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Using a novel biologging approach to assess how different handling practices influence the post-release behaviour of Northern Pike across a wide range of body sizes

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Abstract – There is a growing body of research focused on how angled fish respond to catch-and-release (C&R). However, most of those studies do not span a wide range of body sizes for the targeted species. Physical injury and physiological responses to C&R can be size-dependent, and methods used for landing fish of different sizes vary. As such, studying the response to C&R across a range of fish sizes may help inform best practices that improve outcomes for released fish. Northern Pike (*Esox lucius*) widely ranges in body size. Anglers may land them by hand, cradle, or net, and they are often released voluntarily or to comply with regulations. We angled 25 Northern Pike (total length 620–1030 mm) from one population and recorded fight, handling, and unhooking times across landing methods (i.e., hand, cradle, net). Prior to release, a pop-off biologging package was temporarily affixed to each fish to monitor locomotor activity, depth, and water temperature during a 12-h period post-release to understand how the interaction of landing method and body size influenced post-release behaviour and short-term fate. Fight and handling time increased with increasing body size. Northern Pike landed with a cradle or net had shorter fight times but longer handling times, compared to fish landed by hand. Post-release locomotor activity was greater for larger fish and those landed with a net. Fish <775mm and landed by hand had greater locomotor activity than fish landed with a net or cradle, while fish >775mm landed by hand had reduced locomotor activity compared to fish landed with a net. There was no post-release mortality observed. Collectively, anglers should use a net for Northern Pike >775 mm to avoid long fight times and reduce post-release exhaustion, but also attempt to reduce the extent of handling associated with fish landed by net.

Keywords: Post-release behaviour / pop-off tag / body size / landing method / overall dynamic body acceleration / catch-and-release

1 Introduction

Recreational angling is a popular activity, occurring worldwide (Cooke and Cowx, 2004; Arlinghaus and Cooke, 2009) and growing in popularity (Cooke et al., 2015). Fish that are captured by recreational anglers may be harvested for food (Cooke et al., 2018) or released (Arlinghaus et al., 2007). The reasons for anglers partaking in catch-and-release (C&R) fishing vary and includes compliance with harvest regulations (i.e., slot sizes, limits, seasonal closures; Cooke and Schramm, 2007) and personal conservation ethics (Pitcher and Hollingworth, 2002). Generally, the assumption is that released fish survive the angling interaction with minimal injury and stress (Wydoski, 1977; Cooke and Schramm, 2007), despite a large body of science that has documented sublethal impacts as well as mortality (reviewed in Arlinghaus et al., 2007).

Given that recreational anglers release billions of fish annually (Cooke and Cowx, 2004), it is imperative that fish intended for release are not mishandled to minimize sub-lethal effects (e.g., injury, stress, impairments in immune function, reduced growth) and mortality (Bartholomew and Bohnsack, 2005; Arlinghaus et al., 2007). Some science-based guidance on best handling practices is available for anglers (Pelletier et al., 2007; Danylchuk et al., 2017; Sims and Danylchuk,

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2017), yet some of these practices have not been formally evaluated. It is well known that decisions made by anglers during an angling interaction (i.e., gear type, handling, and air exposure) can potentially influence the fate of fish after a C&R event (Cooke and Suski, 2005; Brownscombe et al., 2017) emphasizing the importance of science-based guidance.

Anglers may choose to use, or not use, landing devices (i.e., handheld net, cradle, hands, gaff, or jaw-gripping devices) when attempting to land a fish at the end of the fight. These landing techniques can vary depending on the habitat, angler experience, fish size, and target species. Generally, jaw-gripping devices are frowned upon for fish that are to be released because these devices cause additional damage and injury to the fish beyond those from the hooking event (Danylchuk et al., 2008; Gould and Grace, 2009). Handheld landing nets are an effective and common tool that anglers may choose to use to retrieve fish from the water at the end of the fight, yet only a few studies have evaluated the influence of landing nets on the post-release fate of fish. Landing nets can provide some important benefits for fish by reducing the fight time (i.e., total exercise time), restricting movement allowing for better control of fish when landed, reducing the possibility of dropping the fish (ground or deck of the boat), allowing anglers to hold fish in the water during the handling and dehooking period, and reducing potential injuries for anglers when dealing with fish that have sharp teeth (Barthel et al., 2003; De Lestang et al., 2008; Lizée et al., 2018).

Anglers select their landing net type based on the targeted species. Landing nets as well as cradles are available in different sizes, mesh material (rubber or polypropylene), knot types (knotted and knotless) and range in price depending on the material used. A poorly designed net (i.e., wrong mesh size and material) or a poorly chosen net by an angler for a given situation (i.e., net is too small or big) can lead to fish getting tangled in the landing net mesh which increases handling time and potentially air exposure (Lizée et al., 2018). Similarly, physical damage to tissues can occur when unsuitable landing nets are selected to land fish (Colotelo and Cooke, 2011; Colotelo et al., 2013; Moltumyr et al., 2022). Although handling time increases when fish are landed with a landing net compared to landing by hand, fight time is increased when fish are landed by hand compared to using a landing net (Lizée et al., 2018; Twardek et al., 2018). Furthermore, body size of the fish has an important influence on the handling time and fight time of the fish. Larger fish generally have a longer fight time and handling period compared to smaller fish (Meka, 2004; Meka and McCormick, 2005; Meyer et al., 2021).

