The role of angler behaviour on the post-release locomotor activity and depth selection of angled fish revealed by biologgers

by

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General Abstract

Catch-and-release (C&R) angling is a growing practice worldwide with the number of fish released each year by anglers in the billions. Research has demonstrated that C&R can result in significant physiological stress for fish, however few studies have been able to observe fine-scale behaviour in the wild after they are released from angling events. Recent advancements in technology have led to the development of smaller biologging devices that are able to be attached to fish externally or surgically implanted in order to gather behavioural data of fish in the wild. The goal of my thesis was to assess fish behaviour in the wild following various angling scenarios using externally attached biologgers. Chapter 2 focused on assessing the impacts of air exposure on the post-release behaviour of three gamefish species. My data suggested that Northern Pike that were air-exposed exhibited decreased swimming activity immediately after release, however the same trends were not observed for Smallmouth Bass or Walleye. In chapter 3, I evaluated the efficacy of assisted recovery methods at reducing post-release behavioural impairments in Rainbow Trout. I determined that assisted recovery was effective at reducing equilibrium impairments, especially if the water temperature in the recovery devices was significantly cooler than ambient surface water temperatures. In both chapters, behavioural data was gathered using externally attached biologgers equipped with tri-axial accelerometers and pressure/temperature sensors. Collectively, these results suggest that the impacts of a C&R event on the swimming activity of released fish can vary greatly with the species targeted, angler behaviour, and environmental factors. My thesis also introduces a novel, minimally invasive method for the external attachment of biologgers on fish for monitoring post-release behaviour in a natural setting.

Dedication

To Steve, thank you for your constant support and positivity throughout my time in the lab. Over the past 3 years I've learnt things that I never would have imagined, such as how to drive a trailer, how to write code, and how to set the hook. I will forever be grateful for all the opportunities that this lab has given me. To Andy, Gabe, and Michael, thank you for your guidance. Advising a student remotely was not an easy task and I am grateful for the mentorship that I received from you all. To my field partners and closest friends: Danny, Alley, Jess, Ben, Pete, Jen and Brooke, thank you for sticking with me through thunderstorms, flat tires, and clouds of horse flies. This thesis wouldn't be possible without you all. To Ben, Rob, and Jake, thank you for your endless help with stats and R, and for always helping me with my code no matter how silly the question. To Britt, thank you for keeping me grounded through all the tough times, and for making me smile every single day. Lastly to my family, thank you for always encouraging and supporting me from the very beginning. You always helped me believe that I could do anything.

Co-authorship Statement

Short-term behavioural impacts of air exposure in three species of angled freshwater fish.

Auston D. Chhor, Daniel M. Glassman, Jacob W. Brownscombe, Alexandria T. Trahan, Andy J. Danylchuk, Steven J. Cooke

This manuscript has been submitted to the journal Fisheries Research. This project was conceived by Chhor, Danylchuk, and Cooke. Fieldwork was completed by Chhor, Glassman, and Trahan. All statistical analyses were conducted by Chhor with assistance from Brownscombe. All authors contributed feedback to the manuscript.

The efficacy of assisted recovery for reducing post-release behavioural impairments in angled Rainbow Trout (*Oncorhynchus mykiss*).

Auston D. Chhor, Jessica L. Reid, Peter E. Holder, Liane B. Nowell, Jacob W. Brownscombe, Andy J. Danylchuk, Steven J. Cooke.

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Chapter 1: General Introduction

1.1 Catch and Release Angling

Catch and release (C&R) angling has long been characterized as a conservation minded approach to recreational fishing. Globally, C&R is growing significantly, and is already established as an economically and culturally important pastime in many countries (Arlinghaus et al. 2007). Over the past half century, the number of fish which are captured and released has increased immensely (Bartholamew & Bohnsack 2005; Brownscombe et al. 2014a). As a result, policies regulating C&R play leading roles in the management of highly sought-after gamefish such as Black Bass (*Micropterus spp.*) (Siepker et al. 2007), Atlantic Salmon (*Salmo salar*) (Kieffer et al. 2002), and Walleye (*Sander vitreus*) (Sullivan 2003). C&R is not without consequences, as many, if not all fish which are captured experience some sort of injury and/or physiological stress. A C&R event can be generally classified into two components: the fight, and landing. Exhaustive exercise during the fight activates anaerobic metabolic pathways and leads to a host of physiological consequences including increasing muscle lactate (Arlinghaus et al. 2009), plasma acidosis (Kieffer et al. 2002), and increasing the production of stress hormones (Meka & McCormick 2005). During landing, fish are often air-exposed when they are netted, dehooked, and/or photographed. In combination with exhaustive exercise, air exposure can increase concentrations of muscle lactate and cause increased extracellular acidosis (Ferguson & Tufts 1992). Upon release, physiological stress can lead to alterations in behaviour and occasionally cause mortality. The abundance of research concerning the negative impacts of air exposure have led many conservation groups and fisheries managers to advocate for minimizing air exposure when practicing C&R. Additionally, improved handling practices can also help mitigate sub-lethal alterations to physiology and behaviour (Ferter et al. 2013; Brownscombe et al. 2017a). Recommendations made to best-practices for handling may also need to vary with species and angling scenarios (Cooke & Suski 2005) due to species-specific or size-specific variation in stress tolerance. In general, physiological disturbances that occur during C&R can often be reversed if the environment which the fish is released in is well oxygenated and free from additional disturbances (Milligan 2000; Suski et al. 2006). As C&R is expected to grow, science supporting handling practices that maximize fish welfare and survival will be an important conservation tool.

1.2 Stress Induced Behavioural Alteration

Behaviour can serve as a qualitative indicator of the physiological and biochemical alterations induced by stress as behavioural changes are often correlated with the production of various stress hormones such as cortisol (Schreck 1997). Moreover, when fish are exhausted Kieffer 2000), behavioural impairments are commonly observed. Observing the post-release behaviour of fish can provide broader predictions of future biological consequences after a C&R event. Stress resulting from a C&R event can lead to impairments of swimming performance, (Schreer et al. 2005), parental care (Suski et al. 2003), and reflex action (Twardek et al. 2018). Deviations from normal behaviour which impact foraging, predator avoidance, reproduction and swimming performance can increase the probability of mortality and/or decrease the reproductive fitness of the individual (Schreck et al. 1997). For instance, Danylchuk et al. (2007a) noted that air exposure was strongly associated with the loss of equilibrium in Bonefish (*Albula vulpes*), and that equilibrium impaired fish were six times more likely to be preyed upon. Elevated water temperature can also play an additive role in determining post-release impairments of Bonefish (Brownscombe et al. 2015). In nest guarding taxa such as Black Bass, stress associated with C&R events can cause males to take longer to return to their nest (Kieffer et al. 1995), reduce parental care (Suski et al. 2003), and increase the likelihood of nest abandonment (Cooke et al. 2000). Such disturbances can leave the nest and offspring vulnerable to predation and result in partial or complete loss of the brood (Steinhart & Lunn 2010; Stein & Philipp 2015). In Atlantic Salmon (*Salmo salar*) C&R angling has been shown to impact upstream migration by increasing downstream resting periods and altering movement patterns (Mäkinen et al. 2000; Thorstad et al. 2007; Lennox et al. 2015; Havn et al. 2015). In non-migratory species, studies have found increased movement activity following a C&R event in Atlantic Sharpnose Sharks (*Rhizoprionodon terraenovae*) (Gurshin & Szedlmayer 2004), Northern Pike (*Esox lucius*) (Klefoth 2008), and African Cichlids (Cichlidae spp.) (Thorstad et al. 2004). Recovery from behavioural disturbance is often achievable, and Brownscombe et al. (2013) found that the usage of recovery bags reduced post-release behavioural impairments. Assays of these behaviours, among others, serve as qualitative indicators of stress and can help to form hypotheses regarding survival, growth, and reproduction (Beitinger 1990).

1.3 Studying behaviour in wild fish

The advent of waterproof data transmitters has allowed researchers to remotely observe fish activity in their natural environment. Remote observation removes potential stressors associated with captivity and thus can allow for a more accurate depiction of natural behaviour. Historically, the majority of data gathered from biologgers involved the usage of radio, GPS, or acoustic telemetry to study broad-scale spatial ecology (e.g., movement patterns, depth usage) (Cooke et al. 2004; Thorstad et al. 2013). While useful for generating knowledge on fish movement, these biologgers lack the resolution require to evaluate short-term (i.e., 0 – 30 min) behaviour after an angling event. Recently, biologgers equipped with tri-axial accelerometers have allowed for the quantification of fine-scale behaviours (Brownscombe et al. 2014b; Lennox et al. 2018) and swimming performance (Murchie et al. 2011; Broell et al. 2013; Brownscombe et al. 2014b). From accelerometric data, algorithms can be produced to classify data into distinct behaviours such as resting, foraging, and burst swimming. Behavioural classification has been accomplished in both terrestrial (Nathan et al. 2012; McClune et al. 2014) and aquatic taxa (Føre et al. 2011; Brownscombe et al. 2014b; Landsman et al. 2015; Lennox et al. 2018). In one study, accelerometer derived behavioural classification was able to identify behaviours with 97% accuracy (Brownscombe et al. 2014). Behavioural classification from accelerometric data allows researchers to remotely study behaviours that may be vital to survival, and thus gives a better understanding about how angling events can impact the short-term welfare of fish. These same devices can also be equipped with sensors that measure pressure (i.e., depth) and temperature to further give insight on depth selection and thermal preferences.

1.4 Introduction to study species

For chapter 2, I studied three recreationally important freshwater fish found in North America: Walleye (*Sander vitreus*), Northern Pike (*Esox lucius*), and Smallmouth Bass (*Micropterus dolomieu*). Walleye are also a commercially important fish, and increased pressure has resulted in population decline in some lakes (Post et al. 2002; Sullivan 2003). Furthermore, a larger proportion of Walleye are harvested compared to other recreationally targeted species. In response, management officials often implement minimum length restrictions to reduce harvest of juvenile or pre-spawn individuals, however the effectiveness of such regulations is dependent heavily on the survival of released sub-legal fish (Sullivan 2003). In comparison, the majority of

Smallmouth Bass and Northern Pike angling is C&R focused. The incidence of C&R practices for Northern Pike is relatively high with the majority of Pike captured being released (Pierce et al. 1995). In North America, management of the Northern Pike fishery is structured around regulatory or voluntary catch and release to manage harvest (Paukert et al. 2001). C&R science suggests that Northern Pike are relatively resilient and recover quickly after an angling event, but still experience some degree of physiological and behavioural impairment, particularly after extended durations of air exposure (Klefoth et al. 2008; Arlinghaus et al. 2009). From a research perspective, Northern Pike can serve as a model species for other *Esox* species, namely Muskellunge (*Esox masquinongy*), who are the target of devoted C&R anglers and can be significantly more difficult to capture and subsequently study. More than 30,000 recreational angling tournaments occur each year in North American waterbodies with a majority of those specifically targeting Black Bass (Schramm et al. 1991). Like most fish, Smallmouth Bass experience physiological distress during angling events however the impairments can also lead to fitness consequences if nest guarding behaviour is affected (Cooke et al. 2002).

Chapter 3 focused on the impacts of angling on Rainbow Trout, a cold-water Salmonid species native to western North America but introduced worldwide (MacCrimmon 1971). There is an abundance of research surrounding the impacts of C&R on Rainbow Trout as they are widely distributed and easily studied. However, a significant portion of such studies have been conducted in laboratory settings under relatively benign conditions (e.g., Ferguson & Tufts 1992; Pope et al. 2007). Climate change is expected to alter water temperatures globally (Eaton & Scheller 1996; Ruiz-Navarro et al. 2016; Chambers et al. 2017), therefore it is critical that C&R studies are conducted in the wild to best represent actual angling scenarios and outcomes.

1.5 Thesis overview and research objectives

The goal of chapter 2 was to determine the behavioural consequences of air exposure in angled Northern Pike, Smallmouth Bass, and Walleye. Fish were angled from lakes in Eastern Ontario, Canada and air exposed for 15 s, 30 s, 60 s, 180 s, or none at all (0 s). Tri-axial acceleration and depth biologgers were externally attached to the fish using Velcro® harnesses and post-release behaviour was monitored for a 10 min period. Acceleration data were used to calculate Overall Dynamic Body Acceleration (ODBA), a measure of total swimming activity. ODBA values were then classified into distinct behavioural categories using unsupervised k-means clustering: resting, steady-state swimming, and high-intensity swimming.

The goal of chapter 3 was to determine the effectiveness of assisted recovery in angled Rainbow Trout. Tri-axial acceleration and temperature biologgers were used to compare post-release behaviour in fish that were retained in recovery devices under various water temperatures and fish that were immediately released. Fish were angled from stocked lakes in western Quebec, Canada and air exposed for 15 s, 30 s, or none at all (0 s) then held in a flow box, water filled cooler, or released immediately. Water temperature in the recovery devices was either ambient temperature (25 – 27 ºC) or cold (17-19 ºC). I attached tri-axial acceleration and temperature biologgers to the fish in a similar fashion to chapter 2 and monitored post-release behaviour for a 10 min period. Time to regain equilibrium was also compared between recovery devices, recovery temperatures, and air exposure treatments.

