium (all $P > 0.05$). Thus, high-velocity recovery emerged as the most effective treatment, with reduced plasma cortisol concentrations relative to the low-velocity group at 15 and 60 min postcapture, and similar plasma sodium and chloride concentrations as control values at all recovery periods. For most recovery periods measured, plasma glucose and potassium concentrations did not differ from control values.

Facilitated recovery and survival to reach spawning areas

Beach seine had the highest survival (57.5%), followed by angling plus air exposure plus recovery (50.0%), angling plus no recovery (30.8%), angling plus air exposure plus no recovery (28.6%), and angling plus recovery (16.7%). We did not have a beach seine recovery group in this study. Significant differences were found for survival to natal subwatersheds among treatment groups ($\chi^2 = 15.688$; df = 4; $P = 0.004$), with the beach seine group having the highest survival. An analysis of survival between the beach seine, angling, and angling plus air exposure groups with the recovery groups excluded revealed that beach seine had significantly higher survival relative to the two angling groups with no recovery ($\chi^2 = 7.379$; df = 2; $P = 0.025$). With the beach seine group excluded from the analysis and only the four angling groups compared, differences were not observed ($\chi^2 = 6.660$; df = 3; $P = 0.084$; Fig. 5). FL did not differ among treatment groups ($F_{[4,168]} = 0.514$; $P = 0.726$).

Discussion

Potential for recovery bag use by anglers

Our survey found that an equal proportion of anglers have generally positive attitudes towards recovery bags and support their implementation compared with the group that does not believe there is a need for recovery. The fact that one-quarter of survey respondents were fully supportive of using recovery bags when asked directly is encouraging, particularly since supporters show overwhelming support for recovery bag use if scientific evidence for their effectiveness were presented to them. While non-

Fig. 4. Plasma variables measured in adult pink salmon (*Oncorhynchus gorbuscha*) following an exercise treatment and a variable recovery period (15, 30, or 60 min) in portable recovery gears under no (black bars), low (light grey) or high (dark grey) water velocity and controls (white bars). Different recovery bag types were pooled for analyses as bag type did not emerge as a significant effect in whole model MANOVAs. Asterisks (*) denote the group differs significantly from control values. Dissimilar letters denote differences among groups at each recovery period.

