North American Journal of Fisheries Management 39:460–467, 2019

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1002/nafm.10285

ARTICLE

Rainbow Trout Migration and Use of a Nature-Like Fishway at a Great Lakes Tributary

Christopher Bunt* **and Bailey Jacobson**
Biotactic Fisheries Research and Monitoring, 691 Hidden Valley Road, Kitchener, Ontario N2C 2S4, Canada

Abstract
Rainbow Trout *Oncorhynchus mykiss* were monitored over two consecutive vernal migration periods at a nature-like fishway on the Beaver River, Ontario, to assess attraction efficiency, passage efficiency, multiple fish passage metrics, and interannual return rates from Georgian Bay, Lake Huron. Fishway evaluations have shifted to fill knowledge gaps related to the passage of nonsalmonids; however, surprisingly little work has been conducted with Rainbow Trout, with no known study assessing attraction or passage at a nature-like fishway. Attraction efficiency was 53% and passage efficiency was 100% in 2017; only two of the radio-tagged fish returned to the fishway in 2018. Upstream passage through the fishway required an average time of 152 ± 122 min. Fish spent 19–43 d upstream before returning to Lake Huron, where downstream passage required as little as 15 min. Overall, there were no significant relationships between any of the fish passage metrics and fish size or condition. These results can be used as a foundation for anadromous *O. mykiss* subspecies passage research and suggest that fisheries managers may need to adjust annual fishway counts. Future research should focus on developing methods to directly integrate temporal passage metrics into estimates of fishway efficiency.

Multiple complex variables converge and interact simultaneously to attract fish into the entrances of fishways and allow successful passage upstream to circumvent dams and other migration barriers. Physical ability, migratory propensity, and underlying motivation required for fish to locate a fishway entrance all vary by species (Roscoe and Hinch 2010; Castro-Santos et al. 2013) and contribute to the overall functionality of a fish passage structure. Attraction to the entrance of a fishway is also affected by engineered characteristics that influence the hydraulic conditions (Aarestrup et al. 2003) and the location of the entrance (Travade and Larinier 2002) relative to potential distractions as well as the environmental conditions experienced, such as discharge and water temperature. After successfully entering a fishway, fish actively ascend upstream, where success or failure to reach the fishway exit is also dependent on multiple biological variables and engineered parameters, such as elevation change, slope, and substrate complexity (Cooke and Hinch 2013). Fishway performance is empirically determined using telemetry, and the capacity for a fishway to attract fish to its entrance is generally reported as attraction efficiency (E_a). The proportion of fish that successfully use the fishway relative to the number of fish that enter is reported as passage efficiency (E_p; Bunt et al. 1999, 2012; Cooke and Hinch 2013; Hatry et al. 2016).

Although fishway evaluations have shifted to focus on filling knowledge gaps related to passage performance of nonsalmonids (e.g., Thiem et al. 2013; Hatry et al. 2016; Kim et al. 2016), basic passage data on the most globally ubiquitous salmonid, the Rainbow Trout *Oncorhynchus mykiss*, is still virtually nonexistent. Indeed, surprisingly little work has been conducted on Rainbow Trout, with only two studies to date that have investigated the E_p of this species quantitatively, both at fishways with “technical” designs. The reported efficiencies from the studies varied greatly, and total fishway efficiency, which is the product of E_a and E_p, ranged from 2% at a vertical-slot