Chapter 2: Short-term behavioural impacts of air exposure in three species of angled freshwater fish

2.1 Abstract

Fish captured and released by recreational anglers are often exposed to air to enable hook removal and for admiration (i.e., photography). It is necessary to identify thresholds for air exposure that minimize sub-lethal impacts to inform best practice guidelines yet doing so in ecological-relevant field settings is challenging. I developed a novel attachment method for tri-axial accelerometer and depth biologgers to quantify short-term post-release behaviour in recreationally angled Northern Pike (*Esox lucius*), Smallmouth Bass (*Micropterus dolomieu*), and Walleye (*Sander vitreus*) following a range of air exposure treatments (i.e., 0, 15, 30, 60, and 180 s). The biologgers were attached to the fish using a quick-release Velcro® harness that facilitated easy retrieval of the device from free-swimming fish without the need to recapture the individual. For this study, biologgers were retrieved after a 10 min recording period. Overall dynamic body acceleration (ODBA) was calculated from accelerometric data to estimate post-release swimming activity. Unsupervised k-means clustering of ODBA was used to classify distinct swimming patterns: resting, steady-state swimming, and high intensity swimming occurrences. In Northern Pike, ODBA in the first minute after release was significantly higher in the 0 s air exposure treatment compared to the 15 s, 30 s, 60 s, and 180 s treatments, though the same patterns were not observed for Smallmouth Bass or Walleye. I did not observe differences in the time spent resting, time spent swimming, or the number of high intensity swimming occurrences among air exposure treatments across the three study species. This proof-of-concept experiment demonstrated the utility of this non-invasive biologger approach for the short-term study of fisheries interactions and also revealed that for the species and context (e.g., water temperatures of 17-25 º C) studied here, air exposure had relatively little negative short-term impact on behaviour or reflex impairment. Nonetheless, I encourage air exposure to be minimized as longer fight times or higher water temperatures may interact with air exposure to increase behaviour impairments and negatively impact survival.

Key Words: Recreational angling, air exposure, biologgers; behaviour, post-release

2.2 Introduction

Catch and release angling (C&R) is practiced worldwide and is an important tool for the conservation of fish stocks whether to comply with regulations or because of angler conservation ethic (Cooke & Schramm 2007). Given that the number of fish released annually by anglers is in the billions (Cooke & Cowx 2004), there is great interest in ensuring that released fish survive and recover from injuries and stress experienced during the process. Indeed, cryptic mortality arising from C&R can complicate management (Coggins et al. 2007) and undermines the value of C&R as a management tool (Wydoski 1977; Cooke and Schramm 2007). Even when fish survive, injuries and stress have the potential to reduce fitness (Arlinghaus et al. 2009) and diminish the welfare status of angled fish (Cooke & Sneddon 2006). As such, there have been great efforts to identify the factors that influence mortality, injury and stress in order to inform best fishing practices (see Brownscombe et al. 2017a).

One of the factors that is regarded as important in influencing outcomes for angled fish is the duration of air exposure (Cook et al. 2015). Although results vary among species and contexts, it is reasonable to conclude that air exposure is not of benefit to fish and that beyond a threshold it can lead to mortality (Cook et al. 2015). What is unclear is how air exposure thresholds translate to post-release behavioural impairments in the field. Such information would be useful for overcoming some of the criticisms of existing research that has been largely restricted to laboratory environments (e.g., Ferguson & Tufts 2001; Cooke et al. 2001; White et al. 2008). One of the few studies that has evaluated the effects of air exposure on fish behaviour in the field revealed that for Bonefish, air exposure was strongly associated with the loss of equilibrium, and fish that were released without equilibrium were six times more likely to experience post-release predation in the short term. (Danylchuk et al. 2007a).

Behaviour can serve as an important biomarker for physiological changes associated with stress (Schreck et al. 1997). In natural settings, stress induced behavioural alteration plays a leading role for the avoidance or tolerance of stressors that could negatively impact fitness. Such behaviours can include predator avoidance, temperature selection, and parental care (Beitinger 1990). Such behaviours serve as qualitative indicators of stress and can help to form hypotheses regarding survival, growth, and reproduction (Beitinger 1990). Extreme deviations from normal behaviour can indicate an increased likelihood of mortality. In fish, stress associated mortality can be predicted by evaluating reflex action mortality predictors (RAMP) such as righting response, body flex upon restraint, and vestibular-ocular response (Davis 2010). Stressors can also alter reproductive behaviour such as nest guarding and mating rituals, which can have serious implications for individual fitness as well as the health of the population (Cooke et al. 2002). Behaviour has the potential to be used to understand the ecological consequences of fisheries interactions (Donaldson et al. 2008) and to identify thresholds for different aspects of a C&R event such as air exposure duration.

Tri-axial accelerometer biologgers have recently been used in a variety of taxa including fish to remotely observe animals in their natural environment (Brownscombe et al. 2014b; Cooke et al. 2016). Studying free-ranging animals removes potential stressors associated with captivity and thus can give a more accurate depiction of natural behaviour (Rutz & Hays 2009). Recently, advances in data processing have allowed for the classification of specific behaviours from tri-axial acceleration data. In the aquatic realm, fine-scale behaviours such as foraging, air breathing, and high intensity swimming have been classified in a number of aquatic species

(Føre et al. 2011; Brownscombe et al. 2014b; Lennox et al. 2018). When compared to visual observations, the analysis of acceleration data has been shown to be able to predict such behaviours in fish with a high degree of accuracy (Brownscombe et al. 2014b).

The objective of my study was to observe the short-term post-release behaviour in angled freshwater gamefish and to determine if behavioural alterations were associated with air exposure. I did not quantitively conduct inter-specific comparisons as fish were captured from different lakes in a variety of environmental conditions, potentially influencing behaviour. Included in my study were Northern Pike, Smallmouth Bass, and Walleye. Northern Pike are a recreationally important freshwater gamefish found throughout the Northern Hemisphere in North America and Europe. In North America, the incidence of C&R practices for Northern Pike is relatively high with the majority of fish being released (Pierce et al. 1995). Previous studies on Northern Pike suggest that C&R events induce some level of physiological and behavioural impairment, however such impairments are short-term and reversible (Arlinghaus et al. 2009; Klefoth et al. 2008). Smallmouth Bass are also an important freshwater gamefish and are one of the two Black Bass species (*Micropterus spp.*) that are highly prized by anglers (Quinn & Paukert 2009). There is a strong conservation ethic among Bass anglers such that release rates are quite high even when harvest regulations are in effect. Walleye are also managed through mandatory/voluntary C&R programs although regulations tend to include smaller bag limits and the extensive use of size regulations given their popularity as a food item (Goeman 2002). By focusing on these species, the outcome of my study aims to contribute to developing species-specific handling guidelines (Cooke & Suski 2005) which benefit the welfare and survival of fish that are released.

2.3 Methods

2.3.1 Study Sites

Northern Pike were angled on Opinicon Lake, located in South Frontenac, Ontario (44.558784 -76.328816) between June 3rd and June 7th, 2019. The lake is relatively shallow (average depth 2.5 m), and moderately developed (CRCA 2017).

Smallmouth Bass were angled on Big Rideau Lake in Lanark County, Ontario (44.729426 -76.239921) between July 10th and July 24th, 2019. The lake is deep (max depth 109 m) and is arguably one of the most developed lakes in the Rideau system and as a result experiences heavy multi-species angling pressure.

Walleye were angled on Mississippi Lake, located in Carleton Place, Ontario (45.030765 -76.202722) between August 7th and August 27th, 2019. Mississippi Lake is a natural lake situated between two stretches of the Mississippi River and is relatively shallow (max depth 9 m) and relatively developed (MVCA 2014). The lake is a productive recreational fishery for Black Bass, Walleye, and Northern Pike and experiences significant fishing pressure both in the summer and winter as a consequence of its proximity to metropolitan areas.

2.3.2 Fish Capture

All three fish species were captured using spinning or baitcasting rods spooled with 13.6 kg break-strength braided line and equipped with artificial lures (crank baits, soft plastics), 1.7 g – 3.5 g jigs tipped with live bait (leeches, worms, minnows), or by trolling 14 g bottom bouncers rigged with crawler harnesses. For each species, I attempted to conduct angling in relatively similar habitat and depths within the lake, however this was not always possible due to environmental factors and catch rates. Generally, Northern Pike were angled along deep channels (3 – 4.5 m) with defined weed edges, Smallmouth Bass were angled along rocky points and drop-offs (4.5 – 6 m), and Walleye were angled off underwater humps and large flats (5 – 7 m). Northern Pike and Smallmouth Bass were primarily caught by casting-retrieving, while Walleye were primarily caught trolling. Both treble and single hooks were used, and all hooks were barbed. Fish were fought for no longer than 30 s from initial hookset to landing, and all fish were landed in a rubber net to minimize mucus loss (Barthel et al. 2003; Lizeé et al. 2018). Fish were quickly transferred to a cooler filled with fresh lake water, and the water was changed between fish to ensure adequate oxygen levels. Once in the cooler, embedded hooks were removed with pliers while the fish remained submerged. Dehooking took no longer than 1 min and fish that were deeply hooked or exceeded the 1 min dehooking threshold were excluded from the study. Total length (mm), surface water temperature (Cº), water depth at the release site (m), and presence/absence of major reflex action mortality predictors were assessed prior to the air exposure treatment. Reflex action mortality predictors (RAMP) are behaviours that can indicate increased risk of mortality in fish which include equilibrium, startle response, mouth clamping, fin erection, body flex upon restraint, and vestibular ocular response (Davis et al. 2010). For the purposes of this study, I assessed three such behaviours (equilibrium, startle response, operculum/eye activity) as they were able to be evaluated without requiring restraint of the fish (i.e., body flex, mouth clamping, gag response). To evaluate post-release behaviour, I attached biologgers (Technosmart Axy-Depth, Rome, Italy, 7.5 g in air, ~ 3.5 g in water, 12 x 31 x 11 mm) (sampling rate: tri-axial acceleration = 25 Hz, temperature/depth = 1 Hz, Resolution: tri-axial acceleration = 8 bit, temperature = 0.1 º C, depth = 5 cm, G scale = 8) around the mid-body of the fish using a custom made harness which consisted of the logger epoxied to a plexiglass plate and threaded through a length of Velcro® tape (3M Scotch Fasteners, Saint Paul, USA, length = 20 – 25 cm, width = 1.5 cm) (Figure 2.1). Harnesses of various lengths were used to accommodate fish of different girths. While fish were submerged in the water filled cooler, a biologger harness was affixed by wrapping the length of Velcro® around the mid-body and positioning the biologger centred on the ventral side between the pelvic fins (Figure 2.2). Care was taken to ensure that the Velcro® straps were not hindering the normal range of motion for both the pelvic and pectoral fins in order to reduce the impact of the harness on the swimming performance of the fish. In Smallmouth Bass and Walleye, attaching the harness required the compression of the dorsal spines against the body. Through analysis of underwater videos and snorkel surveys, I noticed little to no dorsal spine flexion in both Smallmouth Bass and Walleye during normal swimming behaviour, suggesting limited use for propulsion or directional movement. The biologgers harness was then connected to a fishing rod and reel spooled with 27 kg braided spectra line by clipping a small snap swivel through a reinforced hole in one end of the Velcro® strap. The air exposure treatment was then conducted, and the fish was again assessed for equilibrium, startle response, and operculum/eye activity at the moment of release. Fish were released by hand at the side of the boat and the bail on the reel left open, allowing the fish to swim freely without drag. The data collection period lasted 10 min and movement of the boat was minimized. In shallow areas with abundant underwater structure (i.e., submerged trees, large macrophyte stands), fish were released in deeper, open water sites within the vicinity of the capture site (~ 50 m radius) in order to limit entanglement of the line. At the end of the data collection period, the harness was retrieved by tugging the line which subsequently detached the Velcro® and allowed the harness to be reeled in. Before reeling the harness in, the presence of the fish on the end of the line was confirmed by feeling for motion and weight before tugging the line.

2.3.3 Air Exposure Treatment

After attaching the biologger, air exposure was conducted by lifting the fish by hand out of the water filled cooler, placing it in a dry measuring trough, and holding it firmly to reduce the likelihood of accidentally undoing the Velcro® harness. Air exposure was divided into five treatments, 0 s, 15 s, 30 s, 60 s, and 180 s. My minimum air exposure treatment of 0 s constitutes a best-case scenario and can be easily accomplished by having a water filled container ready before landing or removing the hook without removing the fish from the water (e.g., by leaning over the side of the boat or kneeling down on shore). These intervals were determined using a combination of personal observation of online angling videos and time-to-dehook data collected from Trahan et al. (In Progress). While I am aware of efforts to surreptitiously observe anglers to generate real measure of air exposure duration (Chiaromonte et al. 2018), my evidence suggests that a maximum air exposure treatment of 180 s represents a worst-case scenario and could occur with inexperienced anglers or when fish are deeply hooked by multiple treble hooks, while 0 s of air exposure is aligned with emerging social norms in the recreational angling community.

