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ARTICLE

Influence of Landing Net Mesh Type on Handling Time and Tissue Damage of Angled Brook Trout

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Abstract
Recreational catch-and-release angling is a popular activity. Anglers often use landing nets to shorten fight times, reduce stress on the line and rod, restrict fish movement to facilitate dehooking of the fish, and protect fish from undue harm caused by handling or dropping. Landing nets are constructed using a variety of netting materials that could have varied consequences when coming in contact with fish. Salmonids are among the most targeted fishes in the world, but little is known about how landing nets contribute to postcapture tissue damage. We compared handling time and instances of fin fraying, scale loss, and mucus loss sustained by Brook Trout *Salvelinus fontinalis* landed by four net mesh types (i.e., large, knotless rubber mesh; knotless nylon micromesh; large, knotted polypropylene mesh; and small, knotless rubber-coated nylon mesh) or by using bare wet hands in a recreational fishery. The knotted polypropylene mesh resulted in the greatest extent of fin fraying, whereas the bare wet hands method, knotless nylon micromesh, and rubber-coated nylon mesh resulted in the most scale loss. Interestingly, extended handling times were noted for several mesh types (i.e., knotless nylon micromesh and rubber-coated nylon mesh) relative to bare wet hands because of hook entanglement in the netting material. However, using bare wet hands to land Brook Trout resulted in higher odds of the fish being dropped into the bottom of the boat. We concluded that the large, knotless rubber mesh was the least damaging to Brook Trout. Changes to angler practices, such as using appropriate landing tools, can benefit fish welfare in catch-and-release fisheries.

Recreational catch-and-release angling is a popular activity around the globe (Arlinghaus et al. 2007). The premise of catch and release, whether as a voluntary conservation action or as a mandatory action to comply with management regulations, is that the released fish survive with negligible tissue damage, stress, or other

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negative biological consequences (Wydoski 1977; Cooke and Schramm 2007). It is therefore in the best interest of recreational fisheries managers, fishing guides, and anglers to adopt practices that are beneficial for fish, including angler behavior and gear choices (Brownscombe et al. 2017). There is an expanding literature on catch-and-release science that identifies the practices and gear types that are optimal for a variety of factors related to the environment (e.g., water temperature, predator burden, and depth) and the fish (e.g., species, size, and maturation state; Cooke and Suski 2005; Raby et al. 2015; Brownscombe et al. 2017).

One aspect of catch and release that has received relatively little study is the landing net (Arlinghaus et al. 2007). The landing net is a commonly used item of fishing equipment that may influence tissue damage and postrelease mortality of angled fish. Handheld landing nets are simple and effective tools that are available to anglers for retrieving fish from the water (Barthel et al. 2003), reducing the exercise time of a fish, restricting fish movement (Barthel et al. 2003), holding and manipulating the fish during dehooking (De Lestang et al. 2008), and reducing the likelihood of harm to the fish from dropping. Landing nets are available with different mesh sizes, mesh materials, and knot types (e.g., knotless versus knotted); furthermore, some nets are marketed as species specific (e.g., trout nets), ostensibly because they reduce tissue damage in comparison with other mesh types. Landing nets constructed of soft knotless nylon, thick rubber, and knotted polypropylene meshes are widely used in recreational trout fisheries (Barthel et al. 2003). Although landing nets are commonly used in recreational catch-and-release fisheries, their actual effects on fish are uncertain, likely because fish often show little visual evidence of harm and may swim away in seemingly good condition (Barthel et al. 2003). The potential for physical harm to fish from unsuitable net mesh materials includes fin abrasion, fin fraying, bleeding, mucus loss, and scale loss. Poor net design can also lead to prolonged air exposure and prolonged handling of the fish. Fin fraying can compromise the fish's postrelease swimming ability and can lead to fin rot (Latremouille 2003), whereas scale loss or mucus loss can render fish more susceptible to infection and disease (Jones 2001; Colotelo et al. 2013; Schwabe et al. 2014). These three metrics (fin fraying, scale loss, and mucus loss) can index the tissue damage and disturbance experienced by fish upon landing.