*Corresponding author: cbunt@biotactic.com
Received October 8, 2018; accepted March 24, 2019

fishway (Pratt et al. 2009) to 100% at a pool-and-weir fishway (Naughton et al. 2007). Technical fishways are considered those with substrate and internal features constructed from concrete, wood, and metal and are typically built compactly, with elevated slopes and the ability to accommodate high flow capacity. "Nature-like" fishways, on the other hand, are generally more complex and use natural substrate material and meanders, which produce highly variable flow and velocity patterns that mimic the conditions typically found in rivers and streams. Although nature-like fishways appear to be the most effective and promising mitigation strategy for fish passage (Franklin et al. 2012; Steffensen et al. 2013), there are no known studies of Rainbow Trout passage for this type of fishway design. In comparison, one study was conducted with Atlantic Salmon *Salmo salar* (Nyqvist et al. 2017), one was conducted with Brook Trout *Salvelinus fontinalis* (Landsman et al. 2018), five were conducted with Brown Trout *Salmo trutta* (Aarestrup et al. 2003; Calles and Greenberg 2005, 2007; Tummers et al. 2016; Dodd et al. 2017), and 11 studies reported efficiency values for 43 nonsalmonid species at nature-like fishways (Schmutz et al. 1998; Calles and Greenberg 2005, 2007; Franklin et al. 2012; Steffensen et al. 2013; Cahill et al. 2015; Bunt et al. 2016; Kim et al. 2016; Landsman and van den Heuvel 2017; Landsman et al. 2017, 2018). Total efficiencies also varied greatly among these studies and ranged from 7% to 97% for salmonids alone, demonstrating both the design-specific and species-specific characteristics of fishway performance.

Passage of Rainbow Trout and Chinook Salmon *O. tshawytscha* has been continuously monitored from March to November 2011–2017 at a nature-like fishway on the Beaver River, a tributary of Georgian Bay, Lake Huron. Data from a video-based fish counting and identification system installed at the fishway exit showed mean successful passage of 2,410 Rainbow Trout per year (range = 1,072–3,785 per year from 2011 to 2015), but the total efficiency of the fishway and the number of individuals that use the fishway repeatedly from year to year are unknown. Rainbow Trout (i.e., steelhead) entering the Beaver River from Lake Huron are anadromous, iteroparous, and strongly motivated, with as many as three (spring, fall, and winter) yearly spawning migrations (Biette et al. 1981). Great Lakes populations have a high degree of tributary spawning site fidelity (Dodge and MacCrimmon 1970; Biette et al. 1981) as well as stocking site fidelity (Boehler et al. 2012). Although unproven, these characteristics suggest that fish may use or attempt to use the same fishway multiple times throughout their lifetime or even within a single year. This aspect of fish passage (i.e., fishway utilization by the same fish in consecutive migration periods) has received little attention, with the vast majority of multi-year studies using data from different sets of fish tagged and tracked each year rather than investigating the same individuals for multiple years (but see Cahill et al. 2016 and Nau et al. 2017). The objective of this study was to evaluate the upstream and downstream passage of radio-tagged Rainbow Trout at a nature-like fishway during the 2017 and 2018 spring migration periods and to examine temporal passage metrics, fishway E_a and E_p, and interannual return rates.

METHODS

Study site.— Thornbury Fishway, located on the Beaver River, Ontario, Canada, is 126 m long and composed of two turn pools and a series of 29 nature-like step pools with cobble and boulder substrate (Figure 1); each step pool measures approximately 2 × 3 m. The downstream entrance to the fishway has a mechanical control gate that creates a vertical drop of approximately 0.5 m to block access of free-swimming Sea Lampreys *Petromyzon marinus*. The elevation drop between pools is approximately 0.3 m, and the total elevation change is 10 m. The upper section of the fishway consists of two concrete chambers with a removable basket trap and a second mechanical gate to control flow through the fishway. Mean discharge during migration in spring (March–June) and fall (August–November) varies, and the water velocity in the upper chamber ranges between approximately 1.5 and 2.5 m/s. Water velocities and turbulence in the nature-like section of the fishway are highly variable, while flow in the upper chamber near the location of a fishway monitoring camera is generally laminar. Water temperature (°C) was recorded every 5 min by the BRAVO camera system (BRAVO Fish Monitoring Systems Generation 1; Biotactic, Inc., Kitchener, Ontario), and river level (discharge) in the Beaver River was obtained from the Environment Canada Hydrometric water level monitoring station located 2 km upstream in Clarksburg.