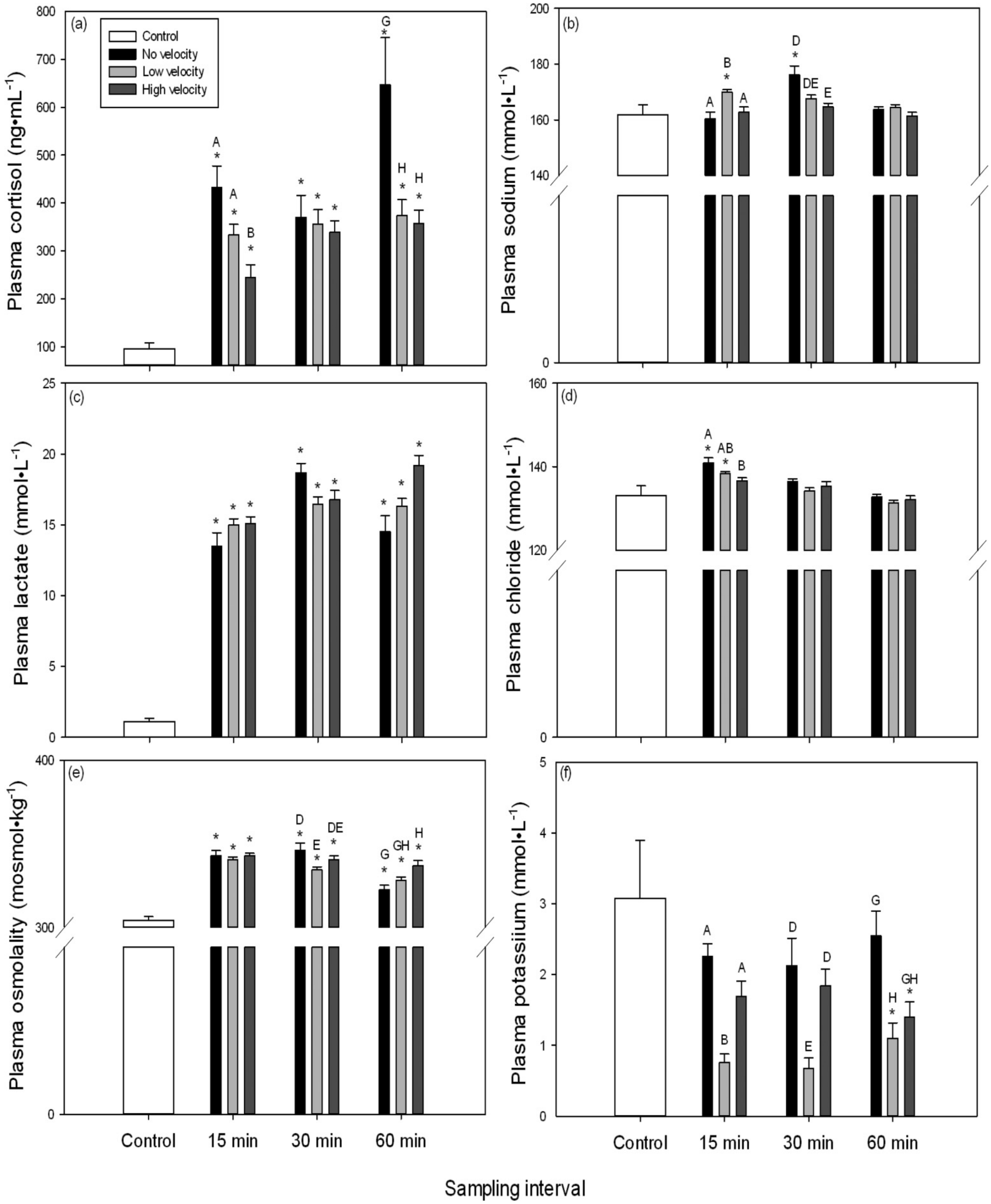
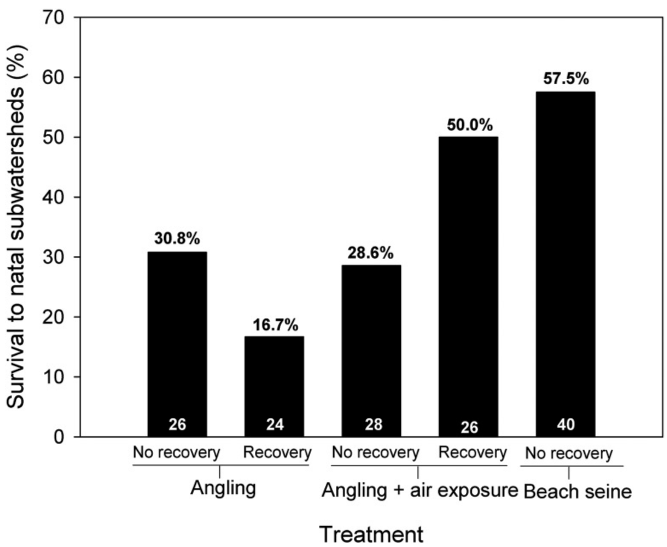


Fig. 5. Survival to reach natal subwatersheds for adult sockeye salmon (*Oncorhynchus nerka*) captured and released by recreational anglers in the lower Fraser River, British Columbia, Canada. Angled fish were either immediately released, placed in a recovery bag for 15 min prior to release, air exposed and immediately released, or air exposed and placed in a recovery bag for 15 min prior to release. Beach seine survival is included for comparison and all individuals from this treatment were immediately released (i.e., none were given a recovery treatment). Sample sizes for each treatment appear within the vertical bars.



supporters may still not agree unanimously with using recovery bags, that group was also more positive towards the use of recovery bags if they were presented with evidence of their effectiveness. Collectively, the social science survey showed that while some stakeholders were directly supportive of recovery bags, most respondents would like to see scientific evidence of their effectiveness before supporting their use. The rationale behind conducting the social science surveys was to determine whether anglers would even be willing to use recovery gear if evidence existed that such techniques could be beneficial to released fish. This is important because conflict between recreational angling communities and managers have been described previously (e.g., Danylchuk et al. 2011), and determining whether the bags would even be hypothetically used in practice was a necessity before proceeding with the physiology and telemetry components. Given the generally positive attitudes, the laboratory and field experiments discussed below are certainly relevant towards assessing the utility of recovery gear in practice.