Salmonids constitute an important group of fish in many areas of the world. In Canada, trout and char are the second most commonly targeted group of species by recreational anglers (Brownscombe et al. 2014), comprising approximately 20% of annual catches, or about 38.3 million fish per year. The Brook Trout *Salvelinus fontinalis* is the most popular trout species captured (DFO 2012). Although trout and char are very well studied in the context of catch and release (Hühn and Arlinghaus 2011), there is a paucity of data available with which to establish recommendations on the landing mesh types that anglers should use. The objective of this study was therefore to assess the effects of various landing mesh types on the tissue damage (including epithelial injury and fin fraying) and handling time of Brook Trout in a recreational catch-and-release fishery. Because a wide variety of nets is available to consumers, we selected nets consisting of varying mesh sizes and materials.

METHODS

Study site.— All angling was conducted on Lake Collins (coordinates: 45°44′33.417″N, −74°48′28.5012″E) at Kenauk Nature in Montebello, Quebec, Canada (www.kenauk.com). Lake Collins is stocked annually with Brook Trout from fish hatcheries near Mont-Tremblant, Quebec. Lake Collins has a surface area of 0.12 km^2, an average depth of 9.14 m, and a maximum depth of 32 m; no information is available on its bathymetry. It was assumed that the stocked Brook Trout would respond similarly to wild individuals during capture. Data were collected on four consecutive days from October 5 to October 8, 2015.

Equipment.— The rods, tackle types, and angling methods (casting and trolling) were implemented in consultation with the Kenauk Nature staff to reflect the practices typical of anglers in the region. A variety of lightweight spinning rods (light gear strength) was used in conjunction with a variety of barbed treble hooks equipped with size-2 inline spinners, either baited with worms or unbaited. Rods and tackle were rotated between anglers. Kerr et al. (2017) found that lure and bait type did not significantly influence hooking injury of Brook Trout in Kenauk. Two small, 3.54-g lead sinkers were attached to braided and monofilament lines approximately 30 cm above the spinner and did not present an entanglement risk.

Focusing on nets of the correct diameter for trout, we compared four different net mesh types that varied in dimensions and materials (Figure 1): (1) a large-mesh (25 mm), knotless rubber net; (2) a micromesh (2 mm), knotless nylon net that was advertised as a "trout net"; (3) a large-mesh (40 mm), knotted polypropylene net; and (4) a small-mesh (6 mm), knotless rubber-coated nylon net. The use of bare wet hands was also included as a treatment because this technique is often employed by anglers to remove the hook and release the fish immediately and because it is often assumed to cause less physical damage than netting the fish.

Angling and landing procedures.— Brook Trout were angled by five proficient anglers of similar experience levels, all of whom were given training prior to the study

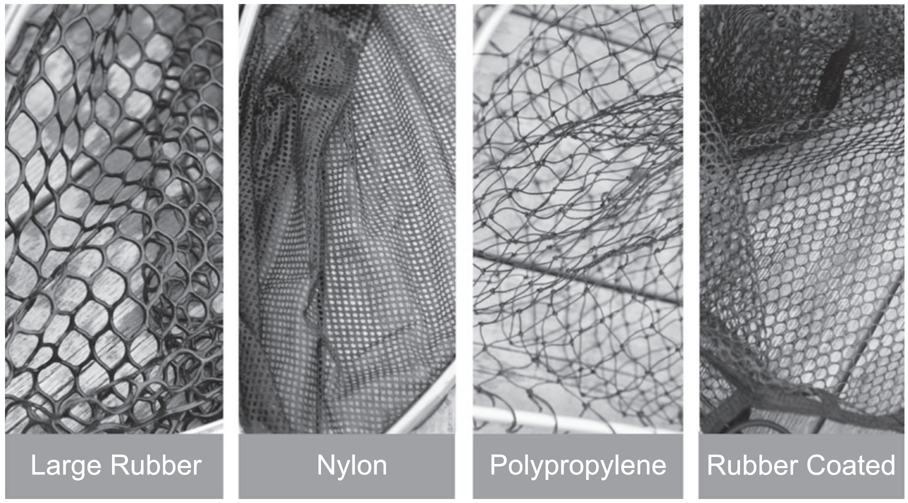

FIGURE 1. Close-up images of the four landing net meshes used in this study: large, knotless rubber mesh (25 mm); knotless nylon micromesh (2 mm); large, knotted polypropylene mesh (40 mm); and small, knotless rubber-coated nylon mesh (6 mm).