Depending on what an angler may choose to do during the landing period (i.e., grabbing fish by hand or with a net), the landing technique used may potentially influence the fate of the fish once released. Post-release survival and fitness may be influenced by injuries sustained when landing nets are used, including frayed fins, dermal abrasion, bleeding, mucus (i.e., slime) loss and scale loss. Fin fray and abrasion can lead to fin rot and reduced post-release swimming abilities (Latremouille, 2003), while mucus or scale loss and abrasion can make fish susceptible to infection such as opportunistic fungal growth (Steeger et al., 1994; Jones, 2001; Barthel et al., 2003; Colotelo and Cooke, 2011; Schwabe et al., 2014). Longer fight times are also associated with greater depletion of white muscle energy stores (e.g., glycogen, ATP) and accumulation of anaerobic by-products such as muscle lactate (Gustaveson et al., 1991; Wood, 1991; Kieffer et al., 1996; Kieffer, 2000). It is generally advised that anglers minimize the fight time duration (Cooke and Suski, 2005) which can be accomplished by using a landing net or cradle. However, cradles are designed in a way that requires two hands to properly function the cradle and therefore landing fish solo with a cradle is challenging and can potentially extend fight and handling times. Although using a landing net or cradle reduces the fight time and the subsequent exhaustion levels, fish that are landed prematurely and are not exhausted can be problematic as they can be difficult to handle which makes them prone to entanglement in the landing net or cradle, increasing handling time and potentially the duration of air exposure and potential for injury (Cooke et al., 2002). However, landing nets and cradles give anglers the ability to temporarily restrain fish at the end of a fight and keep the fish submerged in the water for dehooking, measuring and photography, which can reduce the need for air exposure (see Brownscombe et al., 2017). Conversely, fish landed by hand are often left air exposed during this handling period because of the inability to hold them safely and securely in the water without losing the fish. This extended air exposure period usually occurs while the hooks are being removed from the fish, measurements are being made (e.g., length and/or weight), and pictures are taken. During an air exposure event there is potential for collapse of gill lamellae, adhesion of the gill filaments, and impairments in oxygen uptake leading to blood acidosis (Boutilier, 1990; Ferguson and Tufts, 1992). Regardless of the species, the air exposure period is generally regarded as the most challenging aspects of a C&R event for fish (Cook et al., 2015). Physiological disturbances that occur during the angling event (i.e., fight, handling, air exposure) can impair reflexes, reduce swimming performance, and alter the post-release behaviour of fish (Schreer et al., 2005; Davis, 2010; Brownscombe et al., 2015).

Behaviour is a relevant indicator of stress in wild fish and serves as an important biomarker for physiological changes associated with the degree of stress being experienced (Schreck et al., 1997). The use of biologgers has been useful to assess the post-release behaviour of fish in the wild (Brownscombe et al., 2014; Cooke et al., 2016), especially to investigate the consequences that various capture and handling practices employed by anglers have on fish once they are released (Donaldson et al., 2008). Biologgers equipped with tri-axial acceleration, temperature, and pressure (depth) sensors have become a popular tool for the study of wild animals (Halsey et al., 2009; Gleiss et al., 2011; Wright et al., 2014) and are relevant to studying effects of C&R. Obtaining short-term fine-scale swimming activity from tri-axial acceleration data with removable biologgers (e.g., LaRochelle et al., 2021; Chhor et al., 2022; Griffin et al., 2022; LaRochelle et al., 2022) has provided estimates of overall dynamic body acceleration (ODBA) of fish in the wild, which eliminates the potential stress from being in captivity and provides ecological realism (Rutz and Hays, 2009). The ODBA of fish in the wild is a useful proxy for estimating swimming activity and field metabolic rate (Wilson et al., 2006; Gleiss et al., 2011; Brownscombe et al., 2018). Furthermore, because fish are ectotherms and live in a three-dimensional habitat, the depth and water temperature selected upon release can also indicate their welfare status and health.

The objective of this study was to understand how different landing and handling methods across a range of body sizes influence the survival and post-release behaviour (i.e., locomotor activity, depth, and temperature selection) of Northern Pike (*Esox lucius*). Northern Pike are a popular sportfish that are often released to comply with regulations or personal conservation ethics, and greatly vary in body size. More specifically, we examined how body size and landing method influenced the fight time, handling time and the subsequent post-release behaviour and fate of Northern Pike in the wild. We attached novel pop-off biologgers to the fish to monitor their behaviour for 12 h post-release in the wild after being exposed to C&R scenarios. The results from this study can be used to inform best handling practices for fish across a wide range of body sizes to maximize their welfare status.

2 Methods

2.1 Fish capture

Northern Pike were captured from Lake Saint Joseph (51°05.154' N, 90°36.361' W) in Northwestern Ontario (Canada) between August 3rd and August 22nd, 2022 using a boat and three anglers. Medium heavy action rods equipped with an 18.1 kg braid fishing line were used to capture the fish. Northern pike were captured by actively fishing artificial lures (i.e., spoons and inline spinners) with a single barbless treble hook per line. Once a fish was hooked, a stopwatch was started to record the fight time (seconds) and fight time was stopped when the fish was landed (i.e., angler has control of the fish).