2.3.4 Data Processing

I converted accelerometer logger data to units of g (9.8 m s $^{-1}$) by dividing pitch (x axis), roll (y axis), and yaw (z axis) by 2048, the standard conversion factor for the biologger (Brownscombe et al. 2013; Lennox et al. 2018). Static acceleration was calculated by passing a 2 s box smoother over each axis using the rollmean function in the R package zoo (Zeileis & Grothendieck 2005) and converted to degrees by multiplying values by $180/\pi$. Pitch (x axis) and roll (y axis) were calculated from these values (Brownscombe et al. 2013; Lennox et al. 2018). Dynamic acceleration was calculated by subtracting static acceleration from raw acceleration values for each axis. Overall dynamic body action (ODBA) was calculated as the absolute sum of the dynamic acceleration of each axis. I summarized acceleration data by each second as the resolution of raw data initially gathered by the tag (25/s) was too high for realistic estimates of behaviour. Data was then trimmed to include only the first 10 min of each trial to remove the period of time when the biologger was retrieved. K-means clustering with $k = 3$ was used to cluster ODBA values into three distinct behaviours: resting, steady-state swimming, and high intensity swimming. Rest was defined as the cluster with the lowest ODBA values, swimming was the intermediate cluster, and high intensity swimming was the highest cluster. Number of high intensity swimming occurrences was determined by producing a scatterplot of ODBA vs. time in seconds with clusters as a coloured variable. High intensity swimming occurrences were defined as clusters of the highest ODBA values which contained at least three data points. The *length* function was also used to determine the duration of time the fish spent at the surface, when depth values were less than 10cm. Mean depth was calculated as the mean of 600 (1/second) absolute depth values collected by the biologger during the 10 min trial.

2.3.5 Statistical Analysis

Single factor analysis of variance (ANOVA) was used to compare mean ODBA for the trial, ODBA in the 1st minute after release, time spent resting (s), time spent steady-state swimming (s), number of burst swimming occurrences, mean depth (m), total ramp score, and time spent at the surface (s) between air exposure treatments. Air exposure was analyzed as an ordinal variable with levels 0 s, 15 s, 30 s, 60 s, and 180 s in ascending order. Post-hoc analyses were conducted using Tukey's range test (Abdi & Williams 2010). For each species, Bonferroni corrections were conducted to account for multiple comparisons, resulting in a final critical value of 0.006. I also chose to exclude total length as a predictor as it did not vary significantly among air exposure treatments (ANOVA, Pike: mean = 524 mm, +/- 7 mm, p = 0.844, Smallmouth: mean = 327 mm +/- 9 mm, p = 0.912, Walleye: mean = 388 mm +/-13 mm, p = 0.948). Although body size has the potential to influence exercise and recovery (Klefoth et al. 1996; Gingerich & Suski 2012), the range in body size observed was narrow compared to previous studies that identified size-specific patterns. I ensured assumptions were met by analyzing plots of standardized residuals vs. theoretical quartiles (Q-Q), residuals vs. fitted values, square root of standardized residuals vs. fitted values (scale-location) and examined outliers by calculating Cook's distance.

2.4 Results

2.4.1 Angling statistics and field observations

A total of 145 fish were angled, consisting of 59 Northern Pike, 55 Smallmouth Bass, and 30 Walleye. Surface water temperature fluctuated between 16 ºC – 18 ºC during Northern Pike angling, 24 ºC – 26 ºC during Smallmouth Bass angling, and 22 ºC – 24 ºC during Walleye angling. After accounting for tag malfunctions and harnesses that slipped off before the trial could finish, data for 51 Northern Pike, 44 for Smallmouth Bass, and 29 for Walleye were used for the analysis (successful deployment rate of 86%, 80%, and 97%, respectively). Compared to Northern Pike and Walleye, the wider girth and more uneven body shape of Smallmouth Bass was likely the cause of most premature detachments. Upon release, I observed two general behaviours; some fish immediately burst away from the boat and continued swimming, while others slowly descended to the bottom and remained motionless for the rest of the trial. One mortality was observed; a Walleye in the 15 s treatment that was unable to regain equilibrium immediately after release. I also noted qualitative differences in behaviour among species, with Smallmouth generally being the most active of the three species, and Northern Pike being the least active. Across species, most individuals spent the majority of the trial at rest (Figure 2.5). Nonetheless, quantitative comparisons among species are not informative due to significant variation between study sites, stress responses in species, and angling contexts, so no formal interspecific analyses were conducted.

2.4.2 Post-release activity and behaviour

Sample sizes for each treatment for Northern Pike were n = 11 for the 0 s treatment, n = 10 for the 15 s treatment, n = 9 for the 30 s treatment, n = 8 for the 60 s treatment, and n = 10 for the 180 s treatment. Mean ODBA for the entirety of the trial was marginally influenced by air exposure (ANOVA, df = 4, 46, F = 3.957, $p = 0.007$) and significantly higher in the 0 s treatment compared to the 30 s treatment (TukeyHSD, $p = 0.018$) and marginally higher in the 15 s treatment compared to the 30 s treatment (TukeyHSD, $p = 0.059$) (Figure 2.3). In the first minute after release, ODBA varied significantly among air exposure treatments (ANOVA, df = 4, 53, F = 7.511, $p < 0.001$) and was significantly higher in the 0 s treatment compared to the 30 s and 60 s treatments, (TukeyHSD, $p < 0.001$) (Figure 2.4). Mean depth usage did not vary significantly among air exposure treatments (ANOVA, df = 4, 51, F = 0.745, $p = 0.566$). Air exposure did not influence time spent on the surface (ANOVA, df = 4, 46, F = 2.449, $p = 0.059$), time spent resting (ANOVA, df = 4, 46, F = 1.697, $p = 0.166$), time spent swimming (ANOVA, df = 4, 46, F = 1.867, $p = 0.131$), or the number of high intensity swimming occurrences (ANOVA, df = 4, 46, $F = 0.099$, $p = 0.982$) (Figure 2.5). Total RAMP (sum of scores for equilibrium, startle response, operculum/eye activity) was also not influenced by air exposure (ANOVA, df = 4, 54, $F = 0.643$, $p = 0.634$).

Sample sizes for Smallmouth Bass were $n = 10$ for the 0 s treatment, $n = 9$ for the 15 s treatment, $n = 6$ for the 30 s treatment, $n = 10$ for the 60 s treatment, and $n = 9$ for the 180 s treatment. Mean ODBA for the entirety of the trial did not vary significantly among air exposure treatments (ANOVA, df = 4, 44, $F = 2.483$, $p = 0.057$) (Figure 2.3). ODBA in the 1st minute post-release was also not significantly influenced by air exposure (ANOVA, df = 4, 53, $F = 0.619$, $p = 0.652$) (Figure 2.4). Mean depth usage did not vary significantly among treatments (ANOVA, df = 4, 39 $F = 0.92$, $p = 0.462$) Air exposure did not influenced time spent at the surface (ANOVA, df = 4, 44, $F = 2.112$, $p = 0.095$), time spent resting (ANOVA, df = 4, 44, $F = 1.538$, $p = 0.207$), time spent steady-state swimming (ANOVA, df = 4, 44, $F = 1.591$, $p = 0.194$), or the number of high intensity swimming occurrences (ANOVA, df = 4, 44, $F = 1.569$, $p = 0.199$) (Figure 2.5). Total RAMP score varied significantly among air exposure treatments (ANOVA, df = 4, 44, $p < 0.001$) and was significantly lower in the 180 s treatment compared to all other treatments (TukeyHSD, $p < 0.001$).

Sample sizes for Walleye were $n = 7$ for the 0 s treatment, $n = 6$ for the 15 s treatment, $n = 6$ for the 30 s treatment, $n = 5$ for the 60 s treatment, and $n = 5$ for the 180 s treatment. Mean ODBA for the entirety of the trial was not influenced by air exposure (ANOVA, df = 4, 21, $F = 0.359$, $p = 0.835$) (Figure 2.3). ODBA in the first minute post-release was marginally influenced by air exposure (ANOVA, df = 4, 25, $F = 2.297$, $p = 0.087$), however no significant differences were revealed in pairwise comparisons (Figure 2.4). Mean depth did not vary significantly among treatments (ANOVA, df = 4, 25, $F = 1.651$, $p = 0.193$). Air exposure did not influence time spent on the surface (ANOVA, df = 4, 22, F = 0.773, p = 0.555), time spent resting (ANOVA, df = 4, 22, F = 0.775, p = 0.553,), time spent swimming (ANOVA, df = 4, 22, F = 0.449, p = 0.772), number of high intensity swimming occurrences (ANOVA, df = 4, 22, F = 1.929, p = 0.141) (Figure 2.5), or total RAMP (ANOVA, df = 4, 22 F = 0.864, p = 0.499).

2.5 Discussion

2.5.1 Swimming Activity

My study found minimal impacts of an angling event on the short-term swimming activity of Northern Pike, Smallmouth Bass, and Walleye. Across the three study species, I observed similar 10 min Overall Dynamic Body Acceleration (ODBA) values among air exposure treatments. In Northern Pike, major differences in swimming activity were only apparent in the first minute after release, with ODBA values in control fish 2-3x greater than values in fish that received 15 s, 30 s, or 180 s of air exposure. Similar swimming activity for the rest of the trial and the lack of differences in reflex action mortality predictors (RAMP) among treatments suggest that cognitive impairment, rather than locomotory impairment, caused the reductions in swimming activity observed in the first minute after release. Previous experiments have proposed that fish may be disoriented or "dazed" immediately following an angling event and exhibit cognitive impairment. For example, Spanish Flag Snapper (*Lutjanus carponotatus*) took considerably longer to inspect and enter a refuge when they had been angled and exposed to air (Cooke et al. 2014). Raby et al. (2018) also found a similar effect, with exhausted and air exposed fish spending more time in a vulnerable position while apparently having full locomotory capacity. Cognitive impairment, especially immediately after release, could conceivably increase predation risk if fish are unable to seek adequate refuge. It is important to note that my experiment was conducted at relatively cool ambient water temperatures (16-18 °C for Northern Pike, 22-24 °C for Smallmouth Bass and Walleye). This could explain the lack of more significant behavioural impairments observed, as elevated water temperatures can compound angling stressors and lead to increased behavioural impairments or mortality (Gingerich et al. 2007; Boyd et al. 2010; Wilde et al. 2000). Lastly, my experiment focused on relatively short-term (10 min) behaviour, which may have limited my ability to distinguish behavioural impacts that occur over broader time scales. For example, Algera et al. (2017) observed decreased swimming behaviour in experimentally stressed (using cortisol injections) Smallmouth Bass, however these differences only became apparent after ~ 30 min and differences in swimming activity were present for the entirety of the 64-h observational period. Arlinghaus et al. (2009) also noted serious behavioural impairment in Northern Pike over the course of one hour (Arlinghaus et al. 2009), although impairments were only observed when air exposure duration reached 300 s. Increasing the observational period or changing the data gathering resolution of the biologgers may help future studies discern potential differences in behaviour over longer time scales that mirror longer term physiological disturbances and recovery dynamics.

For all three species, post-release depth use was statistically similar among treatments. In the 60 s air exposure treatment, Northern Pike and Smallmouth Bass tended to spend more time deeper in the water column compared to the non-air exposed fish but these differences were minor (~ 0.5 m) and were not statistically significant. The lack of a linear relationship between air exposure duration and depth usage suggests that other factors, such as variability in aquatic habitat, may be the primary drivers. Some migratory fish have been observed to seek cool, deep water to facilitate recovery following thermal stress (Keefer et al. 2019; Mathes et al; 2009), however further research is needed to determine if fish exhibit similar behaviour following angling events.

No significant differences were observed for time spent resting, time spent steady-state swimming, or the number of high intensity swimming occurrences. Anecdotally, Smallmouth Bass and Walleye were observed to be more active after release compared to Northern Pike. Northern Pike are known to forage primarily by ambush, as opposed to Smallmouth Bass and Walleye who generally spend more time cruising the pelagic zone (Skov & Nilsson 2018). However, variation in physiology as well as environmental factors such as water temperature, aquatic habitat, and other lake effects likely also played a role in the observed differences. Besides angling stressors, differences in post-release behaviour can also be attributed to environmental factors. In Bonefish (*Albula vulpes*), Cooke & Philipp (2004) observed greater periods of rest in fish released in a high predation environment compared to a low predation environment, however these differences were noted over a 1 hr monitoring period. My data also suggest that air exposure may have increased the time spent at the surface in Northern Pike and Smallmouth Bass. In Northern Pike, median time spent at the surface was greatest in the 0 s treatment compared to other air exposure treatments, though the difference between the 0 s treatment and the 180 s treatment was less than 1 s. Equilibrium impaired Northern Pike were observed to recover and swim away within 5-10 s, indicating relatively short recovery periods for equilibrium impaired fish. In comparison, time spent at the surface was highest in the 180 s treatment for Smallmouth Bass, with fish spending on average 20-30 s impaired on the surface before swimming away. Additionally, Smallmouth Bass that received 180 s of air exposure had significantly lower RAMP scores at the moment of release compared to all other air exposure treatments, a difference driven mainly by a lack of equilibrium and startle response. In both species, there was wide variation in the recovery period, with some individuals swimming away immediately and others taking much longer. Previous studies have highlighted the effects of air exposure on equilibrium status of released fish, most suggesting that increased air exposure increases the probability of equilibrium loss (Cooke & Philipp 2004; Thompson et al. 2008; White et al. 2008). Air exposure can also have interactive effects with other stressors such as exhaustive exercise (Ferguson & Tufts 1992) and water temperature (Gingerich et al. 2007) which may further exacerbate equilibrium impairment. Equilibrium status can be an important predictor of later mortality, as Danylchuk et al. (2007a) observed increased predation of equilibrium impaired Bonefish by sharks compared to fish who swam away strongly (Danylchuk et al. 2007a). In the context of my study species, predators such as large birds of prey, otters, or other large fish pose similar threats to impaired fish, however there is little evidence supporting actual predation rates in freshwater environments.