to ensure that fishing and handling techniques were consistent throughout the experiment. All participants angled both by actively casting and retrieving the lure from a stationary boat or by trolling the lures behind the boat while it slowly moved to a new location in the lake. Captured Brook Trout were landed by using one of the four landing nets or by using bare wet hands. Anglers applied a treatment for five landings and then rotated treatments in order to balance the number of fish caught per treatment, until a minimum of 25 fish per treatment group were landed.

Brook Trout were dehooked inside the boat, using pliers when necessary, and then were placed in a 50-L tank full of lake water; no more than three Brook Trout were held in the tank at any given time. Angling time, dehooking time, and handling time (all measured in seconds) were recorded. Angling time started when the Brook Trout was hooked, included the fish being reeled to the boat, and ended upon landing of the fish. Dehooking time started when the Brook Trout was landed, included getting a firm grip on the fish, and ended either when the treble hook was removed from the fish or when the fish shook the hook. The handling time included the same parameters as dehooking time but ended when the fish was placed into the tank. The Brook Trout TL (mm), the hook location, tangling in the net mesh, and the mesh type used were also recorded. No Brook Trout evaded capture by escaping from the various landing treatments.

To minimize air exposure, Brook Trout were transferred to a tank in which reflex action mortality predictors (i.e., RAMPs) could be assessed (body flex, operculum closure, mouth closure, and vestibular–ocular response; Davis and Ottmar 2006). Visual inspection of the fish was conducted to confirm the presence or absence of physical damage (i.e., fin fraying, scale loss, and mucus loss). Only visible, recent damage considered to have been caused by the landing methods were recorded, and any wounds that were partially healed (e.g., adipose fin clips or pelvic and pectoral fin damage from hatchery conditions) were not considered damage from the landing nets. Whether a Brook Trout was dropped or fell to the bottom of the boat was also noted.

Brook Trout were individually tagged for identification by applying numbered, 18-mm standard plastic anchor tags (Avery Dennison, Ltd., Pasadena, California) in the dorsal musculature between the pterygiophore bones with a tagging gun. Fish were then transported to net-pens, either $0.9 \times 0.9 \times 0.9$ m (maximum density = 15 fish) or $1.2 \times 1.2 \times 1.2$ m (maximum density = 30 fish). The Brook Trout were held in the net-pens for a minimum of 1 h and were then assessed for mortality and released once the tags were removed.

Analyses.— All analyses were conducted using RStudio version 0.98.1091 (RStudio Team 2014) running R (R Core Team 2017). Binomial logistic regression tests were used to examine the main effects of the various meshes on the occurrence of scale loss, mucus loss, and fin fraying. For logistic regressions, the bare wet hands method was selected as an outgroup treatment against which to compare the various net mesh treatments. Because bare wet hands would have a different set of consequences than net meshes, assessment of this method can be used to isolate the effect of nets relative to bare wet hands and allows for a contrast among net types to isolate the effects of mesh type across treatments. Linear regression was used to analyze the effects of net types on handling time. The average angling time and dehooking time were also calculated. A Shapiro–Wilk test ("shapiro.test" function in the "stats" package; R Core Team 2017) was implemented to evaluate the normality of residuals, and a square-root transformation of the response variable was deemed necessary to satisfy the assumption of normality of residuals. Owing to nonnormality of residuals, however, we used a nonparametric Kruskal–Wallis test ("kruskal.test" function in the stats package) to identify differences in dehooking time among net treatments, and we used Dunn's test to conduct post hoc multiple comparisons ("dunnTest" function in the R package FSA; Ogle 2016). Model outputs were further analyzed using Tukey's honestly significant difference tests via the "glht" function in the "multcomp" package (Hothorn et al. 2008) to determine any significant differences among categories, and we assessed variable influence by using odds ratios. For all analyses, we present means with SEs unless otherwise specified.