Radiotelemetry.— Thirty adult Rainbow Trout were angled at various locations downstream from Thornbury Dam on April 2, 2017. Fish were sexed, measured (TL, mm), weighed (g), internally tagged with coded radio transmitters (Sigma Eight, Inc., TX-PSC-I-160; 10 × 41 mm; 7.2 g), and released approximately 150 m downstream from the dam. Transmitters were programmed to enter sleep mode from June 2017 to February 2018 to conserve battery life.

Two stationary tracking systems (Lotek SRX_400 W20) were used to monitor the fishway from early March to June 1 in 2017 and 2018 (Figure 1). In 2017, one antenna was installed near the fishway entrance (in the first chamber at the downstream section of the fishway), and the second antenna was installed in the last chamber within the upstream section of the fishway at the fishway exit (Figure 1). In 2018, two additional three-element Yagi

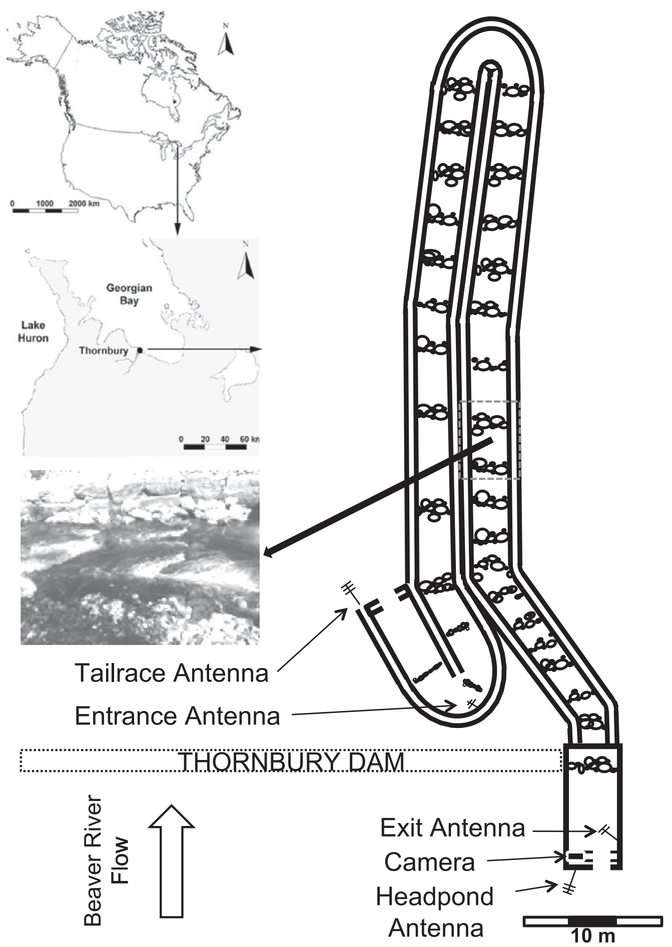

FIGURE 1. Location of the Beaver River and Thornbury Dam in the eastern section of Lake Huron, with a plan view of Thornbury Fishway, showing substrate and typical flow patterns as well as the positions of the tailrace, entrance, exit, and headpond telemetry antennas. Thornbury Dam and Fishway are located approximately 600 m upstream from Georgian Bay.

antennas were installed. One antenna monitored fish entering the fishway tailrace (i.e., the population available to be attracted to the fishway entrance), with a detection distance of approximately 5 m downstream, and the other antenna monitored the headpond to a distance of over 20 m upstream. In addition to the stationary tracking system in 2018, an aerial survey (April 30) and three land-tracking surveys (May 1, 2, and 20) were conducted—covering the Beaver River, surrounding tributaries, and the shoreline of Lake Huron—to relocate tagged fish that were not detected at the fishway. Although we assumed a detection efficiency of 100%, there was a power interruption in 2017 that shut down the tracking system for a period of 5 d beginning on April 17. Only one fish ascended the fishway undetected during this time and was tracked by the system as it traveled downstream through the fishway at a later date. Rainbow Trout remained upstream for a minimum of 19 d, so it was unlikely that tagged fish were completely missed by the tracking system by ascending and descending the fishway, or descending through the dam gates, within the 5-d period.