2.5.2 Non-invasive biologging

An overarching paradox of conservation research is the requirement of many studies to subject study animals to stress or injury. This is especially true for field-based tracking studies, where attachment of biologgers can have a variety of negative effects on study animals. In aquatic species, externally attached biologgers can increase hydrodynamic drag or impede swimming mechanics, leading to increased energetic costs (Jepsen et al. 2015; Rosen et al. 2017). Additionally, devices that require insertion into musculature can create wounds susceptible to infection (Bridger & Booth 2003; Thorstad et al. 2013; Jepsen et al. 2015). In the case of imperiled species, minimizing the negative impacts of conservation research is especially important. In many cases, biologging tags that are physically attached to study species also need to be retrieved after the observational period to download collected data. Retrieval can result in additional stress/injury to study species as animals may need to be recaptured for removal of the biologger. In marine environments, one solution is the use of pop-up satellite archival transmitters (PSATs) which automatically detach from the animal and float to the surface for retrieval. However, development of freshwater PSATs has not yet occurred as current "pop-up" mechanisms rely on saline environments to corrode links (Cooke et al. 2013) and current PSAT devices are too large for most freshwater fish species. Devices that record fine-scale activity, such as accelerometers, almost always require retrieval for the collection of data given the vast quantities of data that are generated. Using Velcro® tape for my attachment method proved to be a simple, minimally invasive method for the attachment of biologgers on wild fish in their natural environments, which was based on a similar method detailed in Lennox et al. (2018). The nature of my design allowed us to limit handling time during the biologgers attachment to < 30 seconds with the animal submerged in a water filled trough and completely eliminated the need for recapture of the animal for retrieval of data. It should be noted that while minimally invasive, my attachment method still involved additional handling time compared to typical C&R scenarios. Additionally, due to the nature of the harness design, air exposure treatments had to be conducted by further handling the fish to prevent the harness from slipping off. Regardless of air exposure, fight duration, and other angling treatments, handling time has been found to be a major predictor of post-release behaviour and survival (Teffer 2018; Chapman et al. 2020). Lastly, my attachment method likely increased hydrodynamic drag on the fish, and the combination of increased handling and other tagging effects may have limited my ability to observe truly natural swimming activity. Future studies should consider trade-offs between security of the biologger on the animal and handling time in order to observe behaviour that is as close to natural as possible.

2.6 Conclusion

Tri-axial accelerometer and depth biologgers were an effective means for monitoring post-release behaviour in free-swimming fish and the use of Velcro® proved to be a simple and minimally invasive method for attachment and retrieval of the biologger. Velcro® harnesses allowed us to quantify fine-scale post-release behaviour in free-swimming fish while eliminating the need to recapture the study individuals. This allowed us to minimize stress and possibly reduced experiment-related mortality. As we begin to understand the negative impacts of biologging on study animals, methods that are minimally invasive and eliminate the need for recapture will help to reduce study-related stressors and allow researchers to better understand the behaviour of wild, free-swimming fish.

My results suggest that air exposure had minimal effects on the post-release behaviour of Northern Pike, Smallmouth Bass, and Walleye. Nonetheless, I encourage air exposure to be minimized as longer fight times or higher water temperatures may interact with air exposure to increase behavioural impairments and negatively impacts survival. The water temperatures (i.e., 17-25 ºC) studied here are moderate and well within the thermal tolerances of these species. Moreover, fight times were short. There is a growing body of literature that has revealed that context is highly important for considering the biological consequences of fisheries interactions (see Raby et al. 2015).

2.7 Acknowledgements

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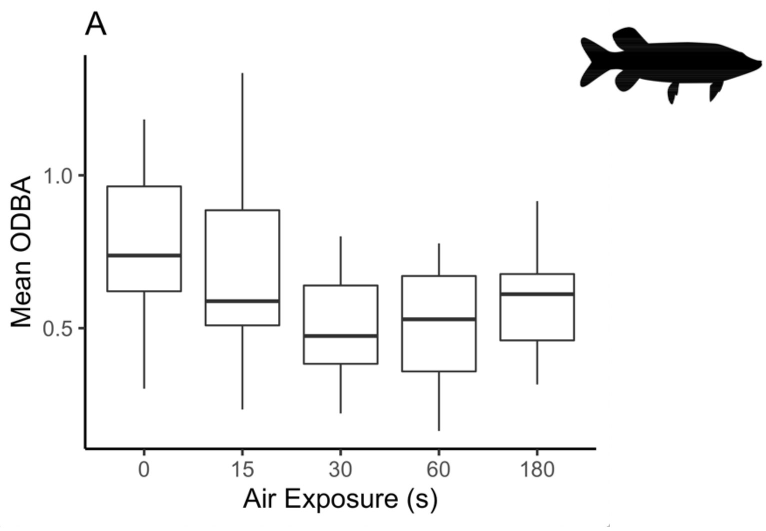
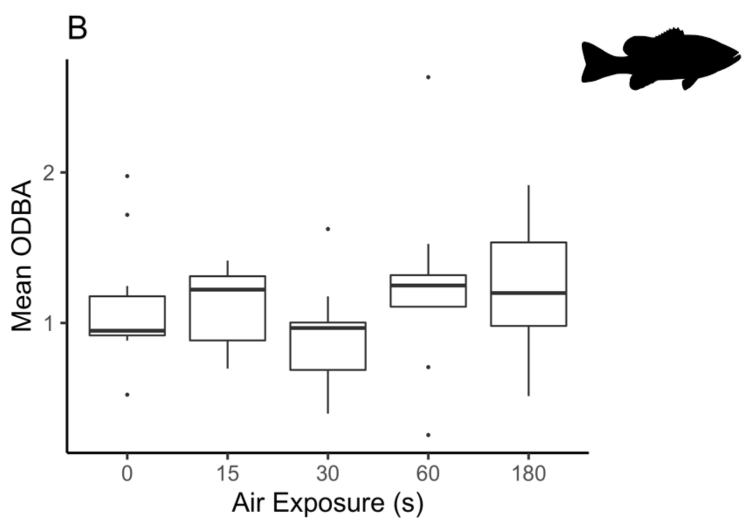
Figure 2.1. A Velcro® harness (black) and the biologger (white). The biologger was secured to a small plexiglass plate using marine epoxy and the Velcro® was threaded through small slits on each end of the plate.

Figure 2.2. A Velcro® harness on a Smallmouth Bass (left) and Walleye (right). The biologger (in white) was positioned on the underside of the fish, with the plexiglass plate pressed against the belly between the two pelvic fins.





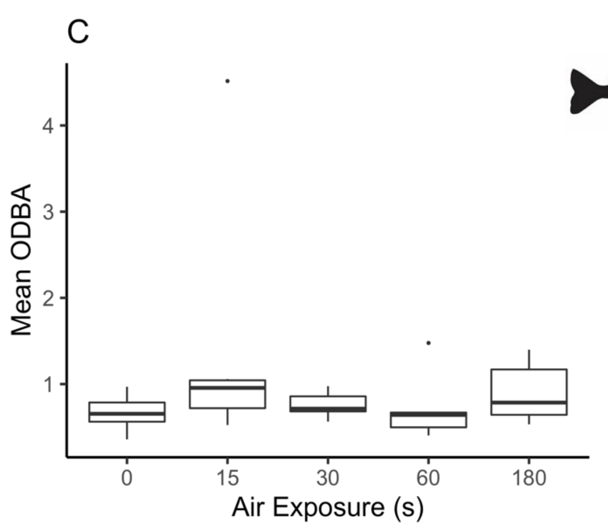


Figure 2.3. Mean overall dynamic body acceleration over a 10 min trial after 0 s, 15 s, 30 s, 60 s, and 180 s of air exposure in Northern Pike (A), Smallmouth Bass (B), and Walleye (C).

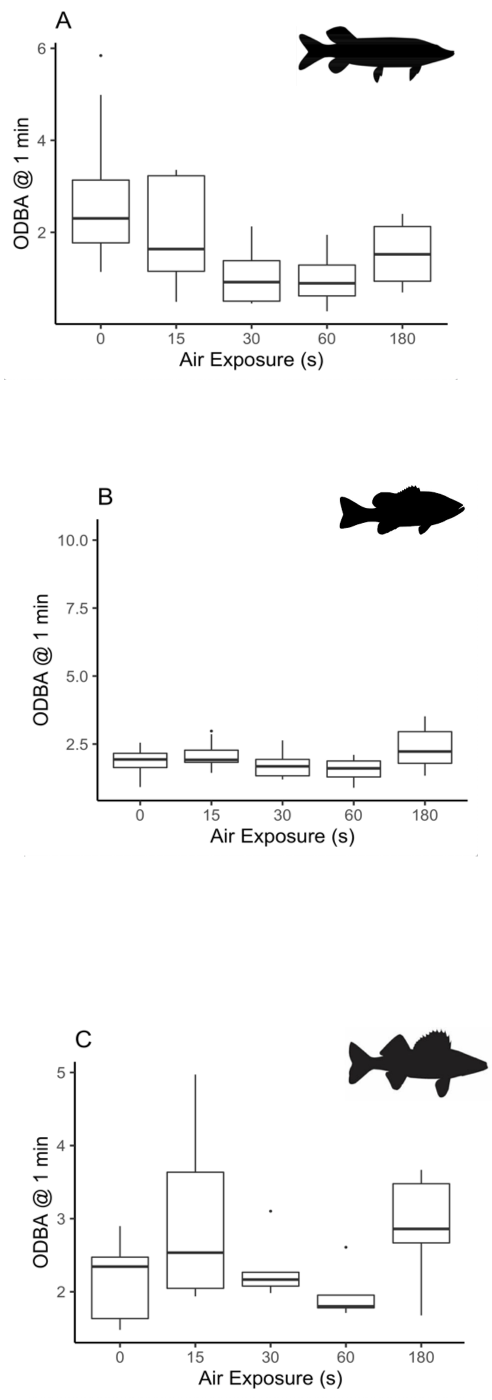


Figure 2.4. Overall dynamic body acceleration in the 1st minute after release for 0 s, 15 s, 30 s, 60 s, and 180 s of air exposure in Northern Pike (A), Smallmouth Bass (B), and Walleye (C).

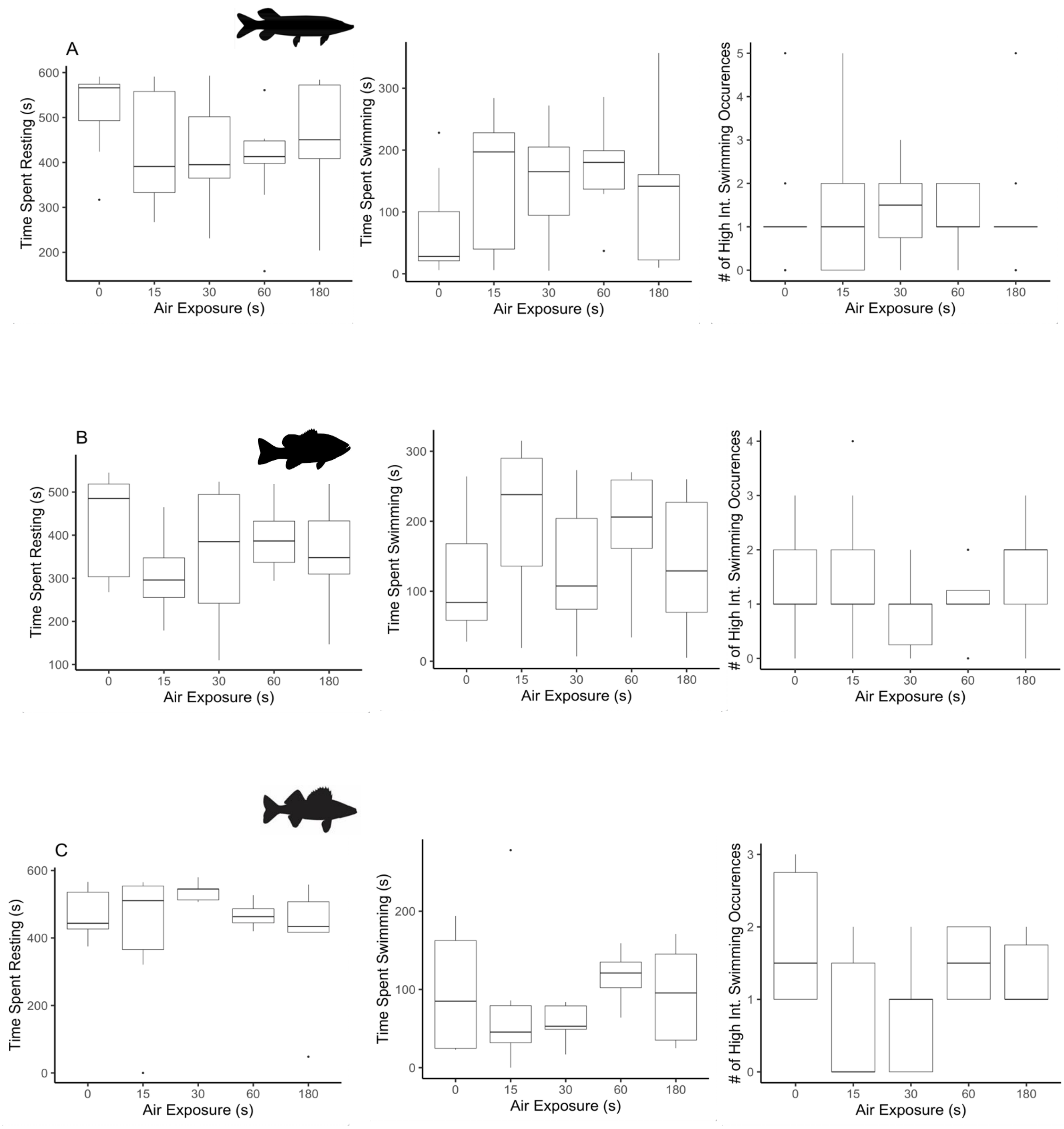


Figure 2.5. Time spent resting (s), time spent steady-state swimming (s), and number of high intensity swimming occurrences after 0, 15, 30, and 180 s of air exposure in Northern Pike, Smallmouth Bass, and Walleye.