Three different landing methods were used to land Northern pike, to which they were randomly assigned prior to a fish being hooked. The fish were either grabbed by hand on the side of boat (hand placed within the gill plate, without grabbing the gills), placed in a Lucky Strike rubber coated mesh net (Lucky Strike; Peterborough Ontario, Canada; 89 × 76 × 86 cm, mesh width 0.5 × 0.5 cm), or placed in a Frabill Pro-Tech Musky cradle (Frabill; Jackson Wisconsin, United-States; 152 × 38 cm). The angler was assisted with landing the fish by a second researcher when using the net or cradle, while fish landed by hand were done by the angler that was fighting the fish as is common in angling events. Once landed, another timer was started to record the handling time which was the period between being removed from the water when landing fish by hand, placed in the net, or cradle until the angler placed their hand (or unhooking tool) on the hook. Only one fish was in the possession of the anglers at any given time. At the point the angler touched the hook (with hands or pliers) and there was an attempt to remove the hook, another timer was started to record the unhooking time. The unhooking process finished with the fish removed from the water for all fish, though the fish landed with a cradle or net remained in the water after being unhooked and prior to hook depth measurement. The hooking depth was scored between 1 (shallow hooked in the jaw area) and 3 (deeply hooked in the gullet area). It was also noted if a dehooking tool (i.e., longnose pliers) was used. After being unhooked, another timer was started to record the extra handling time until the fish was placed in a water filled trough. This period never exceeded 15 seconds and was consistent across all fishing events. Once placed in a water filled trough with fresh lake water, the total length of the Northern Pike was measured (to nearest mm).

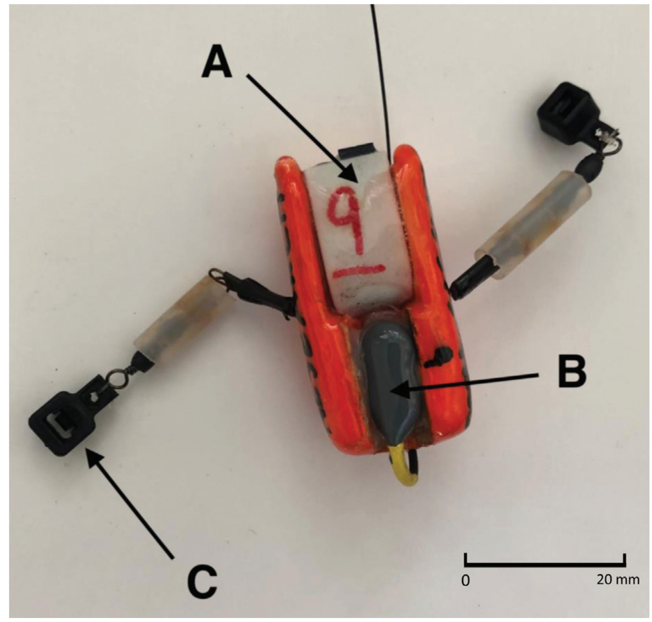

Fig. 1. Floating biologging package made from Balsa wood (45 × 20 × 16 mm; 14 g in air) that was attached to Northern pike. Post-release behaviour data (i.e., locomotor activity, depth, and temperature selection) was recorded with a Axy-5 XS biologger (A), while the biologging package was recovered using a radio transmitter (B). The biologging package was fastened to Northern Pike with two self-locking straps that were a tied together with 5–0 catgut suture and attached to the biologging package with the locking-heads (C).

2.2 Attachment of biologger and post-release monitoring

A pop-off floating biologging package was created from a small cylinder of balsa wood (45 × 20 × 16 mm; 14g in air) that was painted orange and sealed with a clear coat epoxy to avoid waterlogging. The Axy-5 XS biologger (TechnoSmArt, Guidonia Montecelio, Italy; 20 × 10 × 6 mm; 2.5 g in air) was epoxied to the float package (Fig. 1). Additionally, the biologging package was equipped with a BD-2 radio transmitter (Holohil, Carp Ontario, Canada; 1.2 g in air) to locate the biologging package once it popped-off the Northern Pike. The biologging package was secured to the Northern Pike between their pectoral fins (Fig. 2) using self-locking straps. The locking head component of the self-locking strap was cut-off and permanently attached to either side of the biologging package (Fig. 1). The two remaining straps were then tied together with a small dissolvable link (~3 cm long) with a piece of 5–0 plain catgut suture (550B, Ethicon, Somerville, New Jersey, United-States). Once the catgut suture link lost tensile strength, the biologging package would dislodge itself from the body of the Northern Pike and would float to the surface for retrieval. Preliminary trials were performed to determine how long the catgut sutures would retain their tensile strength prior to popping-off the fish to

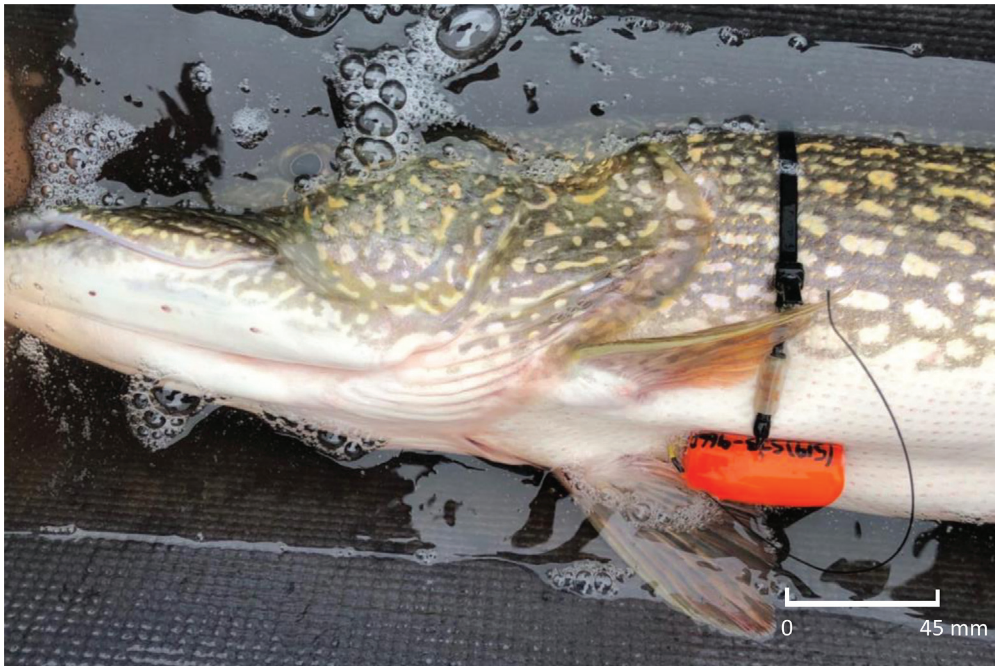

Fig. 2. Biologging package temporarily affixed to the ventral side of a Northern Pike just posterior to the pectoral fins.