Calculations and analyses.— Attraction efficiency (E_a) was calculated as the proportion of radio-tagged fish that were detected at the fishway entrance (N_{ent}) divided by the total number of fish tagged (N_{tagged}); E_p was calculated as the proportion of fish that were detected at the entrance (i.e., N_{ent}) that subsequently passed upstream and were detected at the fishway exit (N_{exit}; i.e., $E_a = [N_{ent}/N_{tagged}] \times 100$; and $E_p = [N_{exit}/N_{ent}] \times 100$; Bunt et al. 1999). Additional fish passage metrics were measured to gain a more comprehensive understanding of Rainbow Trout performance. These metrics included (1) the amount of time spent downstream before moving upstream (d), measured based on the first detection at fishway antennas; (2) the time required for upstream passage (min), measured based on the time elapsed from the last detection at the fishway entrance to the first detection at the fishway exit; (3) the amount of time spent upstream before returning downstream (d) either through the fishway or over the dam gates; and (4) the time required for downstream passage (min), based on the time elapsed from the last detection at the fishway exit to the first detection at the entrance. Comparisons of fish length, weight, and Fulton's condition factor between tagged fish that used the fishway and those that did not were made using Welch two-sample *t*-tests. Pearson's product-moment correlations were used to determine whether there were relationships between fishway passage metrics and fish size or condition. All statistical analyses were conducted using R version 2.13.0 (R Development Core Team 2011) with $\alpha = 0.05$, and means are presented with SDs.

RESULTS

In spring 2017, 25 wild (unclipped) female Rainbow Trout (mean TL = 569 ± 46 mm; mean weight = 2,591 ± 450 g) and 5 wild males (mean TL = 568 ± 64 mm; mean weight = 2,682 ± 566 g) were tagged. Fish began using the fishway at 4 d postrelease, when the water temperature was over 3.5°C. Sixteen of the 30 radio-tagged Rainbow Trout entered the fishway, and all 16 of those fish were detected at the fishway exit. The E_a value was therefore 53%, and E_p was 100%. There were no significant differences in TL ($t = -0.204$, df = 27.134, $P = 0.84$), weight ($t = -0.266$, df = 23.131, $P = 0.792$), or Fulton's condition factor ($t = -0.275$, df = 27.361, $P = 0.786$) between the 16 Rainbow Trout that used the fishway and the 14 fish that did not (Figure 2). Mean time for upstream passage through the fishway was 152 ± 122 min ($n = 8$), which occurred between 1200 and 2000 hours for 73% of