Chapter 3: The efficacy of assisted recovery for reducing post-release behavioural impairments in angled Rainbow Trout (*Oncorhynchus mykiss*)

3.1 Abstract

The effectiveness of C&R as a conservation practice assumes minimal impacts to released fish. In most cases, angling-related stressors can be mitigated via changes to angler behaviour that reduce fight duration, handling, and air exposure. Nevertheless, stressors that exceed tolerance limits can often impact the ability of fish to engage in normal swimming behaviour upon release. In these scenarios, it may be beneficial for anglers to assist recovery or retain fish until they are adequately recovered. In my study, I investigated the effectiveness of two assisted-recovery devices at facilitating behavioural recovery in angled Rainbow Trout (*Oncorhynchus mykiss*): 1) retention in a flow box or 2) retention in a water-filled cooler. Additionally, I compared the effects of assisted recovery in ambient surface water (24 ºC – 27 ºC) or cold water pumped from the hypolimnion (17 ºC – 19 ºC). From July to mid-September of 2020, 169 fish were angled from five stocked lakes at Kenauk Nature (Montebello, QC). Trout were air exposed for 0, 15, or 30 s and held in a flow box or a water filled cooler for 3 min, while fish in a control group were immediately released. Tri-axial acceleration and temperature biologgers were temporarily affixed around the trunk of the fish with Velcro® to observe post-release swimming behaviour for 10 min after release. Trout that were held in either assisted recovery device regained equilibrium significantly quicker compared to those that were immediately released, and fish that were recovered in cold-water (17 – 19 ºC) regained equilibrium the most rapid of all. In fish that were air exposed for 30 s, individuals that were held in recovery devices exhibited greater swimming activity compared to those that were immediately released. My study demonstrates that for Rainbow Trout, assisted recovery devices can reduce equilibrium impairment, especially when water in the recovery devices is significantly cooler than the relatively warm ambient surface water temperature. Global water temperatures are expected to rise as a result of anthropogenic climate change, and best practices for angling should be adapted to reflect increased thermal stressors for many game fish species. Ensuring fish are vigorous upon release is imperative for reducing post-release mortality through predation or thermal stress.

Key Words: recreational angling, rainbow trout, catch-and-release, water temperature

3.2 Introduction

Catch-and-release (C&R) angling is a well-established recreational activity for many people around the globe and has been embraced as a conservation tool for the management of a variety of fish species (Arlinghaus et al. 2007). However, the effectiveness of C&R as a conservation practice is contingent on low mortality in fish that are released and the assumption of minimal sub-lethal consequences (Wydoski 1977; Cooke & Schramm 2007). In practice, C&R strategies can take the form of regulations or voluntary actions of anglers. Actions that are commonly embraced may involve altering handling practices (i.e., limit air exposure, limit contact with dry surfaces, minimize fight time), or decreasing angling effort during vulnerable periods (i.e., during spawning, when water temperatures are high) (Cooke & Suski 2005; Boyd & Guy 2010; Brownscombe et al. 2017a). Despite the relative success of some of these measures at reducing mortality (Nelson 1998; Taylor et al. 2001; Bartholomew & Bohnsack 2005), C&R events still trigger a stress response in fish which can result in a variety of sub-lethal alterations to physiology (Pankhurst & Dedualj 1994; Cooke et al. 2013; Gagne et al. 2017) and impair behaviour (Thorstad et al. 2004; Klefoth et al. 2008; Arlinghaus et al. 2009).

Equilibrium loss is one such behavioural impairment that is significantly correlated with physiological stress and shown to be a strong predictor of post-release mortality (Davis 2010). Additionally, fish that are released without equilibrium have limited locomotory function and are therefore more vulnerable to immediate predation (Danylchuk et al. 2007a; Holder et al. 2020). In lotic systems, behavioural impairment can also increase displacement of fish downstream (Raby et al. 2014; Gagne et al. 2017), possibly altering migration success or increasing energetic costs. In these scenarios, among others, it can be beneficial for anglers to temporarily retain fish until they have recovered enough to regain equilibrium and swim away independently. The angling community has supported various interventions that are perceived to help fish recover after capture, although the effectiveness of many strategies is unclear (Pelletier et al. 2007). Some interventions require minimal effort (i.e., holding fish upright, positioning mouth towards current), while others may be more involved (i.e., livewells, flow boxes, mesh holding bags), however there is mixed scientific evidence to support them. For example, Brownscombe et al. (2017) found no evidence to support the efficacy of maneuvering Largemouth Bass (*Micropterus salmoides*) and Brook Trout (*Salvelinus fontinalis*) in a figure-8 or back-and-forth pattern in the water at facilitating behavioural recovery. Alternatively, some purpose-built recovery devices such as flow boxes and mesh recovery bags have been shown to be somewhat helpful. For instance, Brownscombe et al. (2013) found that Bonefish (*Albula vulpes*) held in flow-through recovery bags exhibited less locomotory impairment and depredation post-release, while Farrell et al. (2001) found decreased post-release mortality in gillnet-caught Coho Salmon (*Oncorhynchus kisutch*) held in a flow box. In addition, Raby et al. (2015) found reduced reflex impairment in Sockeye Salmon held in a flow box. However, Robinson et al. (2013) and Robinson et al. (2015) did not observe differences in post-release survival and migration success of Chinook (*Oncorhynchus tshawytscha*) and Sockeye (*Oncorhynchus nerka*) Salmon held in a similar flow box. Flow boxes are designed to facilitate the flow of fresh water of the gills of fish, however they also may force fish to swim at low velocities. Sustained swimming following exercise may help to clear metabolites and reduce recovery times (Milligan et al. 2000). However, Kieffer et al. (2011) found that low-velocity swimming was detrimental to recovery rates in Brook Trout (*Salvelinus fontinalis*), indicating that there may be species specific variation in flow box efficacy. Additionally, there may be threshold stress levels where use of a flow box is more beneficial, as Farrell et al. (2001) determined that lethargic fish received the most benefits from retention in a flow box, compared to fish that were more vigorous.

Success of assisted recovery methods can also be dependent on context and environmental factors. For example, retaining fish in recovery bags was shown to increase the abundance of sharks in a high-predation environment, potentially leading to increased post-release predation (Lennox et al. 2017). Water temperature has also been shown to influence recovery after angling, as Prystay et al. (2017) reporting increased energy expenditure during recovery in elevated water temperatures. In an assisted recovery context, Suski et al. (2007) observed impaired recovery of lactate and ATP when Largemouth Bass were held in a livewell filled with water that was 7 ºC warmer than ambient water. While elevated temperatures are known to be physiologically stressful, recovery can also be impaired under cold temperatures, as the same study also found that fish held in water 10 ºC colder than ambient water exhibited impaired recovery. Rapid exposure to cold temperatures can cause cold shock, which triggers a host of physiological changes as the fish attempts to regain homeostasis (Donaldson et al. 2008). Apart from this study, there is limited additional evidence on the influence of water temperature during assisted recovery.

Rainbow Trout are a cold-water species, native to North America and Asia but have been introduced worldwide (MacCrimmon 1971). As with almost all fish species, Rainbow Trout experience physiological stress in response to exhaustive exercise and air exposure experienced during an angling event, and the stress response is magnified in elevated water temperatures (Wydoski et al. 1976; Meka & McCormick 2005). For Rainbow Trout, a large portion of C&R science has been conducted in a laboratory setting using simulated C&R techniques, which may not accurately represent the stressors experienced in natural settings. One such laboratory study revealed increased plasma cortisol, blood lactate and mortality in fish that were exhaustively exercised and air exposed (Ferguson & Tufts 1992). However, the invasive experimental process may have played a role in increasing stress and subsequently artificially increasing mortality rates. In contrast, another laboratory study demonstrated a survival rate of over 95% in fish that were subjected to simulated C&R events that consisted of hooking, chasing, and air exposure (Pope et al. 2007). Another criticism of laboratory studies is that many are conducted in relatively cool water temperatures (~15º C), when it is known that elevated water temperatures can play a key role in capture stress during angling events (Wilde 1998; Wilde et al. 2000; Boyd & Guy 2010; Gale et al. 2013; Havn et al. 2015). In the wild, angling of Rainbow Trout has been shown to have negative effects on reproductive processes, as acute stress associated with capture can decrease the production of gonadal steroids (Pankhurst & Dedualj 1994). Another study conducted on Rainbow Trout (in this case, anadromous Steelhead) noted that fish caught in warmer water exhibited greater blood lactate concentrations and increased blood acidosis (Twardek et al. 2018). Overall, C&R events can significantly impact the physiology, behaviour, and survival of fish that are released yet the magnitude of such impacts can vary greatly with angling context and environmental factors. Previous studies have suggested that the combination of elevated water temperature, air exposure, and exhaustion can have an interactive role at increasing physiological and behavioural distress in angled fish (Cooke & Suski 2005; Brownscombe et al. 2016). While C&R continues to grow, climate change is expected to increase thermal stressors on fish, especially for cold-water species like salmonids (Eaton & Scheller 1996; Ruiz-Navarro et al. 2016; Chambers et al. 2017). Therefore, identifying strategies that improve the recovery of released fish will be important to sustain healthy recreational fisheries in a warming world.

The overall goal of my study was to add to the limited research that has tested the techniques and devices for facilitating recovery of fish that are exhausted from an angling event. Specifically, my first objective was to determine the efficacy of two methods of assisted recovery: a flow box and an uncirculated cooler, at facilitating recovery from reflex impairment in Rainbow Trout after an angling event. My experiment used a stocked population of Trout in lakes where surface water temperatures exceeded the known lethal limit (> 25 ºC) (Hokanson et al. 1977; Matthews & Berg 1997; Bear et al. 2007) and were considerably higher than the optimum temperature for swimming performance and growth (~ 15 ºC) (Bear et al. 2007; Yin et al. 2020). As such, I also compared to use of ambient (23 ºC – 27 ºC) and relatively cool (17-19 ºC) water in the recovery devices by drawing water either from the surface of the lake or from a depth where water temperatures were cooler. My second objective was to compare post-release swimming behaviour and temperature usage between recovery treatments by means of externally attached tri-axial accelerometer and temperature biologgers. Elevated temperatures can magnify stressors experienced by fish during a C&R event, therefore I expected the use of cold (17-19 ºC) water in assisted recovery devices to be beneficial for reducing post-release behavioural impairments in Rainbow Trout.

3.3 Methods

3.3.1 Study Site

This experiment was conducted at Kenauk Nature, a private fish and game reserve in Quebec, Canada. The area contains a variety of small lakes which are stocked with hatchery grown Rainbow Trout. Angling occurred at five such lakes (Taunton Lake: max depth = 12 m, avg depth = 6 m, n = 89, Mills Lake: max depth = 29 m ft, avg depth = 12 m, n = 59, Twins

Lake: max depth = 11 m, avg depth = 6 m, n = 19, Otter Lake: max depth = 15 m, avg depth = 7 m, n = 4, and Pumpkinseed Lake: max depth = 8 m, avg depth = 6 m, n = 1). Angling was conducted in the months of July and September 2020 between the hours of 9 am and 7 pm. Cold water treatments were conducted exclusively at Taunton Lake as water drawn up from 4.7 m on Mills Lake was not cold enough to reach my definition of a cold-water treatment (17 ºC – 19 ºC).

3.3.2 Fish Capture

Fish were captured by trolling artificial flies with single barbed hooks on 6-weight fly rods spooled with full sinking line tipped with 2.7 kg or 3.6 kg fluorocarbon leader. Fight times were measured as the time from initial hookset until the fish was landed with a rubber mesh net. Fish were dehooked underwater at the side of the boat and immediately transferred to a water filled trough for measurement of total length (mm). Fish that were hooked in the gills, gullet, or foul hooked were immediately released and not used for the study. Fish that received air exposure were held completely out of the water in a rubber net for 15 s, 30 s, or not at all (0 s) and transferred to either the flow box or the uncirculated cooler. Fish received one of 11 treatments, which varied in air exposure (i.e., 0, 15, 30 s), recovery method (i.e., flow box, cooler), and water temperature (i.e., ambient/surface, cold/deep) used.