Table 1. Total number of Northern Pike (*Esox lucius*) across the various landing methods including the mean length of the fish per group and the range of body size across the three landing methods.

Landing method	*n*	Mean (mm) ± S.D.	Minimum (mm)	Max (mm)
Hand	8	833 ± 144	620	1030
Cradle	9	826 ± 117	635	1020
Net	8	845 ± 130	650	1030

provide an estimated duration of attachment of approximately 12 hr. The overall sample size was restricted by time and equipment constraints.

Post-release locomotory activity, depth, and water temperature selection were collected using Axy-5 XS dataloggers. Acceleration data was recorded in three axes (x = surge, y = sway, z = heave; in respect to attachment orientation) at a frequency of 25 Hz with an 8-bit resolution. The temperature sensor had a resolution of ± 0.1°C and the pressure sensor (depth) of ± 5 cm. Absolute dynamic acceleration estimates were obtained by using a 2-s box smoother to remove the static acceleration (gravity) from the dynamic acceleration (animal movement) as described in Shepard et al. (2008) and Brownscombe et al. (2018). The total locomotor activity (i.e., ODBA) was obtained by summing the absolute dynamic acceleration for all three axes (Wilson et al., 2006; Halsey et al., 2011).

2.3 Statistical analysis

One-way ANOVA was used to test for mean difference in body length across landing methods and across anglers. To understand what influenced the fight time (time from hooking to landing), a linear model (LM) was fit with fight time as the response variable and landing method, angler, and body length of the fish as predictor variables. Total handling time was also modelled with a LM with the same predictor variables. For modelling unhooking time, landing method, angler, the use of an unhooking tool, hook depth in the mouth, and total length of the fish were used as the predictor variables in a LM. Models with significant factor variables were followed up with a pairwise Tukey post-hoc test.

Post-release behaviour (i.e., locomotory activity, water temperature used, and depth used) was modelled using linear mixed effects models (LME). Fish ID was included as a random effect to account for the repeated measures for each individual. For total locomotor activity (i.e., ODBA), the explanatory variables were the interaction between landing method and total length of Northern Pike, unhooking time, and experienced water temperature with depth post-release. Models were then followed up with an ANOVA to determine which predictor factor variables were significant. Again, a Tukey post-hoc test was used for differences in ODBA between landing methods. Two separate models, one with water temperature used post-release as the response variable and the other with depth used post-release as the response variable were both fit with minutes post-release as the predictor

Table 2. Total number, mean (SD) and range in body size of Northern Pike (*Esox lucius*) among anglers in the study.

Angler	*n*	Mean (mm) ± S.D.	Smallest (mm)	Largest (mm)
1	8	833 ± 143	636	1030
2	4	741 ± 119	635	889
3	13	863 ± 110	620	1030

variable. For each model, Dunnet post-hoc tests were used to see if there were significant difference in water temperature or depth selected upon-release between the initial 15 min post-release and the following time periods (15-min intervals) during the post-release monitoring period.

The data were analysed in R (4.1.3) via R Studio (2022.07.1) and all the figures were created using the *ggplot2* package (Wickham, 2016). Tukey post-hoc tests were carried out with the *glht* function from the R *multcomp* package (Hothorn et al., 2008). All post-release behavioural models were fit using the *lmer* function from the *lme4* package (Bates et al., 2015).

3 Results

In total, 25 Northern Pike (mean = 834 mm +/− 130 S.D.) were caught and landed by hand ($n = 8$), cradle ($n = 9$), or net ($n = 8$; Tab. 1). Mean body length of Northern Pike was similar across the different landing methods used ($F_{22,2} = 0.042$, $p = 0.959$) and among the three anglers (Tab. 2; $F_{22,2} = 1.307$, $p = 0.291$). Fight time had a significant positive relationship with total body length of Northern Pike (Fig. 3A; $t_{19} = 5.172$, $p < 0.001$), where larger Northern Pike had longer fight times than smaller Northern Pike. Fight times were significantly shorter when a net was used to land Northern Pike compared to landing them by hand (Fig. 4A; $z_2 = -4.490$, $p < 0.001$), but fight time did not differ between fish landed with a net and those landed with a cradle ($z_2 = -2.188$, $- = 0.073$). Similarly, Northern Pike landed by hand had significantly longer fight times than those landed with the cradle ($z_2 = 2.609$, $p = 0.025$). Fight times significantly differed between angler 1 and 3 ($z_2 = -2.355$, $p = 0.048$), but not between angler 1 and 2 ($z_2 = -1.794$, $p = 0.169$) or angler 2 and 3 ($z_2 = 0.027$, $p = 1.000$).