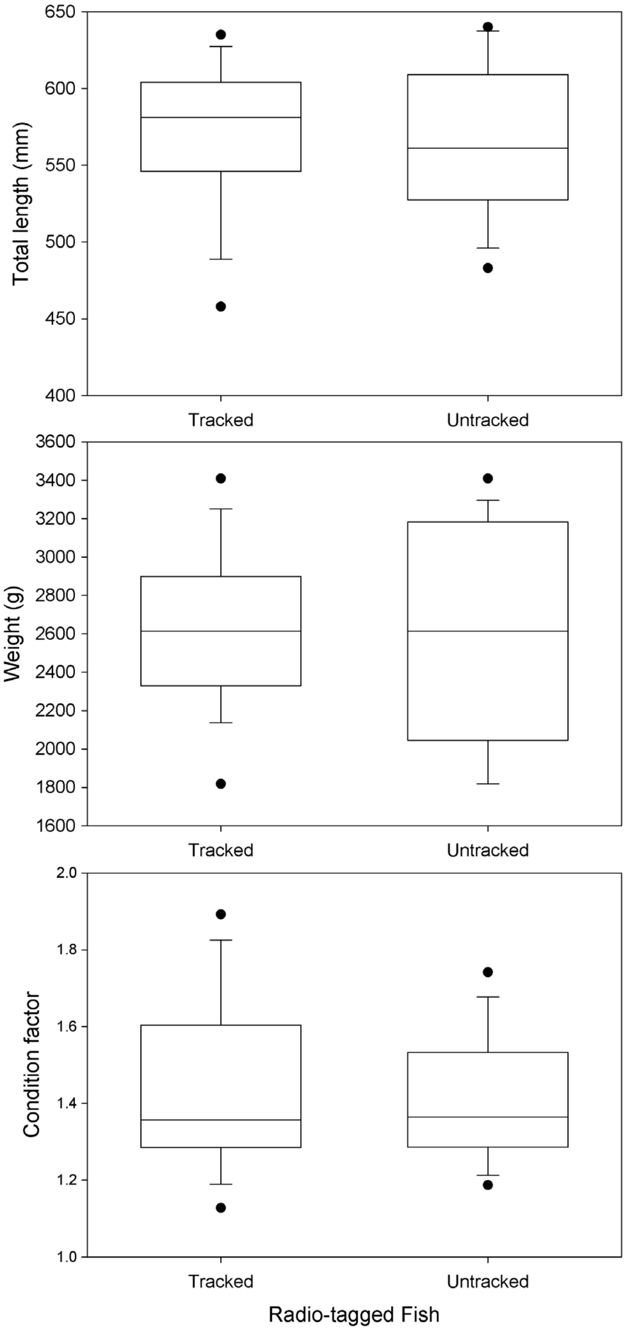

FIGURE 2. Comparisons of fish TL, weight, and Fulton's condition factor between radio-tagged Rainbow Trout that used Thornbury Fishway (tracked: n = 16) and those that did not (untracked: n = 14). The line in the box plot is the median, boundaries of the box are the 25th and 75th percentiles, and whiskers are the 10th and 90th percentiles. No significant differences were found between tracked and untracked groups based on Welch two-sample t-tests.

individuals. Fish spent, on average, 30 d (n = 11) upstream before returning to Lake Huron, with downstream passage through the fishway requiring as little as 15 min. No significant relationships were found between any of the fish passage metrics and fish TL, weight, or Fulton's condition factor (Figure 3) after the single downstream travel time outlier of 12,960 min was removed; with inclusion of the outlier, only the relationship between downstream travel time and fish TL was significant.

By the time transmitters re-activated in late February 2018, at least four fish (13%) had been caught by recreational anglers. These fish were captured in the Bighead River at the town of Meaford (located ~13.7 km to the west of the Beaver River mouth) as well as at a bay in Lake Huron located about 12.4 km to the east of the river. Two of the fish were released, whereas two fish were removed from the population of tagged fish.

In total, seven fish were relocated during 2018. Three individuals were detected with the stationary tracking array at the fishway, all of which had also used the fishway in 2017. Of these three fish, two were detected on both downstream and upstream antennas, indicating that they used the fishway for a second time in spring 2018. The remaining fish was only detected on the upstream antenna at the dam headpond. This fish returned to Lake Huron at the end of the monitoring period in 2017; therefore, it used the fishway for a second time during fall 2017, when tags were deactivated. Four additional individuals were relocated with aerial and mobile land surveys. Two fish were unique detections and had not been detected at the fishway in 2017. Both of these fish were found in a nearby bay located approximately 8.8 km to the west of Thornbury between the Beaver and Bighead rivers. The remaining two fish had used the fishway in 2017; however, these fish were never tracked as returning downstream and instead were found upstream of an additional dam (Clendenan Dam) located upstream from Thornbury, and they occupied riffle–pool habitat approximately 40 km upstream of the fishway, suggesting that they had overwintered in the river.