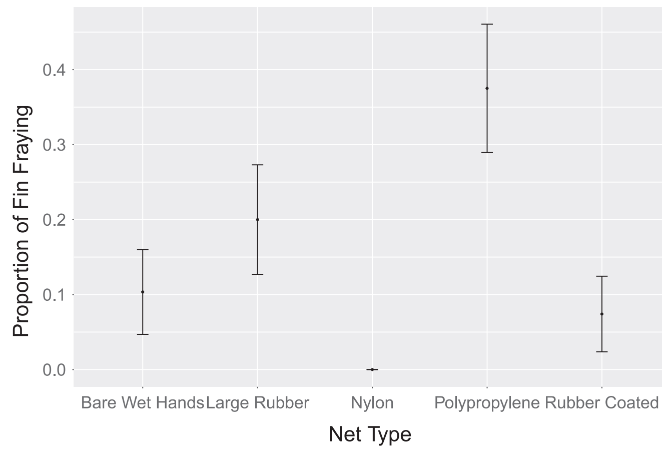

FIGURE 2. Proportion (mean ± SE) of Brook Trout that exhibited fin fraying for each net treatment (see Figure 1) as well as the bare wet hands treatment.

RESULTS

Mean surface water temperature at the study site was 13.7°C (SD = 0.8°C), and mean air temperature was 14.8°C (SD = 2.5°C). In total, 146 Brook Trout were caught and handled for this study; the fish had a mean length of 310 mm (SD = 34 mm; range = 255–468 mm). The TL of Brook Trout differed among treatment groups ($F = 3.04$, $P = 0.02$); however, Tukey's test showed that there was only a significant difference between fish in the rubber-coated nylon and bare wet hands treatments ($t = 3.28$, $P = 0.01$). Angling time was not significantly different among treatment groups ($F = 0.61$, $P = 0.66$); however, dehooking time was significantly different ($F = 6.10$, $P = 0.00$). There was no immediate mortality, and all Brook Trout survived 1 h of holding in net-pens.

The only mesh that was found to cause significant fin fraying was the knotted polypropylene mesh ($z = 2.32$, $P = 0.02$; Table 1), for which the odds of fin fraying increased by 5.20 times compared to the bare wet hands treatment. Otherwise, no significant differences in fin fraying were detected between fish in the four mesh type treatment groups (Table 1; Figure 2).

The knotless nylon mesh resulted in the highest frequency of scale loss in Brook Trout (proportion = 0.21; Figure 3), with odds increasing by 1.31 times ($z = 0.40$, $P = 0.70$; Table 2) relative to the bare wet hands method. Brook Trout that were landed with bare wet hands (proportion = 0.17; Figure 3) and with rubber-coated nylon mesh (proportion = 0.15; Figure 3) also showed similarly high frequencies of scale loss. The lowest incidence of scale loss was observed among Brook Trout that were landed with the knotted polypropylene mesh (proportion = 0.03; Figure 3).

Knotless nylon mesh most frequently caused mucus loss (proportion = 0.32; Figure 4), increasing the odds by 1.49 times ($z = 0.67$, $P = 0.50$; Table 3) compared to the bare wet hands method. The knotted polypropylene mesh, rubber-coated nylon mesh, and bare wet hands also yielded similarly high proportions of mucus loss (range = 0.23–0.30; Figure 4). The large rubber mesh was associated with the least mucus loss (proportion = 0.07; Figure 4) and decreased the odds to 0.22 relative to the bare wet hands method.

The type of net mesh influenced the handling time of Brook Trout in our study. The longest average handling time (52.6 s) was observed for the knotless nylon mesh; this mesh type resulted in the greatest frequency of hook tangling in mesh (proportion = 0.68) and, in turn, longer durations of air exposure. The bare wet hands method

TABLE 1. Results of logistic regression comparing fin fraying of Brook Trout that were landed using various net types. Note that the bare wet hands treatment served as the reference level.