Handling times were significantly influenced by the total body length of Northern Pike ($t_{19} = 3.279$, $p = 0.004$), where larger fish took longer to handle than smaller fish (Fig. 3B). Landing method significantly influenced the handling time (Fig. 4B). Handling times for Northern Pike landed by hand were significantly reduced compared to those landed with a net ($z_2 = 3.216$, $p = 0.004$) or cradle ($z_2 = -3.574$, $p = 0.001$). However, there was no significant difference in the handling times between Northern Pike landed with a net or cradle ($z_2 = -0.104$, $p = 0.994$). Handling times were significantly longer for angler 1 compared to angler 2 ($z_2 = 2.634$, $p = 0.023$), but were not significantly different between angler 1 and 3 ($z_2 = 0.528$, $p = 0.860$), nor were they different between angler 2 and 3 ($z_2 = 1.513$, $p = 0.282$). Unhooking time did not significantly differ across landing methods ($p > 0.05$), angler ($p > 0.05$), nor did the total body length of Northern pike influence the unhooking time ($t_{17} = 0.461$, $p = 0.651$). However, there was a positive relationship between the total length of the fish and the unhooking time ($r_{23} = 0.37$, 0.067). All 25 Northern pike were hooked in the mouth and the hooking depth did not significantly influence the unhooking duration ($t_{17} = 0.163$, $p = 0.872$), nor did the use of a dehooking tool influence the unhooking duration ($z_1 = 0.333$, $p = 0.739$).

Post-release locomotor activity of Northern pike was significantly influenced by the landing method used ($F_{25,2} = 7.539$, $p = 0.003$). Northern pike that were landed with a net had significantly greater locomotor activity post-release compared to those landed by hand (Fig. 5; $z_2 = -3.847$, $p < 0.001$), while there was no significant difference in the locomotor activity between fish landed with the cradle compared to those landed with a net ($z_2 = -1.656$, $p = 0.222$), and there was no difference in post-release locomotor activity between fish landed by hand and with a cradle ($z_2 = 2.178$, $p = 0.075$). Overall, there was a significant positive linear relationship between the length of Northern pike and the post-release locomotor activity (Fig. 5; $F_{25,1} = 14.881$, $p = 0.001$). When considering the interaction between the landing method and total length of Northern pike ($F_{25,2} = 8.776$, $p = 0.001$), larger Northern Pike landed by hand had significantly lower locomotor activity compared to smaller Northern pike landed by hand (Fig. 6; $t_{25} = -2.214$, $p = 0.036$). There was also a significant positive relationship between the time it took to unhook Northern pike and their post-release locomotor activity ($F_{25,1} = 9.449$, $p = 0.005$). Northern pike that used warmer water also showed a significant increase in their post-release locomotor activity ($F_{65,1} = 7.488$, $p = 0.008$). Finally, post-release locomotor activity of Northern pike had a significant negative relationship with water temperature selected, where fish in warmer water temperatures had greater locomotor activity ($F_{1175,47} = 2.195$, $p < 0.001$). Water temperature used by Northern Pike during the post-release monitoring period was significantly influenced by the time elapsed throughout the monitoring period ($F_{1175,47} = 2.195$, $p < 0.001$). Northern pike used significantly warmer water temperatures during the initial 15-min post-release compared to the remainder of the 12-h monitoring period (mean = 19.5°C, S.D. = ± 1.0, lower range = 17.6°C, upper range = 21.9°C; Fig. 7A; $p < 0.001$). Similarly, locomotor activity of Northern pike significantly decreased with increasing depth used post-release ($F_{1175,47} = 14.881$, $p = 0.001$). Furthermore, depth used post-release significantly decreased (i.e., fish moved shallower) with increasing time during the 12-h post-release monitoring period ($F_{1175,47} = 1.449$, $p = 0.027$), but depth used did not significantly differ between the depth used during the initial 15-min post-release period and the depth used in the remaining 12-h monitoring period (Fig. 7B).

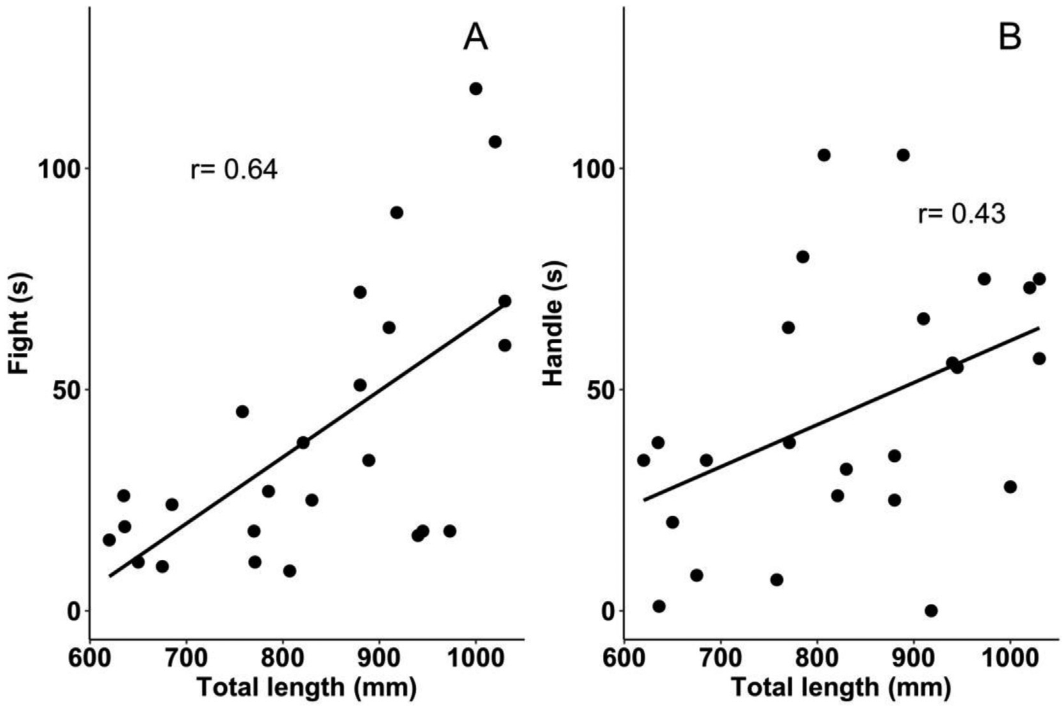

Fig. 3. Linear relationship between fight time (A) and handling time (B) for Northern Pike across a range of body lengths captured with rod and reel in August 2022 from Lake St-Joseph in Northern Ontario, Canada.