Environmental conditions potentially experienced by Rainbow Trout at the fishway during the 2017 monitoring period were also potentially experienced by fish at the fishway during 2018 monitoring. Mean discharge was 28.04 m^3/s (range = 14.4–35.6 m^3/s) during fishway use in 2017 and 16.64 m^3/s (range = 5.7–45.9 m^3/s) over the monitoring period in 2018. Mean water temperature was 6.3°C (range = 1.7–9.1°C) during passage in 2017 and 10.9°C (range = 0.3–24.2°C) during the 2018 monitoring period.

DISCUSSION

Values of E_a and E_p for Rainbow Trout migrating from Lake Huron into the Beaver River at the nature-like fishway in 2017 were 53% and 100%, respectively. These findings are consistent with the mean E_a of 52.7% but slightly higher than the mean E_p of 83% reported for other salmonids (i.e., Atlantic Salmon, Brown Trout, and Brook

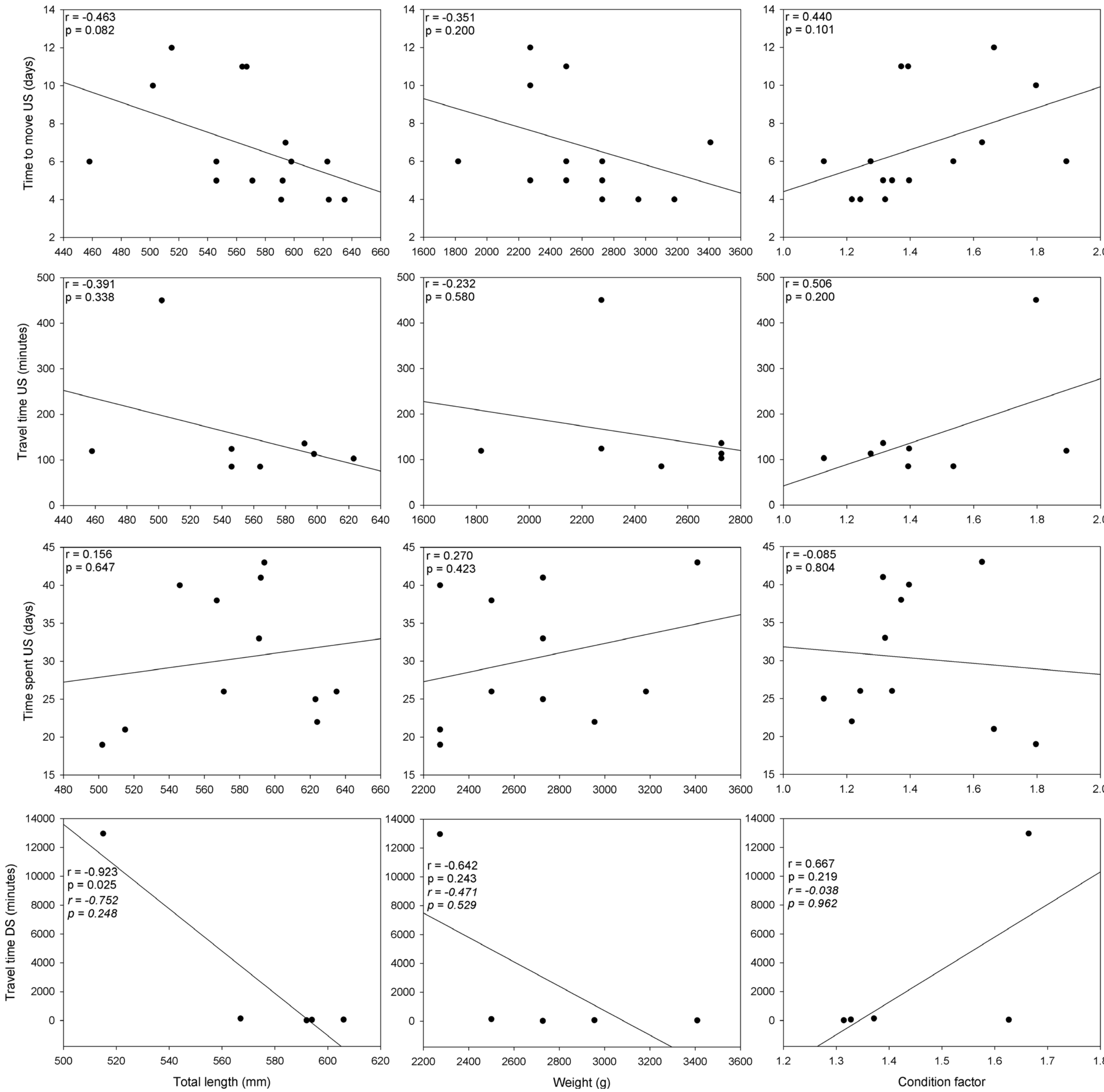

FIGURE 3. Relationships between Rainbow Trout TL (column 1), weight (column 2), or Fulton's condition factor (column 3) and fish passage metrics, including time to move upstream (US; row 1), travel time US (row 2), time spent US (row 3), and travel time downstream (DS; row 4). Pearson's product-moment correlation coefficient (*r*) and significance value (*p*) are given for each relationship. For row 4, correlations with the outlier removed are given in italics (regression not shown).

Trout) at nature-like fishways (Bunt et al. 2016; Tummers et al. 2016; Dodd et al. 2017; Nyqvist et al. 2017; Landsman et al. 2018). The lower E_a values at fishways of this design have been attributed to insufficient attraction flow (Bunt 2001; Noonan et al. 2012; Landsman et al. 2018) and in the case of Thornbury Fishway, insufficient attraction flow to compensate for other sources of discharge that distract fish downstream from Thornbury Dam, such as spillway gate and micro-hydroturbine discharge. Flow augmentation or operational modifications may be considered at Thornbury Fishway and other nature-like fishways to increase E_a and the number of fish arriving at the fishway.