Air exposure intervals were selected based on earlier trials that showed serious behavioural impairment or even mortality in fish that were air exposed for 30 seconds and handled in the trough for a short period (to simulate attachment of the biologger) in water that was 27 ºC. For treatments involving immediate release, air exposure was conducted by holding the fish securely with two hands above a water filled cooler as attachment of the bio-logger had to be conducted prior to air exposure. On September 18th, 2020, 11 fish representing a single round of treatments were angled when the surface water temperature was ~ 16 ºC. These fish were included in order to observe the effect of recovery when ambient surface water temperatures were similar to the cold-water treatments utilized during the summer. Treatments involving 0 s of air exposure and the use of a recovery method were not included in my study as immediate release acted as a benchmark to measure assisted recovery treatments to.

3.3.3 Recovery Methods

My custom-made flow box was wooden and rectangular (77.5cm x 14cm x 17.5cm) (Figure 3.1). It used a portable bilge pump and 4.6 m of rubber tubing attached to the intake to draw in lake water at one end, and had a drainage slit at the other. Incoming water from the pump was diffused by a small showerhead and two panes of screen material, and the box was closed with a hinged lid comprised of a panel of window screen material framed by sealed wood to prevent the fish from escaping. For cold water treatments, water was drawn from a depth of ~ 4.6 m which provided us with temperatures that were consistently between 17-19 ºC. Water was drawn from the surface for warm-water treatments. Fish were positioned with their mouth towards the incoming flow to facilitate ventilation. Almost all fish were equilibrium impaired in the flow box and did not engage in steady state swimming action. Due to logistical constraints, flow velocity was not measured. The uncirculated cooler measured 30 cm x 60 cm x 30 cm and was filled with ~23 L of fresh lake water and closed with a plastic lid for each trial. Water in the cooler was changed between each trial, and fish were held in each recovery device for 3 min before being released.

3.3.4 Biologger Attachment

To evaluate post-release swimming activity, I attached biologgers (7.5 g, 12 x 31 x 11 mm, Technosmart Axy-Depth, Rome, Italy; sampling rate: tri-axial acceleration = 10 Hz, temperature/depth = 1 Hz, Resolution: tri-axial acceleration = 8 bit, temperature = 0.1 ºC, depth = 5 cm, G scale = 8) around the trunk of the fish using custom made harnesses which consisted of a length of Velcro® tape (Scotch Fasteners, length = 20 – 35 cm, width = 1.5 cm) threaded through a plexiglass plate that was epoxied to the logger **(**Figure 3.2**)**. With the fish underwater in the cooler or flow box, the length of Velcro® tape was wrapped once around the fish anterior to the dorsal fin, positioning the biologger on the lateral side above the pectoral fin (Figure 3.2). I found that this position was the most secure and prevented the harness from slipping off the fish. While I used harnesses of different lengths to accommodate the variation in girth among individuals, all harnesses were only wrapped once around the fish. The average duration of the attachment process was 22 s and rarely exceeded 60 s. The harness was then connected to a rod spooled with 27 kg braided spectra line using a snap swivel that clipped through a reinforced hole in the Velcro®. All fish were released upside-down and immediately assessed for equilibrium status. For fish without immediate equilibrium, I recorded the time (s) until the fish righted itself and swam away independently. The fish was then allowed to swim without resistance or on "free-spool" for 10 min before the logger was retrieved by tugging the line which released the Velcro®, allowing the harness to be reeled in.

3.3.5 Data Processing

Raw biologger data were processed using techniques derived from Brownscombe et al. (2013) and Lennox et al. (2018). Acceleration data was converted to units of g (9.8 m s^{-1}) by dividing pitch (x axis), roll (y axis), and yaw (z axis) by 1.5, the conversion factor for the g scale setting on the tag (8 g). Static acceleration was calculated by passing a 2 s box smoother over each axis using the rollmean function in the R package zoo (Zeileis & Grothendieck 2005) and converted to degrees by multiplying values by 180/π. Pitch (x axis) and roll (y axis) were also calculated from these values. Dynamic acceleration was calculated by subtracting static acceleration from raw acceleration values for each axis. Overall dynamic body acceleration (ODBA) was calculated as the absolute sum of the dynamic acceleration of each axis. I summarized acceleration data by each second as the resolution of raw data initially gathered by the tag (10/s) was too high for realistic estimates of behaviour. Data were then trimmed to include only the first 10 min of each trial to remove the period of time of which the biologgers was retrieved.

3.3.6 Statistical Analysis

Multiple regression was applied to determine the influence of fight time, time to dehook, biologger attachment time, surface water temperature, and fish total length on the time to regain equilibrium. Backwards stepwise selection using a threshold p-value of 0.05 resulted in the minimum best fit model of total length, surface temperature, and biologger attachment time as significant predictors. Generalized linear models (GLM's) were also applied with time to regain equilibrium as the response and air exposure, recovery device, or recovery temperature as individual predictors. For analysis of ODBA and temperature usage, I used generalized linear models with ODBA or temperature (ºC) as the response and the interaction of air exposure and recovery temperature, the interaction of air exposure and recovery method, the interaction of recovery method and recovery temperature, and minutes post-release as the predictors. I ensured linear model assumptions were met by analyzing plots of standardized residuals vs. theoretical quartiles (Q-Q), residuals vs. fitted values, square root of standardized residuals vs. fitted values (scale-location), and examining outliers using Cook's distance. All post-hoc tests were conducted using Tukey's range test. For the purposes of this study, potential lake effects were not included in the analysis. The majority of fish were captured from 2 lakes, which had similar surface water temperatures and underwater habitat. Ideally, this study would have been conducted on a single lake to remove potential biases however logistical constraints associated with conducting research in a private game reserve prevented us from doing so.

3.4 Results

3.4.1 Field Observations

I captured 169 fish between July 13th, 2020 and September 18th, 2020 (n = 158 between July 13th and August 28th, surface water temperature: 21 ºC – 27 ºC, n = 11 on September 18th, surface water temperature: ~ 15 ºC). Eighty-eight fish were angled on Taunton Lake, 57 from Mills Lake, 19 from Twins Lake, 4 on Otter Lake, and 1 on Pumpkinseed Lake. Mean total length of Rainbow Trout in the study was 390 ± 4.7 mm and ranged from 320 - 630 mm. Dehooking time ranged between 1 - 60 s and was a mean of 8 ± 0.7 s. Attachment of the biologger took a mean of 23 ± 1.2 s and ranged between 4 - 80 s. Mean fight time was 51 ± 2 s and ranged between 8 – 210 s.

3.4.2 Equilibrium and Post-release swimming activity

Time to regain equilibrium was positively correlated with surface water temperature, total length, and attachment time (r = 0.07, df = 3, 165, temp: p = 0.042, length: p = 0.04, attach: p = 0.026). Time to regain equilibrium was also significantly influenced by recovery temperature

(ANOVA, df = 1, F = 26.74, $p < 0.01$) and was significantly higher when fish were recovered in ambient surface water compared to cold water (Tukey HSD, $p < 0.01$) (Figure 3.3). Time to regain equilibrium was also influenced by the recovery (or lack thereof) method used (ANOVA, df = 2, F = 7.13, $p < 0.01$) and took significantly longer when fish were immediately released compared to fish that were held in the flow box (TukeyHSD, $p < 0.01$) or the cooler (TukeyHSD, p = 0.030) (Figure 3). Air exposure marginally influenced time to regain equilibrium which tended to be longest for fish in the 0 s treatment and shortest in the 15 s treatment (ANOVA, df = 1, F = 2.99, p = 0.053) (Figure 3.3).

Swimming activity (ODBA) varied significantly amongst minutes post-release release and there was a significant interaction between air exposure and recovery device (ANOVA, minutes: df = 9, F = 9.946, $p < 0.01$, air*tank: df = 6, $p < 0.01$). In all fish studied, ODBA was highest in the first minute after release and was significantly higher compared to the 2nd minute (p = 0.05), 3rd minute (p = 0.014), and the 4th – 10th minutes after release ($p < 0.01$) (Figure 3.4). ODBA was also significantly higher in the 2nd minute and the 3rd minute compared to 4th – 10th minutes after release ($p < 0.01$) (Figure 3.4). ODBA was higher when fish were immediately released following 0 s or 15 s of air exposure compared to fish that were immediately released following 30 s of air exposure (Figure 3.5). Additionally, ODBA was higher in fish that were held in a recovery device after 30 s of air exposure compared to those that were immediately released (Figure 3.5).

By ~ 1 min after release, fish tended to occupy water temperatures of ~ 15 ºC, where they stayed for the remainder of the trial. Temperature usage was significantly influenced by the time (minutes) after release and its interaction with recovery temperature (ANOVA, minutes: df = 9, F = 28.587, $p < 0.01$, minutes*draw: df = 9, F = 2.270, p = 0.013) (Figure 3.6). After the 5th

minute, trout that were recovered in cold water spent more time in warmer water (~14 ºC) compared to trout that were recovered in surface water or immediately released (~12 ºC) (Figure 3.6).

3.5 Discussion

Even when best practice handling guidelines for handling are adhered to, fish can still experience significant physiologically-mediated behavioural impairment following an angling event, especially in unfavourable environmental conditions that increase stress (Cooke & Suski 2005; Arlinghaus 2007). Support for the benefits of assisted recovery of fish following capture is mixed. Some studies have demonstrated that retention in recovery devices can facilitate physiological and/or behavioural recovery in angled fish (Farrell et al. 2001; Brownscombe et al. 2013; Donaldson et al. 2013). Alternatively, others did not find evidence of improved behavioural recovery (Robinson et al. 2013; Robinson et al. 2015; Brownscombe et al. 2017b). These differences could be due to variation in angling context, species-specific stress tolerances, and the length of time fish are held in recovery devices (Suski et al. 2007; Nguyen et al. 2014; Raby et al. 2015). Overall, my study determined that holding Rainbow Trout for 3 min in a flow box or water filled cooler reduced equilibrium impairments, especially when water in the recovery device was significantly colder than the ambient surface water temperature. Trout also exhibited greater swimming activity when they were held in the flow box or cooler after 30 s of air exposure, compared to those that were immediately released after 30 s of air exposure. Finally, trout that were recovered in cold water spent more time in water temperatures of ~ 14 ºC after release, compared to trout recovered in surface water or immediately released, which tended to occupy temperatures of ~ 12 ºC.

Almost all trout captured for my study exhibited impaired equilibrium upon landing. From an angling context, loss of equilibrium can be associated with air exposure and handling time (Danylchuk et al. 2007a; Danylchuk et al. 2007b; Pinder et al. 2019) while in my case, measuring total length, attaching the biologger, and transferring the fish between holding tanks may have resulted in increased handling time compared to normal C&R scenarios. Extended fight times, confinement in the flow box or cooler, and elevated surface water temperatures may have also contributed to increased physiological stress. I used a relatively niche angling method of trolling flies on fly rods and sinking line, which involved letting out extremely long lengths of line to ensure the flies sank to an adequate depth. This most likely resulted in significantly greater fight times compared to some angling methods for trout but may reflect times associated with use of light tackle or novice anglers. I found that trout regained equilibrium most rapidly when held in water temperatures that were significantly cooler than ambient water temperatures, contrary to results found by Suski et al. (2005) and Shultz et al. (2011), however both studies used warm water fish (Largemouth Bass, Bonefish, respectively). The temperature optima for Rainbow Trout is ~ 15 ºC and the upper incipient lethal temperature is ~ 25 ºC (Hokanson et al. 1977; Bear et al. 2007; Yin et al 2020), therefore it was not unexpected that recovery was maximized when trout were held at their optimal temperature. In lotic systems, Rainbow Trout seek cold water refuge when ambient water temperatures are high, often cold-water upwelling areas or cold tributary outflows (Kaya et al. 1977; Ebersole et al. 2001). In lentic systems, cold water refuge is found at depths below the thermocline, and upon release I observed many trout to immediately descend to seek cooler water temperatures. In my study, on some occasions after the trial period, fish that were still exhibiting equilibrium impairment could be recovered by manually pushing the fish below the surface to deeper, colder water. Equilibrium impaired fish have a diminished ability to descend and may continue to be thermally stressed by high surface water temperatures. This impairment can lead to a degenerative cascade of events where fish require cooler temperatures to regain equilibrium but lack the ability to attain thermal refuge, compounding the stress they are seeking to relieve. Retaining trout in cold water before release may reduce equilibrium impairments and can allow fish to quickly descend to avoid thermal stressors at the surface.

Fish that are equilibrium impaired are also more likely to suffer immediate predation (Danylchuk et al. 2007a). In my study, I observed attempted predation by Ospreys (*Pandion haliatus*), Bald Eagles (*Haliaeetus leucocephalus*), and Gulls (Laridae spp.) on equilibrium impaired fish on multiple occasions. Almost all equilibrium impaired fish floated at the surface upside-down, which may have increased their visibility to avian predators as their light-colored undersides were more visible against the surface of the water (Ross & Hokenson 1997; Fairchild & Howell 2004). In marine environments, fish with impaired equilibrium are at greater risk for predation by other large fish or sharks (Danylchuk et al. 2007a; Holder et al. 2020). In environments with high predator densities, retaining fish until they are able to regain equilibrium quickly could reduce the incidence of post-release predation (Raby et al. 2014).