Net type	*n*	Estimate	SE	*z*-value	Pr(>|*z*|)
Intercept	27	−2.1595	0.6097	−3.542	0.000398
Large rubber mesh	30	0.7732	0.7617	1.015	0.310041
Nylon mesh	28	−16.4066	1,232.663	−0.013	0.989381
Knotted polypropylene mesh	32	1.6487	0.7107	2.32	0.020358
Rubber-coated nylon mesh	29	−0.3662	0.9549	−0.384	0.701312

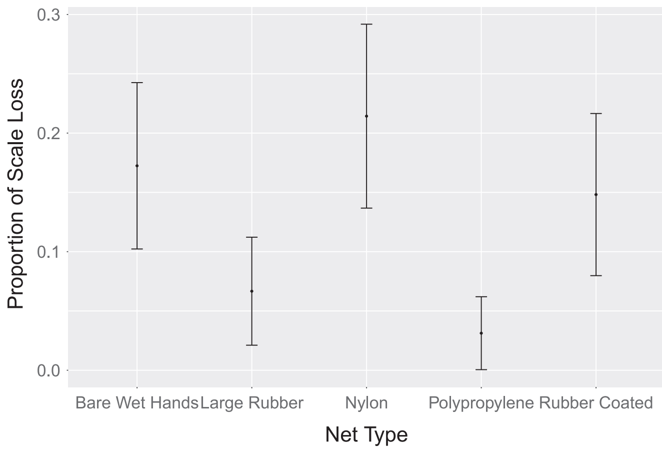

FIGURE 3. Proportion (mean ± SE) of Brook Trout that exhibited scale loss for each net treatment (see Figure 1) as well as the bare wet hands treatment.

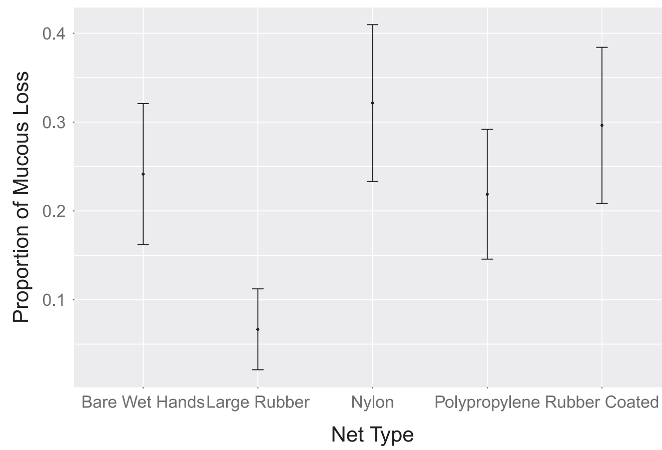

FIGURE 4. Proportion (mean ± SE) of Brook Trout that exhibited mucus loss for each net treatment (see Figure 1) as well as the bare wet hands treatment.

TABLE 2. Results of logistic regression comparing scale loss of Brook Trout that were landed using various net types. Note that the bare wet hands treatment served as the reference level.

Net type	*n*	Estimate	SE	*z*-value	Pr(>|*z*|)
Intercept	27	−1.5686	0.4916	−3.191	0.00142
Large rubber mesh	30	−1.0704	0.8817	−1.214	0.22472
Nylon mesh	28	0.2693	0.6736	0.400	0.68929
Knotted polypropylene mesh	32	−1.8654	1.1287	−1.653	0.09839
Rubber-coated nylon mesh	29	−0.1806	0.7315	−0.247	0.80502

TABLE 3. Results of logistic regression comparing mucus loss of Brook Trout that were landed using various net types. Note that the bare wet hands treatment served as the reference level.

Net type	*n*	Estimate	SE	*z*-value	Pr(>|*z*|)
Intercept	27	−1.1451	0.4339	−2.639	0.00832
Large rubber mesh	30	−1.4939	0.8509	−1.756	0.07914
Nylon mesh	28	0.3979	0.5933	0.671	0.50245
Knotted polypropylene mesh	32	−0.1278	0.6092	−0.21	0.8338
Rubber-coated nylon mesh	29	0.2801	0.6049	0.463	0.6433

had the shortest average handling time (23.4 s). The large rubber mesh ($t = 2.01$, $P = 0.05$; Table 4) and knotless nylon mesh ($t = 4.60$, $P < 0.01$) treatments produced significantly different handing times (Figure 5). Otherwise, no significant differences were found among the remaining mesh types. The brief handling time for the bare wet hands method was also probably related to the incidence of Brook Trout shaking the hook free, which was highest for this treatment (proportion = 0.31)—almost three times the average incidence when landing Brook Trout with any of the treatment meshes (average proportion = 0.11).