While differences in E_p between Rainbow Trout and other salmonid species may be related to the physical characteristics of the specific fishways investigated, differences may also be related, at least in part, to Rainbow Trout motivation and swimming capacity, which generally exceed those of most other salmonid species. For example, Rainbow Trout have a maximum swimming capacity of 2 m/s compared to 1.3 m/s for Brown Trout (Peake 2008), which generally had the lowest mean E_p of 79.5% (Bunt et al. 2016; Tummers et al. 2016; Dodd et al. 2017); therefore, this species may be more adept at navigating the range of flows experienced within fishways with a nature-like design. Given the degree of similarity between nature-like efficiencies for other salmonids and those found here for Rainbow Trout, the E_a and E_p at Thornbury Fishway may provide a useful foundation for researchers studying passage of the many migratory *O. mykiss* subspecies endemic to the west coast of North America.

Rainbow Trout are iteroparous, spawning up to five times (Scott and Crossman 1998), and are considered to have a high degree of spawning site fidelity (Dodge and MacCrimmon 1970; Biette et al. 1981), thus potentially encountering and using the same fishways multiple times throughout their life history; however, only two of the tagged Rainbow Trout within this study returned to the fishway in 2018. This lack of return was not considered to be an artifact of differing environmental migration windows, as the conditions potentially experienced by fish at the fishway in 2017 were also present in 2018. Note that although they did not return to the fishway, interannual homing was also displayed by the two individuals found between the Beaver and Bighead rivers, as these fish were within the approximately 8-km distance previously used to discern homing behavior from straying behavior (Biette et al. 1981). No data were available on commercial or aboriginal fishing pressure or mortality for Rainbow Trout in Lake Huron, but there was evidence of high recreational angler pressure, with 13% of the tagged fish captured by fall 2017. This was unsurprising given that the Rainbow Trout makes up a significant portion of the Great Lakes (and associated tributary) recreational sport fishery: 422,000 steelhead anglers spent 2 million days angling in 2016 on just three of the five Great Lakes (USFWS and U.S. Census Bureau 2016), and $\$2.33 \times 10^9$ were spent in 2000 on recreational fishing in Ontario by Canadian anglers alone (CTC 2012). In total, five fish were found within the Beaver River in 2018, with the three additional individuals located upstream from previous spring or fall migration events.