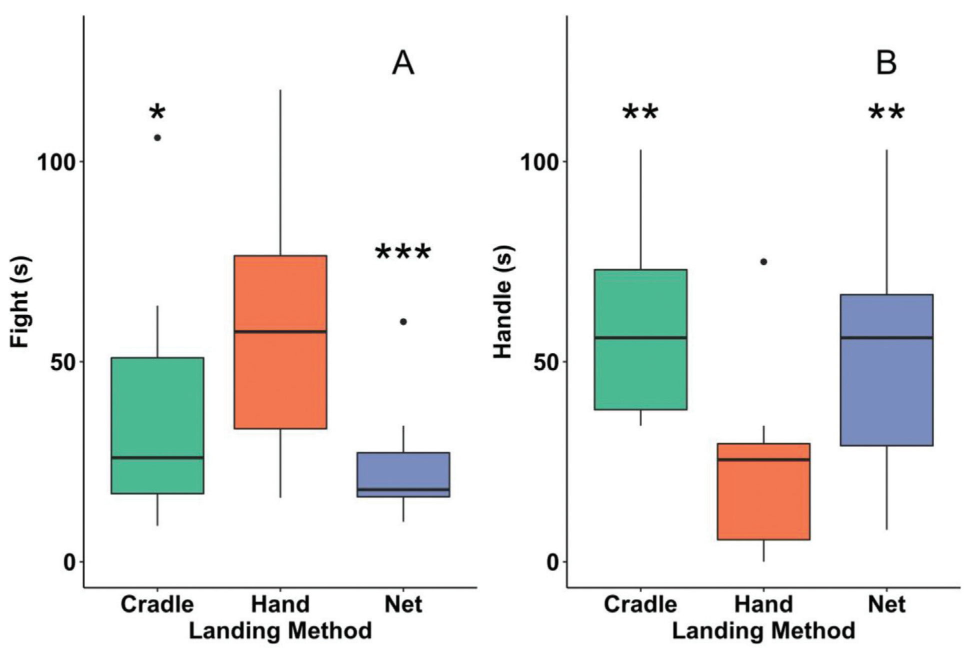

Fig. 4. Duration of fight time (A) and handling time (B) for three landing techniques for Northern Pike captured with rod and reel between August 3 and August 22, 2022, from Lake St-Joseph in Northern Ontario, Canada. Asterisks represent the significant difference between Northern Pike landed by hand and compared to the ones landed with a cradle or net. Horizontal bars are medians and vertical bars extend to the most extreme values.

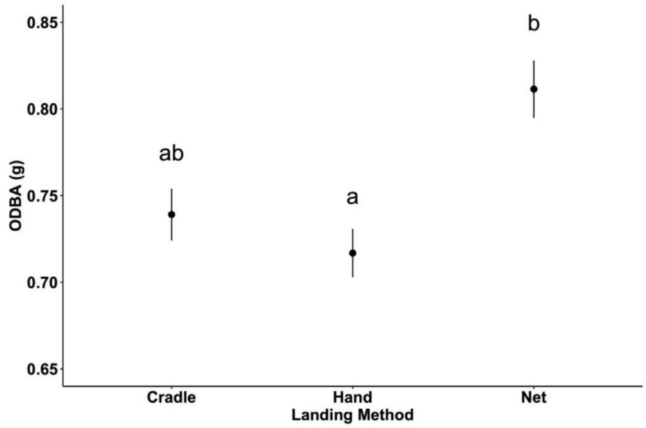

Fig. 5. Post-release locomotor activity (overall dynamic body acceleration – ODBA) collected with pop-off biologgers during a 12-h monoiroting period for Northen Pike for fish landed with a cradle ($n=9$; mean ODBA ± SE = 0.74 ± 0.02 g), by hand ($n=8$; 0.72 ± 0.01 g) and by net ($n=8$; 0.81 ± 0.02 g). Dissimilar letters represent significant difference in locomotor activity across the landing methods used. Vertical bars indicate the standard error of the mean.

4 Discussion

Generally, larger Northern Pike demonstrated greater post-release locomotor activity compared to smaller Northern Pike and there was a positive relationship between unhooking time and post-release locomotor activity. We speculate that the hyperactivity associated with longer unhooking times is a result of a confounding effect with the total length of Northern Pike. There was a positive relationship between the total body length of Northern Pike and the unhooking time, while larger fish also demonstrated greater post-release locomotor activity. We therefore believe that the total body length of Northern Pike is acting as a confounding effect on the post-release locomotor activity. Landing method influenced the post-release locomotor activity of Northern Pike in our study although it should be noted that during our study, the angler landing the fish was assisted by another team member. Assisted landing has the potential to reduce the time and skill required to land larger fish compared to a solo landing event, which is a potential limitation of this study. Northern Pike landed with a net had the greatest locomotor activity upon release, followed by fish landed with a cradle, and the fish landed by hand which had the least locomotor activity post-release (Fig. 5). However, this was also dependent on the total size of the Northern Pike, because larger (> ~775 mm) Northern Pike landed by hand had reduced locomotor activity during the post-release monitoring period relative to larger fish landed with a net or a cradle (Fig. 6). It is also clear that both the landing method used, and the total length of Northern Pike had cascading effects on other aspects of the angling interaction, such as the fight time and handling time.