Facilitated physiological recovery

The capture simulation resulted in pink salmon mounting a major stress response, typical of exercise stress (Milligan 1996). The combined exercise and air exposure treatment resulted in fish generally showing signs of fatigue, including equilibrium loss and inability to burst swim following the treatment. As a consequence many fish were unable to engage in normal swimming after treatment and likely would have drifted downstream of the study area if they had not been placed immediately in recovery bags. At 15 min, the high velocity resulted in reduced plasma cortisol concentrations relative to the non-recovery group, a result consistent with previous studies of rainbow trout (Milligan et al. 2000) and coho salmon (Farrell et al. 2001*a*, 2001*b*). Recovery using high water velocity was the only treatment where sodium and chloride concentrations consistently remained unchanged, further supporting the superiority of this velocity for recovery. This is an important result for anadromous fish that had recently undergone a shift in osmoregulatory physiology upon transition from marine to freshwater environments. Impaired osmoregulatory function has been linked with the initiation of rapid senescence and premature death in sockeye salmon (Hruska et al. 2010), and plasma chloride concentrations can correlate strongly with longevity for this species (Jeffries et al. 2011). Plasma potassium did not differ between control and recovery treatments for the 15 and 30 min recovery periods. Exercise can result in increased plasma potassium as this ion is lost from muscle (Sejersted and Sjøgaard 2000), but we found that plasma potassium was unchanged relative to treatment. Likewise, plasma glucose was the same among groups and recovery periods and fell in the range measured in adult coho salmon captured by dip net from hatchery raceways (5–6 mmol·L^{-1}, Donaldson et al. 2010*a*) and sockeye salmon captured by hook-and-line or net and sampled rapidly (6–7 mmol·L^{-1} Donaldson et al. 2011), both in freshwater. These results suggest that facilitated recovery was generally effective at reducing the cortisol response and maintaining ion–osmoregulatory balance and metabolic state, although plasma lactate remained elevated postexercise.

Despite a positive effect of recovery bags for some parameters measured, recovery was not complete to the extent observed for rainbow trout in the laboratory by Milligan et al. (2000). Kieffer et al. 2011 reported that metabolic recovery of brook trout was not expedited for fish swimming at certain speeds, although they did observe that fish with access to higher flows swam for longer periods of time during a swimming challenge and that fish had a tendency to move towards areas of higher flow after exercise stress. Likewise, Farrell et al. (2001*b*) found that adult coho salmon placed in Fraser recovery boxes for 1 or 2 h had only a partial recovery of muscle metabolites and that plasma metabolites and indices of stress and ion–osmoregulatory balance did not recover. Increased plasma osmolality and lactate as observed in our study are typical postexercise, owing to a decrease in muscle and blood pH caused by lactic acid dissociation (Wang et al. 1994), which in turn disrupts ion–osmoregulatory balance as water shifts from blood to muscle (Wood 1991). Plasma cortisol concentration, even in our most effective high-velocity treatment, was still 2.5-fold higher than in controls, but still much lower than in our no-velocity group. Plasma cortisol concentration in the present study was also lower than that for coho salmon following a 1 or 2 h recovery in a Fraser box (i.e., 380–1270 ng·mL^{-1} (Farrell et al. 2001*b*). The generally high plasma cortisol values are expected, since this parameter tends to be higher in the final stages of reproductive maturation for Pacific salmon and can vary greatly by sex, with females typically having higher circulating values (Sandblom et al. 2009; Donaldson et al. 2010*a*).

Facilitated recovery and survival to reach spawning areas

Aside from the beach seine only treatment that was included for reference, the air exposed recovery treatment represents the highest survival of the angling groups. These survival results must be interpreted cautiously, since the significant differences observed in this comparison appear to have been driven by the beach seine group, likely owing to the low number of individuals reaching spawning areas for some of the angling groups. Even still, the recovery bag treatment resulted in >20% higher survival relative to immediately released fish for the air exposure group, suggesting that this method could benefit fish exposed to air. The nearly twofold decrease in survival for the non-air exposed group suggests that care must be exercised when determining which fish require facilitated recovery and which would instead benefit from immediate release. This may lend further support to the recommendations of Farrell et al. (2001*b*), who suggest immediate release of individuals in vigorous condition (e.g., capable of maintaining equilibrium and burst swimming) or perhaps individuals that underwent less stressful handling (i.e., short duration of air exposure). In the present study, following the air exposure treatment in particular, fish were incapable of burst swimming and many had difficulty maintaining equilibrium, suggesting that these individuals may have had short-term difficulty accessing locations of suitable velocity for recovery of their own volition. The increased survival for the air-exposed recovery group relative to the air-exposed immediate release group may be the result of expedited physiological recovery and reduced metabolic costs associated with the stressor, as observed by Farrell et al. (2001*b*).

The survival of beach seine and angling capture groups (52.2% and 36.3%, respectively) in a study by Donaldson et al. (2011) compare favourably with those identified in our study, which used the exact same telemetry and experimental methods, but without an experimental air exposure treatment and without facilitated recovery. Interestingly, the beach seine group had higher survival than either the angling or angling and air exposure groups that were not given the recovery treatment, providing additional evidence that release following beach seine capture can result in higher survival for sockeye salmon relative to angling (Donaldson et al. 2011). To put our survival proportions in context, Martins et al. (2011) found that sockeye salmon captured in freshwater environments by either fish wheel or tangle net had survival to spawning areas ranging between 30% and 50%. However, sockeye salmon captured and released by purse seine in the marine environment had >70% survival from their first detection in the lower Fraser River to spawning areas (Martins et al. 2011). These marine tagged individuals may represent the best available telemetry survival data that approach true baseline survivorship values for the freshwater migration, since tracking them from river entry (i.e., excluding mortalities that occur in the marine environment) enables the exclusion of capture and handling effects that occur in freshwater environments. Based on this 70% baseline survival value, we conclude that beach seine capture and release resulted in 12.5% reduced survival relative to baseline, recovery bag following angling and air exposure resulted in 20% reduced survival relative to baseline, and other treatments resulted in approximately 40% or greater reduced survival relative to baseline.