The dehooking time of Brook Trout was significantly different among net types ($\chi^2 = 16.53$, $P < 0.01$; Figure 6). However, according to Dunn's post hoc comparisons, the only significant pairwise difference was between the large rubber mesh and knotted polypropylene mesh nets ($z = 4.05$, $P < 0.01$). The frequency of dropping a Brook Trout was nearly four times higher for bare wet hands (proportion = 0.24) than when any of the landing nets (average proportion = 0.05) were used.

DISCUSSION

This study described the physical impacts of landing net mesh types on recreationally captured salmonids. We found that landing Brook Trout with any of the four mesh types resulted in longer handling times than the use of bare wet hands, probably because the treble hooks of the lures frequently became entangled in the mesh of each net type. In a study conducted on the same system, Kerr et al. (2017) reported that treble hooks did not have a significant effect on mortality compared to single hooks but did increase handling time and air exposure because they encumbered the dehooking of fish. Based on our research, anglers could use rubber-mesh nets to dehook fish efficiently and reduce the duration of air exposure

TABLE 4. Results of linear regression using the square root of handling times for Brook Trout that were landed with various net types. Significant *P*-values are shown in bold italics.

Net type	*n*	Estimate	SE	*t*-value	Pr(>|*t*|)
Intercept	27	4.6147	0.3499	13.189	$<2 \times 10^{-16}$
Large rubber mesh	30	0.9868	0.4907	2.011	***0.0462***
Nylon mesh	28	2.2979	0.4992	4.603	***<0.01***
Knotted polypropylene mesh	32	0.6077	0.4831	1.258	0.2105
Rubber-coated nylon mesh	29	0.7043	0.5039	1.398	0.1644

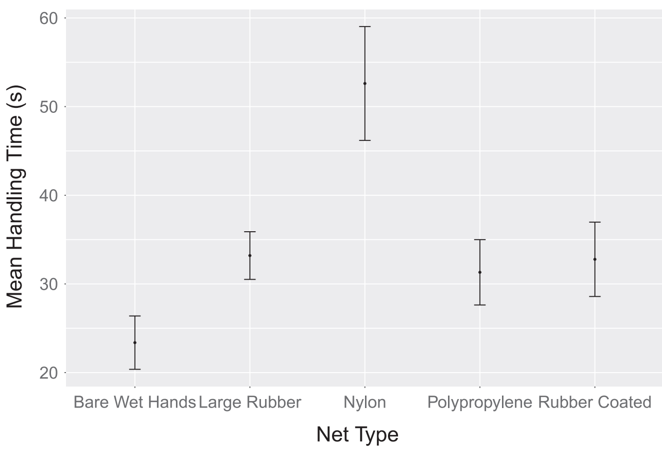

FIGURE 5. Handling time (mean ± SE) of Brook Trout that were landed by using various net types (see Figure 1) as well as the bare wet hands treatment.

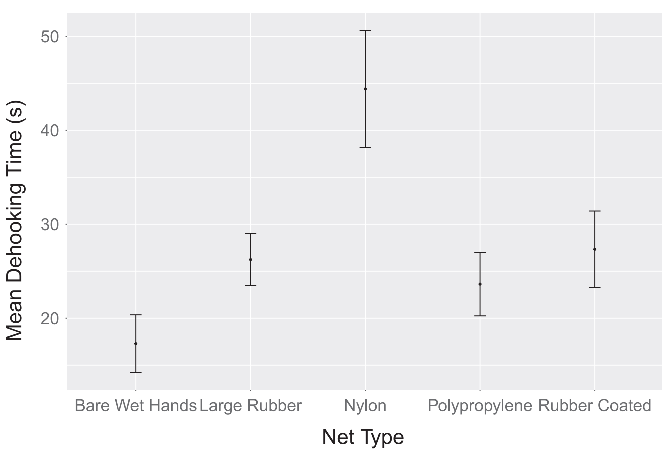

FIGURE 6. Dehooking time (mean ± SE) of Brook Trout that were landed by using various net types (see Figure 1) as well as the bare wet hands treatment.