Landing method used and the total length of Northern Pike had an influence on the total fight duration. The total length of Northern Pike was influential on fight times, where fight times increased with increasing total length of Northern Pike (Fig. 3A; Meka, 2004). Fish landed by hand had longer fight times compared to those landed with a net or cradle (Fig. 4A), likely due to increased precautions by anglers to avoid being impaled by hooks and the sharp teeth of Northern Pike, while also landing the fish so as not to touch and damage the gills (important organs for gas exchange and respiration; Ferguson and Tufts, 1992). Alternatively, using a net or cradle can enable anglers to quickly land fish, sometimes prematurely, because anglers would not have to worry about sustaining injuries to themselves or the fish when landing the fish. Further, increased fight times (i.e., anaerobic exercise), depletes energy stores, and leads to an accumulation of anaerobic by-products such as lactate (Gustaveson et al., 1991; Wood, 1991; Kieffer et al., 1996). Physiological changes that occur with extended fight times can have cascading effects on the post-release locomotor activity of fish and potentially survival (reviewed in Brownscombe et al., 2017; Holder et al., 2022). Depletion in energy stores associated with longer fight times could be the reason that large Northern Pike landed by hand (long fight time) had lower locomotor activity compared to Northern Pike landed with a landing device (shorter fight time) that had increased post-release locomotor activity. In the context of our study, higher locomotor activity is an indication of a fish that has greater welfare, less exhausted, and less stressed, but this may not be the case for all studies and species. These results would also be exacerbated with novice anglers, where fight time, handling time, and air exposure period are often increased (see Brownscombe et al., 2017). Nevertheless, using a landing net or cradle can reduce the total fight time (as seen in Lizée et al., 2018; Twardek et al., 2018), but there are caveats associated with using landing devices.

We found that using a net or cradle to land Northern Pike increased handling times compared to fish landed by hand (Fig. 4B) but enabled fish to be held in the water while unhooking, thus reducing air exposure. Our results further support previous findings by Lizée et al. (2018) that demonstrated longer handlings time are associated with using a net to land Brook Trout (*Salvelinus fontinlais*). Although the exact causes of the increased handling times while using a landing net or cradle are not clear, we speculate that the increased handling times associated with these landing devices occurred because Northern Pike often get entangled (e.g., teeth, fins, lure, hooks, etc.) within the mesh of the net or cradle. This generates a situation where an extended handling period is needed to successfully remove Northern Pike from the landing device prior to being able to release them. We also found that handling times increased with increasing size of Northern Pike (Fig. 3B). Precautions must be taken by anglers when handling fish to ensure they have control (i.e., secure grip on the fish) over large Northern Pike so they do not injure themselves by cutting their hands on the teeth of the fish or impaling themselves with a hook when grabbing the fish from the landing device. The angler must also gain control of the Northern Pike prior to being able to measure them or take a photograph, which would often occur with a trophy fish in a C&R event. Furthermore, smaller Northern Pike (< ~775mm) landed with a landing device most likely had lower post-release locomotor activity because of the added handling time associated with using a net or cradle, while Northern pike in that size range landed by hand had minimal handling time and could be released much quicker. Furthermore, although handling period is extended when using a net or a cradle,

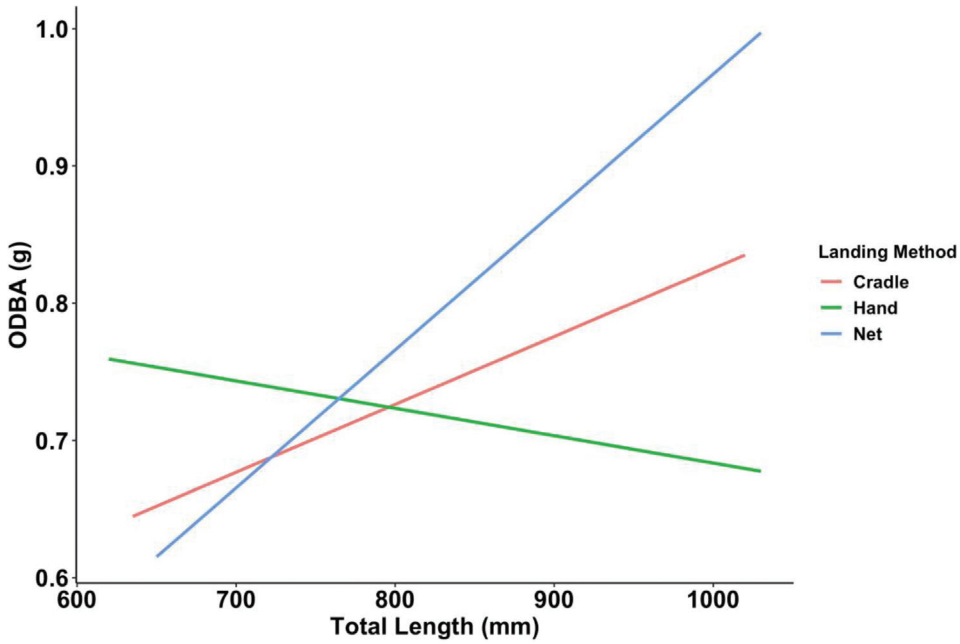

Fig. 6. Linear relationship between the total body length of Northern Pike and their locomotor activity (overall dynamic body acceleration – ODBA) for different landing methods.