I did not find differences in recovery in fish that were held in circulating water and those held in static water. Prior research has focused on the use of assisted ventilation methods which increase the flow of oxygen over the gills (Robinson et al. 2015; Brownscombe et al. 2017b), however my results indicate that water temperature can also influence recovery success in cold water fish. Retention itself may be beneficial, even if it does not decrease the actual time to recover. Differences in the time to regain equilibrium between retained and released fish could be due to the period of time (3 min) that fish were retained on the boat, which may have allowed fish to recover before release. When predator densities are high, allowing fish to recover in the relative safety of a boat can reduce the likelihood of post-release predation given that fish are provided with good water quality.

Swimming activity of trout was greatest in the first minute after release and gradually decreased, plateauing around 5 min into the trial. Most trout spent the entirety of the trial swimming or alternated between periods of rest and periods of swimming. This was likely due to the habitat structure of the study lakes, as all were deep basins with relatively little cover. In the first minute after release, trout exhibited greatest swimming activity which could be attributed to trout seeking thermal refugia below the thermocline. Stressors that impact swimming performance immediately after release can have serious implications for short-term survival if fish are unable to reach cooler water. In trout that were immediately released, swimming activity was lowest in fish that were air exposed for 30 s. Across treatments, trout that were air exposed for 30 s displayed greater behavioural impairment upon release compared to those air exposed for 15 s or 0 s. Of the two mortalities that were observed in the experiment, both fish were air exposed for 30 s. These individuals did not regain equilibrium and floated at the surface for the entirety of the trial, presumably dying from physiological stress. Compared to other studies, I selected a relatively short duration of air exposure as my maximum treatment, as my early observations determined that air exposure exceeding 30 s significantly increased the probability of mortality. Additionally, Lamansky & Meyer (2016) determined through observations of anglers that the average air exposure time for fly-caught trout is ~ 30 s. My results highlight the importance of studying the impacts of angling in the field as environmental factors can play a significant role in changing the outcome of a C&R event. Overall, fish that were held in a recovery device after 30 s of air exposure were more active compared to those that were immediately released. These findings could indicate that assisted recovery could be more beneficial when fish are more severely stressed. These results are similar to those highlighted by Farrell et al. (2001), who identified that recovery in a flow box was more beneficial in fish that appeared to be more lethargic. Retention in the flow box may have helped to facilitate ventilation and forced fish to swim at low velocities, which has been shown to increase metabolic recovery in Rainbow Trout (Milligan et al. 2000). However, these benefits were only observed after 1-2 hours of retention (Milligan et al. 2000; Farrell et al. 2001). It is unclear why trout retained in the cooler were more active than those immediately released, however the differences could be attributed to the time course of the physiological response to stress. The biologgers did not start gathering data until the moment of release, so retention in the cooler for 3 min could have allowed for some level of physiological recovery before acceleration data were collected. This could explain the increased swimming activity in retained trout overall, as trout that were immediately released did not have time to recover before the start of data collection.

In most fish, changes in water temperature influence physiological processes by altering the activity of enzymes. Recovery from physiological stress can therefore be affected by temperature as the activity of enzymes that facilitate lactate clearance or replenish energy stores in muscle can be altered. Prior studies have showed that retention in cold water after exercise can delay recovery from physiological stress in trout (Galloway & Kieffer 2003; Hyvärinen et al. 2004). However, both studies were conducted with control water temperatures that were relatively cool (~ 14 ºC – 18 ºC), and cold-water recovery treatments conducted significantly colder (~ 5 ºC). In my study, trout that were recovered in cold water (~ 17 ºC – 19 ºC) exhibited different temperature preferences compared to those that were immediately released. Following recovery in cold water, trout tended to seek water temperatures of ~ 14 ºC after 5 min, while trout that were immediately released sought colder water (~ 12 ºC) and continued to descend during the trial. These results could indicate that to a certain temperature limit, Rainbow Trout may prefer recovery in water temperatures that are slightly colder than their typical surroundings.

Ultimately, science supporting the use of assisted recovery techniques is only effective if anglers are willing to adopt them (Danylchuk et al. 2018). Anglers may be hesitant to adopt practices if they are inconvenient or if they require additional costs. A survey conducted by Donaldson et al. (2013) found that anglers were generally supportive of the usage of recovery bags, a simple assisted recovery method, and support increased if research showed that the method was effective. In my case, recovery in the flow box was considerably more involved compared to recovery in the cooler, however the outcomes of fish that were released did not differ significantly provided that cold water (17 ºC – 19 ºC) was used. It also should be acknowledged that flow boxes are not commercially available, nor would they be simple to construct for those without woodworking knowledge or access to tools. Additionally, flow boxes only serve a single purpose and anglers may be reluctant to carry them, especially if there are weight or space constraints. Water filled containers such as coolers or live-wells may be more easily adopted as assisted recovery devices since many anglers already carry these or have them on their boats. While I used a portable bilge pump to draw cold water to fill the recovery devices, anglers could achieve similar temperatures by other methods such as ice packs. It is not only important that assisted recovery methods are effective, but also that they are easily implemented, affordable, and that science supporting their benefits are widely shared.

3.6 Conclusion

My study demonstrated that assisted recovery of angled Rainbow Trout by means of a flow box or water filled cooler was successful at reducing post-release equilibrium impairments and reducing impacts to post-release swimming. These benefits were also maximized if water temperatures in the assisted recovery devices were cooler than the ambient surface water temperature, and close to the optimal thermal range of Rainbow Trout (17 ºC – 19 ºC). While it is often noted that increased handling of angled fish increases stressors, there may be certain scenarios (i.e., high predation environments, elevated water temperatures, equilibrium impaired fish) where the benefits of assisted recovery outweigh the cost of increased handling. It is also important to note that there is a high degree of variation in the literature regarding the efficacy of assisted recovery of fish. Of future interest to researchers would be to identify the variables (species, angler behaviour, environmental factors) that influence the success of assisted recovery in order to provide relevant guidance to anglers and fisheries managers. As global water temperatures continue to rise, assisted recovery in cold-water is also a promising strategy for the recovery of angled fish, however more research is necessary to identify possible benefits on other cold-water species, and in lotic ecosystems.

3.7 Acknowledgements

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Figure 3.1. A Rainbow Trout held in the custom flow box.

Figure 3.2. A biologger harness attached to a Rainbow Trout.

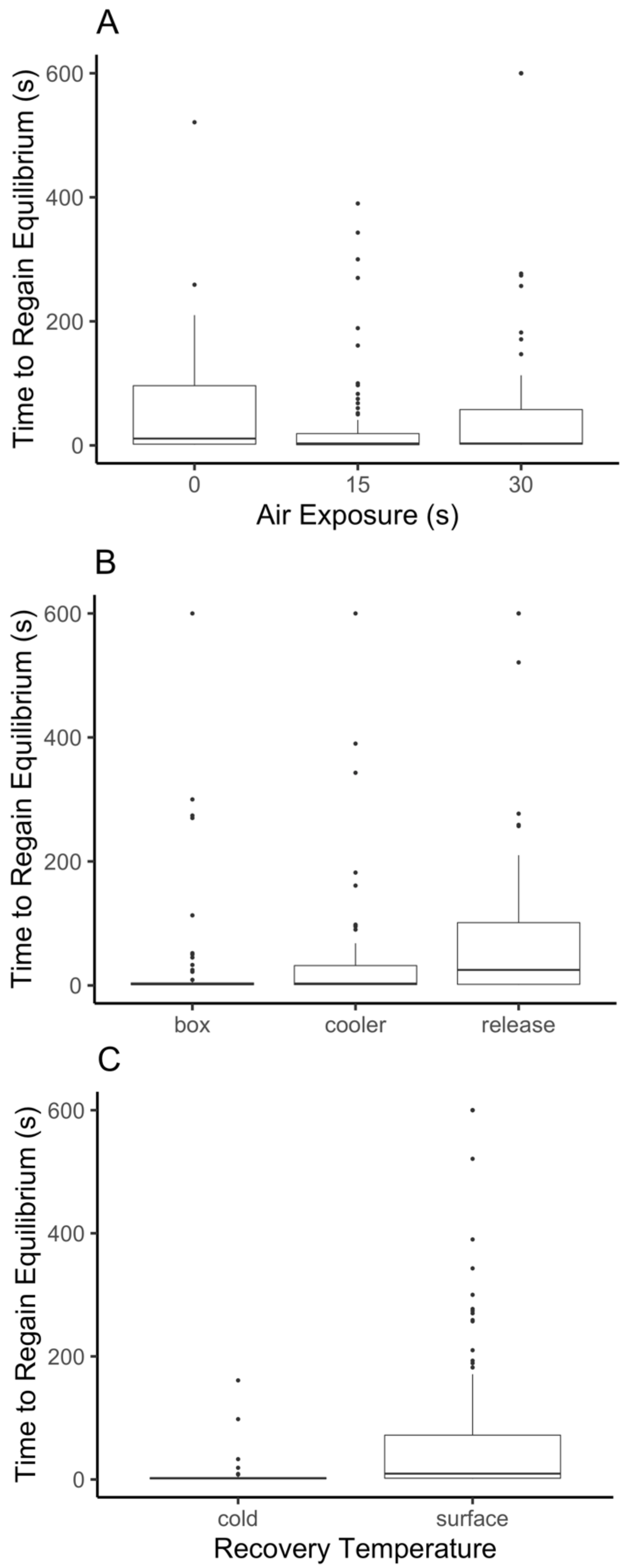


Figure 3.3. Time to regain equilibrium (s) after air exposure of 0, 15, and 30 s (A), recovery in the flow box, cooler, or immediate release (B), and recovery in cold water or surface water (C). Fish that were immediately released were placed in the surface group.