(Arlinghaus et al. 2007), a practice that is often recommended as the best option for anglers to land fish (Pelletier et al. 2007; Brownscombe et al. 2017).

Our findings are similar to those of Colotelo and Cooke (2011), who determined that knotted nylon mesh caused extensive epithelial damage to Northern Pike *Esox lucius* in comparison with rubber mesh. However, Colotelo and Cooke (2011) also reported that neither knotted nylon mesh nor rubber mesh caused noticeable damage to Largemouth Bass *Micropterus salmoides*. In a study by Barthel et al. (2003), Bluegills *Lepomis macrochirus* that were landed by hand had lower tissue damage rates and mortality than those that were landed by using any net mesh type. Interspecific differences in scale loss, mucus loss, and fin fraying would likely arise from differing behavior exhibited by Bluegills, Largemouth Bass, and Brook Trout while being handled and held out of water. Brook Trout are muscular, are difficult to handle manually, and can have strenuous avoidance reactions (e.g., confamilial Rainbow Trout *Oncorhynchus mykiss*; van Raaij et al. 1996), leading to instances of dropping the fish that might not have occurred with species that can be handled more securely in air. Barthel et al. (2003) also found that coarse knotted mesh was overall the most damaging to Bluegills, which is consistent with our observation that Brook Trout were most heavily damaged by the large, knotted polypropylene mesh. Barthel et al. (2003) observed that fish landed in knotless mesh, fish landed in rubber mesh, and control fish (held out of water but not placed in nets) had similarly low rates of dermal disturbance and that the coarse- and fine-knotted meshes resulted in higher rates of scale and mucus loss.

Overall, we found inconsistent patterns of tissue damage among mesh types, highlighting the challenges and tradeoffs faced by anglers when selecting a landing method. The extent of fin fraying and the odds of fin fraying were higher when Brook Trout were landed in larger-mesh nets. When Brook Trout were landed by using nets with large mesh, their fins tended to protrude from the net, increasing the likelihood of developing damage to connective epithelia, such as lacerations to the fins. Smaller mesh sizes were more likely to support fins, but they also increased the odds of scale loss. The large rubber mesh resulted in a much lower incidence of mucus loss than the other treatments. These conflicting patterns of injury reveal that tissue damage from landing nets is likely caused by multiple attributes of the net types; thus, further inquiry into the independent effects of net mesh materials and mesh sizes is warranted.

Proper landing nets can effectively reduce the frequency of tissue damage and physiological disturbances experienced by Brook Trout in recreational fisheries. Our data suggest that large rubber mesh—rather than just rubber-coated mesh—is the best for mitigating tissue damage when landing Brook Trout because this mesh type minimized mucus loss and scale loss and resulted in only moderate fin fraying. Rubber mesh has a firm yet flexible construction that allows Brook Trout to be supported; the larger mesh size and rubber material also reduce the occurrence of hook tangling, thereby allowing for relatively short handling times that minimize air exposure (Arlinghaus et al. 2007; Pelletier et al. 2007; Brownscombe et al. 2017). We discourage the use of bare hands as a landing method because Brook Trout were more likely to be mishandled and dropped when that treatment was applied.

Many different salmonid species are exposed to capture with fishing nets in commercial, recreational, and subsistence fisheries. Although assessments of injury and condition in salmonids that are captured and released as bycatch from commercial or subsistence fisheries (i.e., seine nets; e.g., Donaldson et al. 2011; Raby et al. 2015) have provided insight into the impacts of net injuries, the present study is one of the first to focus on landing nets, which are used in recreational fisheries and also in other contexts for sorting or transporting fish (see Raby et al. 2015). Further investigation of rubber-meshed nets of various mesh sizes is recommended to establish better and more specific recommendations regarding which nets are best suited to individual fisheries.

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