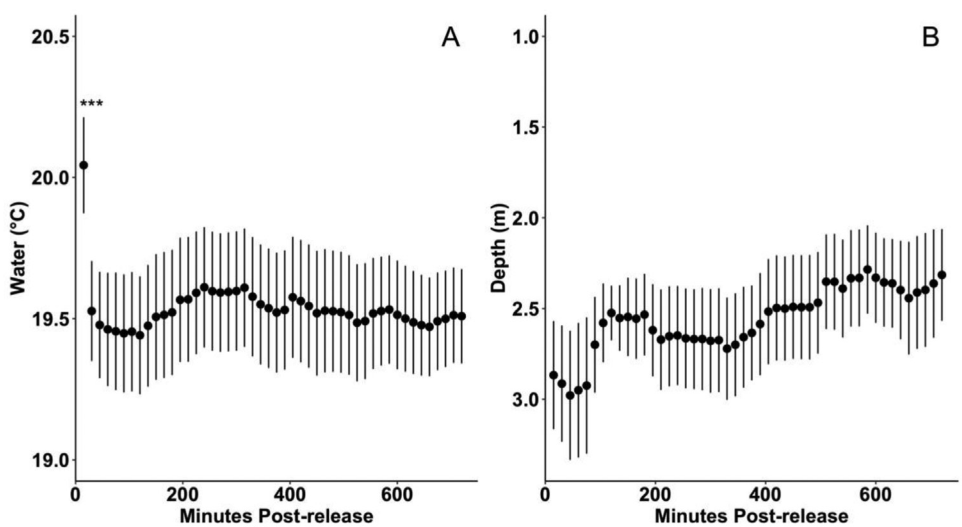

Fig. 7. Water temperature (A; mean ± SE; $n = 1200$; 19.5 ± 0.03 °C) and depth (B; $n = 1200$; 2.6 ± 0.04 m) used by Northern Pike during a 12-h monitoring grouped in 15-min blocks. Asterisk in panel A represent the significant difference in water temperature used during the first 15 min post-release compared to the rest of the monitoring period. Vertical bars represent the standard error of the mean.

these landing devices provide a vessel that can safely hold fish in the water momentarily during which anglers can get a camera and measuring device ready. It seems that there is a trade-off that occurs where an extended handling period might eclipse the influence that a longer fight time has. In other words, anglers using a net will reduce the fight time, but in turn, have a longer handling period. This longer handling period, if the fish remains in the water and is not air exposed, presumably provides a greater benefit to the welfare of fish, compared to longer fight times and shorter handling periods common with landing Northern Pike by hand. However, these results are based on a small sample size for each the three landing methods used and monitoring only occurred for a 12-h period post-release.

The novel freshwater pop-off biologging package (Figs. 1 and 2) used in this study was a useful tool to monitor the short-term (i.e., 12 h) post-release survival, locomotor activity, depth and water temperature used by Northern Pike. This small pop-off biologging package provided some benefits that allowed us to monitor post-release behaviour for a longer period post-release (12 h) without constraints such as of a line attached to a fish and the researcher having to tend to the line for the desired monitoring period. Previous studies that used a line with a biologger attached to a Velcro strap that was then fastened to the fish were only able to monitor post-release locomotor activity, water temperature and depth used for 9–30 min (LaRochelle et al., 2021; Bieber et al., 2022; Chhor et al., 2022; LaRochelle et al., 2022), because longer monitoring periods become time consuming and potentially challenging. Furthermore, had we performed more preliminary trials with these biologging float packages on Northern Pike, we may have decided to use a larger size of catgut suture (3–0 instead of 5–0) as the dissolvable link to further extend the post-release behavioural monitoring period. Our success with the 5–0 catgut suture ranged from monitoring fish for a few seconds post-release to a maximum of 6 days. We noticed that the dissolvable suture would rarely break, but instead lose tensile strength and slide off the Northern Pike as they engaged in swimming activity. For future studies that are going to use pop-off biologging packages for freshwater research, we recommend using a larger size catgut suture (3–0) for larger bodied fish to extend the length of the monitoring duration, while the 5–0 catgut suture material might be sufficient for smaller bodied fish such as Black bass (*Micropterus* spp.). Furthermore, future studies should evaluate the effects of using landing devices (net and cradle) on fish that grow much larger than *Esox* spp. to see if there is a maximum total length that landing devices are beneficial. Also, future studies could investigate to see if there are benefits of holding fish in a net or cradle prior to release to see if this holding period increases physiological stress or whether the holding period acts as a controlled recovery period that could potentially improve the outcome for fish once released.

There was no immediate or short-term post-release mortality of Northern pike during the 12-h monitoring period using pop-off biologgers. However, locomotor activity differed across the various landing methods used and the body size of Northern Pike caught. Fight time and handling times generally increased with increasing size of Northern Pike and using a net or cradle reduced the total fight time but did however increase the total handling time. We also found that Northern Pike released after being landed with a net generally had the greatest post-release locomotor activity indicating these fish may be less exhausted and fish landed by hand had the least locomotor activity, which is an indication of exhaustion. These findings could be further applied to other species such as the Muskellunge (*Esox masquinongy*) and other large predatory fish. Northern Pike larger than 775mm tended to have the longest fight times and showed the least amount of post-release locomotor activity, a clear symptom of exhaustion because of an extended fight period. We conclude from our results that anglers should use a net rather than a cradle to land Northern Pike > 775mm and land Northern Pike by hand when they are < 775mm to minimize exhaustion and maximize the welfare of fish following release.

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