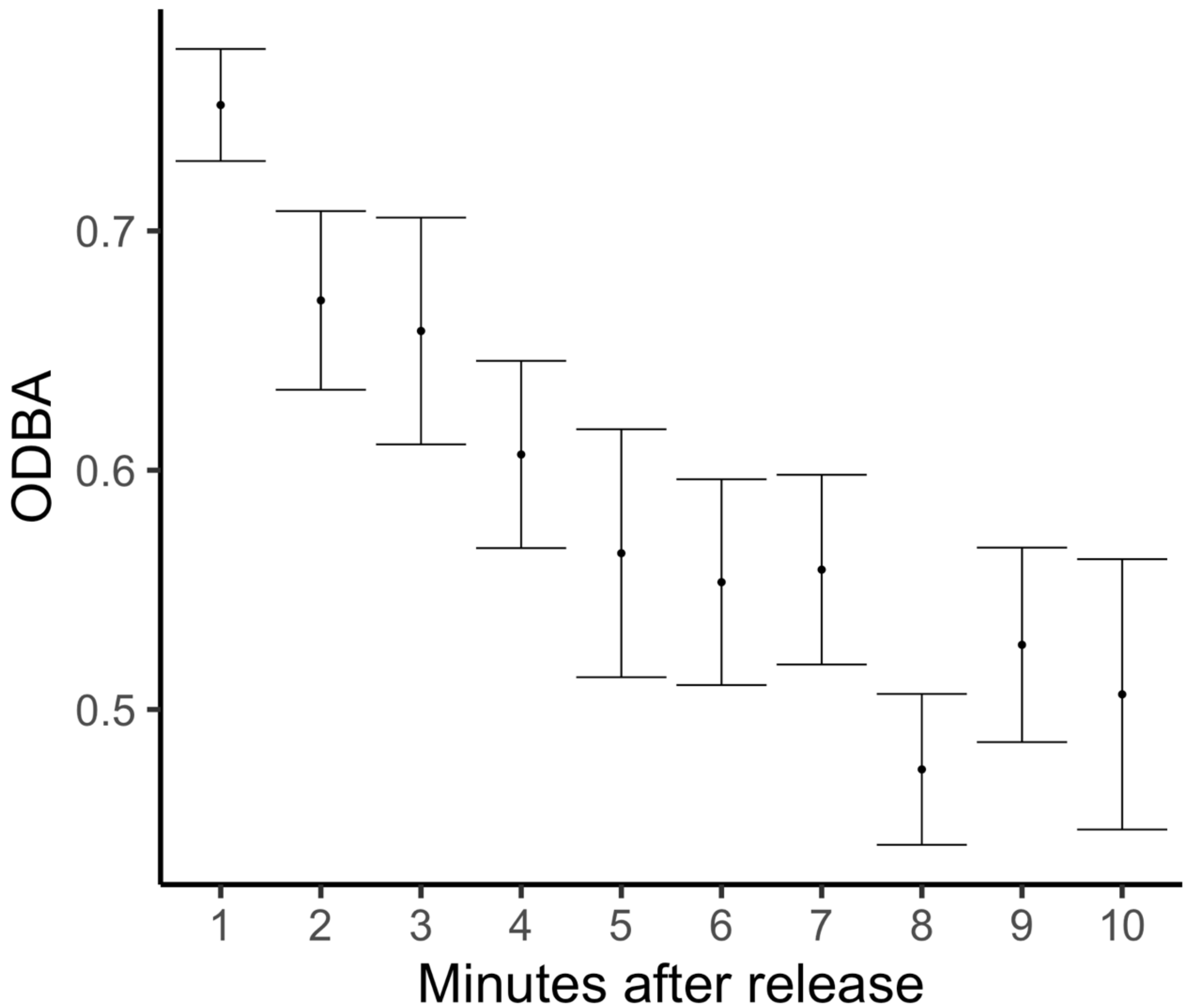
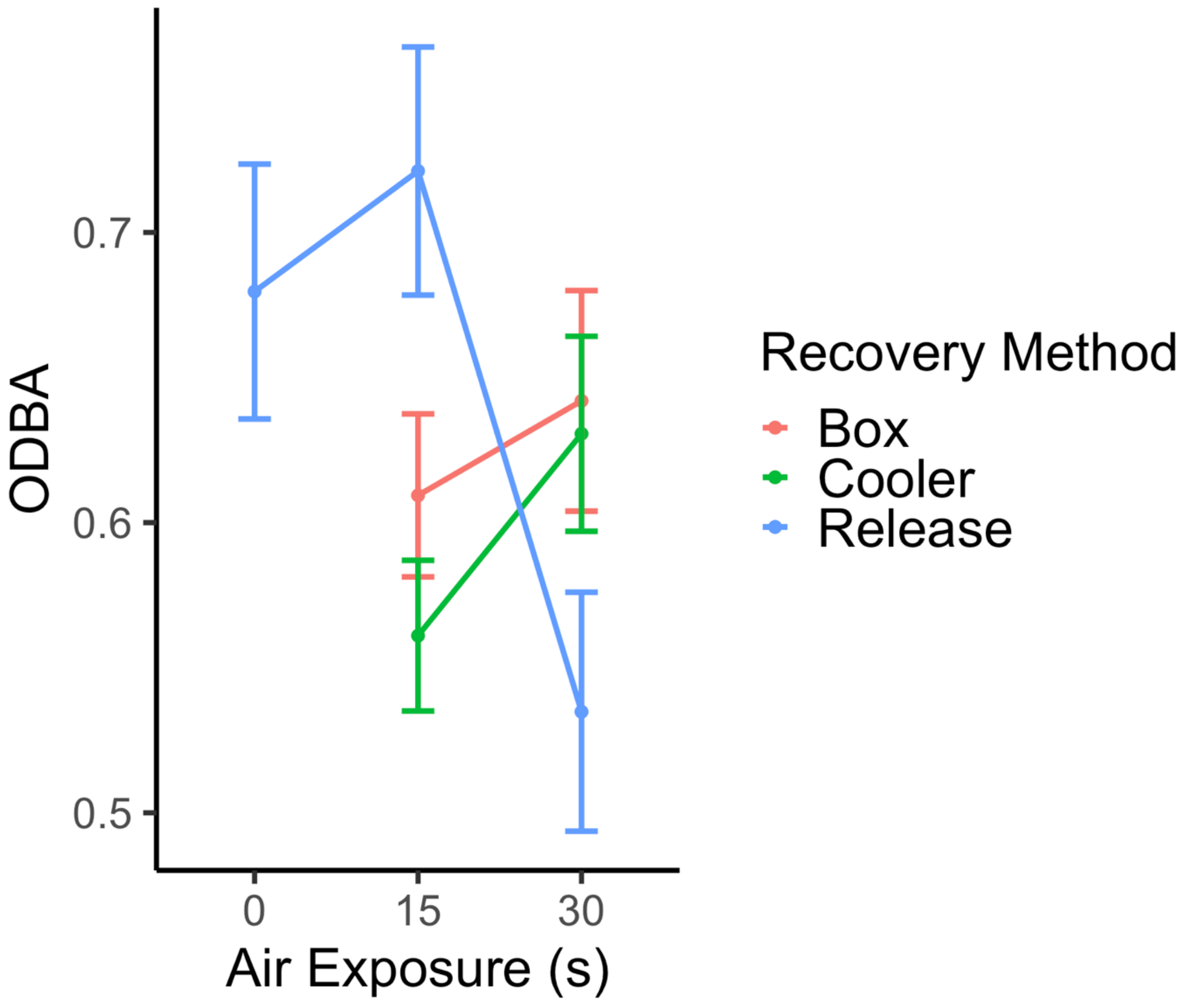


Figure 3.4. Mean (± 1 SE) overall dynamic body acceleration (ODBA) for each minute after release.

Figure 3.5. Mean (± 1 SE) overall dynamic body acceleration (ODBA) in fish that were



subjected air exposure of 0, 15, and 30 s, and held in the flow box, cooler, or immediately released.

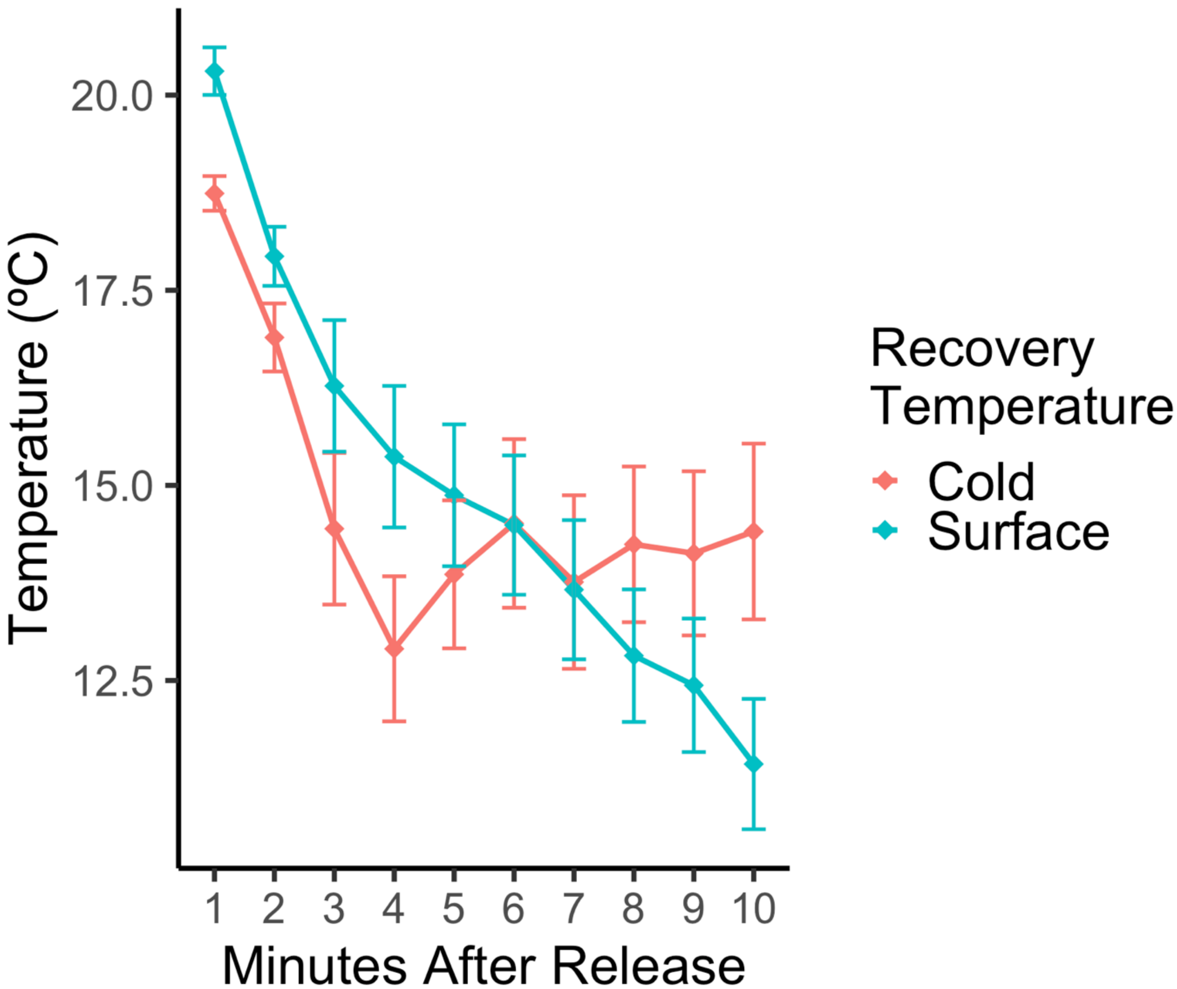


Figure 3.6. Mean (± 1 SE) water temperature usage over 10 min trial of Rainbow Trout in fish that were recovered in cold water and surface water.

Chapter 4: General Discussion

4.1 Main Findings and Significance

This thesis aimed to apply a novel attachment method for tri-axial acceleration biologgers to answer key questions regarding behavioural outcomes for fish released after an angling event. Chapter 2 set out to determine the impact of air exposure on the post-release behaviour of Northern Pike, Smallmouth Bass, and Walleye. Analysis of overall swimming performance (ODBA), depth usage, and characterization of unique swimming patterns was conducted after fish were captured and air exposed. For the three species studied, I found negligible differences in overall swimming activity and swimming patterns across all air exposure treatments. However, it was noted that Northern Pike that were not air exposed exhibited greater swimming activity in the first minute after release compared to those that were air exposed. The lack of behavioural alteration observed may have been due the relatively cool water temperatures during the study period, as elevated water temperatures are known to increase stress during C&R scenarios (Cooke & Suski 2005; Brownscombe et al. 2016). Additionally, my data collection period was relatively high-resolution, starting immediately after the fish was released and ending 10 min after. This may have reduced my ability to detect broader behavioural changes that occur over longer time frames. Nevertheless, chapter 2 represented the first successful deployment of my newly developed biologger attachment method using Velcro®, which allowed us to minimize handling time during the attachment and retrieval of the biologgers.

The goal of chapter 3 was to utilize the same attachment method from chapter 2 to determine the efficacy of assisted recovery following angling of Rainbow Trout. Biologgers were attached to captured fish and equilibrium status, post-release swimming activity (ODBA) and temperature usage were monitored after fish were held in a flow box or a water filled cooler for a short period before release. Assisted recovery devices were filled with either cold (17 ºC – 19 ºC) or ambient (25 ºC – 27 ºC) water to determine the effects of temperature on recovery. Most notably, this study found that fish held in assisted recovery devices regained equilibrium more rapidly compared to fish that were immediately released, and fish held in cold water treatments regained equilibrium the fastest. Additionally, fish that were air exposed for the maximum duration of 30 s had greater overall swimming activity when held in a recovery device compared to those that were immediately released. Surface water temperatures during the study period were well above the optimal thermal range for Rainbow Trout and the cold-water treatments were within the thermal optima, which may explain the potential recovery benefits I observed. Regardless of water temperature used, holding fish until they regain equilibrium before release may also be beneficial if risks such as high predator abundance and strong current are present at the release site. Overall, chapter 3 determined that there may be certain scenarios (high surface water temperatures, high predator densities, high flow) where the benefits of assisted recovery outweigh the negatives associated with increased handling confinement stress.

These results demonstrate that behaviour of fish released from an angling event can vary greatly with species, angler behaviour, angling context, and environmental factors. This thesis also presents a simple method for the external attachment of biologgers on wild fish.

4.2 Future Research Directions

In chapter 2, I did not observe differences in post-release behaviour in fish that were air exposed and fish in the control group. There is a large body of evidence demonstrating physiological impacts of air exposure in fish, however my experiment did not include assays of physiological status (e.g., blood lactate and cortisol) in conjunction with behavioural observations. Future research should focus on the link between physiological impairment and behavioural impairment by using a combination of physiological data from blood samples and behavioural data from visual and biologger collected data. Additionally, my study was conducted using relatively benign angling treatments (cool water temperatures, short fight times). Altering other variables of a C&R event such as fight time, angler experience, water temperature and handling time may allow researchers to better understand how post-release behaviour is impacted by multiple components of an angling event.

In chapter 3, I determined that assisted recovery in 17 ºC – 19 ºC water can reduce post-release behavioural impairments in Rainbow Trout. My study was the first to demonstrate benefits of retaining fish in cold water after an angling event to facilitate post-release recovery in Rainbow Trout. However, my study was conducted in relatively warm, small lakes, when a large proportion of Rainbow Trout angling occurs in lotic systems and at cooler water temperatures. Of interest to future studies would be to examine the efficacy of assisted recovery methods in lotic systems or when ambient water temperatures are close to optimal for Rainbow Trout. Along the same lines, it would be useful to determine if there are temperature thresholds where the benefits of assisted recovery are maximized, or if there are temperatures where the stressors associated with assisted recovery (increased handling, confinement stress) outweigh the benefits. Additionally, creel surveys and other angler outreach methods would also help better understand the willingness of anglers to utilize assisted recovery methods, and to identify strategies that would be most readily adopted.

Finally, the novel biologger attachment method I developed may not be as effective in environments that are abundant in underwater structure or with high flows which could cause entanglement of the line. Further research is needed to develop minimally invasive biologger attachment methods that are more applicable to complex and dynamic environments. Developing techniques to measure swimming distance would also provide an additional metric related to post-release behaviour. Overall, attachment and monitoring methods that minimize stress and injury will allow researchers to observe the most natural behaviour possible while simultaneously maximizing the welfare of study individuals.

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