Although it would have been useful to track fish during the 2017 fall migration, our assumption is consistent with Biette et al. (1981), who found that fall-run Rainbow Trout in the Beaver River were likely to overwinter in the river and spawn in the spring. It is possible, however, that additional fish used the fishway in the fall and ascended and descended within the period when this behavior would have been missed due to deactivated tags. We are confident, however, that no winter migration was missed, as the fishway was closed from mid-November 2017 to March 23, 2018, and the tracking system was otherwise online beginning in late winter, when the water temperature was still below the thermal threshold required for fishway use (3.5°C).

At least one individual was found to have used Thornbury Fishway repeatedly within the same year. As such, the annual fishway count data obtained from the video-based monitoring system installed at the dam may require adjustment. Indeed, if a proportion of the fish that used the fishway in the fall represents the same individuals that used the fishway in the spring, then annual counts would be an overestimate of the total number of Rainbow Trout using the fishway annually. Assuming that just 1 of 16 individuals used the fishway twice per year, the annual recorded mean count of 2,410 Rainbow Trout passed per year at Thornbury Fishway would become 2,259 fish/year. Given that the E_a was 53%, the larger extrapolated population of 4,547 individuals downstream of the dam becomes 4,262 individuals. The same rationale could also be applied to interannual returns (here, 2 of 16) and counts, allowing for adjustment of totals by the interannual overlap of individuals to estimate the number of unique fish within the larger population each year. As fishway managers often use annual count data at fishways to assess spawning escapement and to help estimate stock size (Reddin et al. 1992), more studies investigating this overlooked aspect of fish passage should be conducted, allowing adjustment of counts to more accurately reflect the number of individuals within the population and thus helping managers to devise more effective management plans necessary to maintain desired population sizes.

Traditional E_a and E_p metrics, such as those used within this study, are undoubtedly simplified and disregard several important variables that have potentially significant bioenergetic and fitness consequences for migrating fish. Examples of such factors include temporal passage components, such as downstream delay and fishway passage time, as well as the number of failed attempts and physical injuries incurred before successful passage. Although these factors may be independently measured, as temporal passage metrics were here, there is currently no standard or accepted way of directly integrating these factors into the efficiency calculations themselves by scaling down a measure of E_p based on the amount of time spent in the fishway. The ability to do so may be particularly relevant in the case of increasingly studied nonsalmonids. These species have differing and arguably reduced motivational propensities for upstream movement or capacity for long-distance dispersal, among other biological and behavioral differences. Altering the number of tagged individuals used within E_a calculations by the proportion of the population that displays upstream movement, for example, may allow for a more accurate assessment of fishway performance. Future work should focus on how best to realistically measure E_a and E_p for different species while addressing and incorporating the biological complexities frequently overlooked in the ever-evolving field of fish passage research.

ACKNOWLEDGMENTS

Partial funding for this project was provided by Bruce Power and the Town of the Blue Mountains for maintenance and continued operation of the BRAVO fish counting system. Jody Schiefley, Shawn Carrie, and Zach O'Krafka (Ontario Ministry of Natural Resources and Forestry) also helped with funding and/or operation of the fish monitoring systems and the fishway during this project. Ralph Fisher operated the fishway daily, and Dana Eddy, Bill Sack, Tim Fernandes, Tyler Scruton, Roger Klein, Jeremy Webster, Sam Bunt, Jacob Bunt, and Andy Plater provided invaluable expert field assistance. Thank you to Dave Lawson, Nelson Murikami, and volunteer anglers who helped us catch the fish used for this study. We appreciate the anonymous referees for comments on a previous version of the manuscript. There is no conflict of interest declared in this article.

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