Synthesis

Facilitated recovery has the potential to increase postrelease survival (Farrell et al. 2001*a*, 2001*b*), which has great relevance to freshwater fisheries, where fish may be released or escape from various fisheries sectors and gear types. While angler response was not unanimous, respondents were generally supportive of the possibility of recovery bag use, particularly if there is evidence of their effectiveness. Engaging anglers early is important because the method by which the bags are used by anglers will undoubtedly influence their effectiveness for recovery. Our physiology results suggest that the type of bag is less important than the water velocity itself, since several bag designs resulted in a reduced physiological disturbance relative to no velocity, particularly for the 15 min high-velocity group. We found that the 15 min recovery period with a high water velocity was most effective, and this seems like a pragmatic time point for anglers. However, inability to find suitable velocity water could be problematic. For our telemetry study, bags were placed in the highest available velocity at the site of the study area, but these velocities were still lower than the optimal “high velocity” treatment from the physiology study. The observed benefit of recovery bags to air-exposed fish survival suggests that velocities of $\sim$0.1 $m \cdot s^{-1}$ could still improve survival for fish in poor condition; however, more research is required to further elucidate the optimal conditions for recovery and the minimum velocities required to promote survival. Fish in vigorous condition may benefit from immediate release, whereas those in poor condition (i.e., unable to burst swim or maintain equilibrium) are more likely to benefit from a short-duration facilitated recovery, provided that suitable water velocities can be located.

Directions for future research

Given the promising but not unequivocal results presented here, additional studies are required to further optimize recovery methods before such techniques could be used as a conservation tool in freshwater fisheries. A comparative study that tests different water temperatures, water velocities, timing, and recovery gear type is warranted. With the importance of water velocity in enhancing recovery, future work might focus on determining optimal velocities and exploring bag designs that optimize water velocity within the bag. Combining laboratory-based (e.g., under different temperature conditions and water velocities) and field-based (e.g., telemetry) study designs as we have done here would be likewise beneficial, since it provides mortality as an endpoint but also enables greater insight into the mechanisms that may contribute to mortality.

Use of a light-weight, collapsible bag remains beneficial for this purpose, since it can be easily transported. However, modifying Fraser boxes (Farrell et al. 2001b) for portability could be useful for certain fisheries that are easily accessed by roads and have a high density of anglers or on-shore net fisheries. Using light-weight construction materials and portable pumps (e.g., battery or solar operated) could provide sufficient flow even in low-flow areas.

Given the species-specific nature of the stress response in fish (Black 1955; Turner et al. 1983), many research opportunities exist to determine the most effective methods of facilitating recovery depending on the physiological needs of different species. For example, low-velocity swimming appears to not enhance recovery from exhaustive exercise in centrarchids in the way it does for salmonids. Even within the salmonid family there can be important species-specific responses to stress (Pottinger 2010) and recovery (Donaldson 2012), and swimming during recovery from exercise has been shown to not expedite physiological recovery for brook trout (*Salvelinus fontinalis*; Kieffer et al. 2011). Even so, the general principles of expedited recovery first observed for rainbow trout (Milligan et al. 2000) seem to be applicable to at least some other salmonid species (e.g., Farrell et al. 2001*a*, 2001*b*). Future work needs to explore how, or whether, facilitated recovery would be beneficial for species other than the closely related salmonid species examined here.

Together, these three studies suggest that recovery bags hold promise for facilitating physiological recovery and promoting survival of Pacific salmon captured in fresh water. The generally positive attitudes towards recovery bag use by anglers, particularly if such techniques were found to be effective, provides rationale for further exploration of facilitated recovery methods. Our physiology and telemetry studies provide evidence that recovery bags have potential for promoting physiological recovery and survival, respectively, and lay a foundation for enhancing facilitated methods. Given that recovery bags can be a simple, inexpensive, and portable means of facilitating recovery, they could be conducive for use in the recreational fishery and, owing to this sector's similarities with many commercial fisheries (Cooke and Cowx 2006), other small-scale inland fisheries that operate from shore. Our results provide an important step forward in identifying methods for promoting recovery from fisheries capture stress, which has consequences for increasing the sustainability of freshwater catch-and-release. This work provides a unique example where conservation physiology and social science can be integrated to address a management concern, and we hope that other researchers seek out similar opportunities in the future.

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