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INDIVIDUAL VARIATION IN WINTER BROOK TROUT (SALVELINUS FONTINALIS) MOVEMENT IN A SMALL NORTHERN MICHIGAN STREAM

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By

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INDIVIDUAL VARIATION IN WINTER BROOK TROUT (*SALVELINUS FONTINALIS*) MOVEMENT IN A SMALL NORTHERN MICHIGAN STREAM

This thesis by Benjamin C. Bejcek is recommended for approval by the student's Thesis Committee and Department Head in the Department of Biology and by the Dean of Graduate Education and Research.

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ABSTRACT

INDIVIDUAL VARIATION IN WINTER BROOK TROUT (*SALVELINUS FONTINALIS*) MOVEMENT IN A SMALL NORTHERN MICHIGAN STREAM

By

Benjamin C. Bejcek

Winter is a time of year of low temperatures and limited food availability. Brook trout (*Salvelinus fontinalis*) survival in winter is dependent on several factors including their condition after spawning in the fall and possibly their behavior in winter. Ice that forms during winter can potentially aid in survival by decreasing predation risk, decreasing stress, and acting as a thermal refuge. The emphasis of this project was to evaluate the relationship between movement patterns of brook trout and winter ice distribution. In the fall of 2017 and again in the fall of 2018, brook trout in a northern Michigan stream were collected by electroshocking. All fish had their length and weight measured, and fish over 100 mm were tagged with a Passive Integrated Transponder (PIT). Following tagging, fish were tracked and their locations within the field site were recorded as well as if they were in open water or under ice cover. In the spring of 2018 and 2019, electroshocking surveys were performed again, and tagged fish were measured for length and weight. Tracking surveys occurred biweekly and showed that brook trout used ice covered areas. Two movement groups were present, a sedentary group consisting of 90% of fish and a mobile group consisting of 10%. Surface covering ice was used by fish throughout all stages of winter. Recaptured brook trout did not demonstrate any statistically significant change in their Fulton's condition factor. These results highlight the importance of specific surface cover during winter to brook trout behavior and their movement during winter.

Dedication

This thesis is dedicated to my parents Bruce Bejcek and Sara Ehlke-Bejcek.

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List of Abbreviations

GPS	Global Positioning System
PIT	Passive Integrated Transponder
RFID	Radio Frequency Identification
S.E.M	Standard Error of the Mean

Chapter 1: Winter Ecology of Brook Trout (*Salvelinus fontinalis*) Distribution, Movement, and Growth

Chapter Summary

The formation of ice is a component of winter that can benefit the survival of brook trout (*Salvelinus fontinalis*). Ice that forms during winter can limit predation risk, influence foraging, and provide thermal cover. By conducting biweekly tracking surveys, the relationship between movement patterns of individual brook trout (≥100 m) and winter ice distribution were evaluated. The results indicated there was a sedentary and a mobile group of individuals within the brook trout population. The sedentary group (movement <100 m) consisted of 90% of the brook trout while 10% were more mobile (movement ≥ 100 m). Both movement groups used ice covered areas extensively. Fulton's condition factors were calculated and compared to habitat use. No relationship was found between condition factor and surface cover use. This study demonstrated that brook trout use ice extensively and suggests that ice is very important in their winter ecology.

Introduction

Brook trout (*Salvelinus fontinalis)* are native to cold lake and river ecosystems over a wide area in eastern North America (Huckins et al. 2008). Particularly in their northern range, brook trout habitat is commonly subjected to harsh winter conditions that can include fluctuating water levels, cold temperatures, decreased light conditions, and limited food availability. Since winter occurs after fall spawning, which is a period of high activity for brook trout, the condition and behavior of brook trout when they enter winter may affect their ability to survive winter. As a result, brook trout have developed seasonal behavior and habitat use. Aggression has been documented to change depending on the season. In summer, salmonids tend to be more aggressive as demonstrated by forming dominance hierarchies, defending territory, and competing for resources (Bachman 1984; Hughes and Dill 1990; Fausch 1998; Heggenes et al. 1999; Young 2001; Forseth et al. 2003). However, aggression diminishes at low temperatures (Hartman 1963; McMahon and Hartman 1989; Heggenes et al. 1993; Whalen et al. 1999; Vehanen and Huusko 2002), and as a result, territorial behavior decreases (Cunjak and Power 1987a; Hillman et al. 1987; Riehle and Griffith 1993; Griffith and Smith 1993). The size of an individual may also have an influence in use of winter habitat (Harwood et al. 2002). Along with changes in behavior, habitat use in winter changes. Several studies have demonstrated that during winter, individuals seek out areas with low water velocities, stable temperatures, and cover (Cunjak and Power 1986, 1987b; Cunjak 1996). In winter, structure or cover can take the form of ice which can play a role in fish biology. Using a certain habitat indicates that the type of habitat that is being used may be important for individual survival (Rosenfeld 2003). Habitats that brook trout use could also be dependent on the formation of ice.

According to Cunjak (1996), winter is described as the period of time after egg deposition in the autumn for fall-spawning salmonids that extends to the loss of surface ice in the spring. This definition allows for inter-annual variability across the calendar year and responsiveness to environmental change. However, it has also been proposed that winter should be divided into three stages: early, middle, and late (Prowse and Gridley 1993). Early winter is characterized by water beginning to freeze. Early winter, which starts as the transition from fall to winter, is a time when temperatures decrease and ice can begin to form, particularly in lentic habitats such as lakes and ponds. Areas within rivers, streams, and other lotic areas with the lowest velocity may also begin to form ice at this time. Ice that typically forms in early winter sometimes remains until spring thaw. Areas that remain ice covered or completely open throughout winter are considered stable environments (Prowse and Gridley 1993; Huusko et al. 2007). Faster-flowing areas in lotic environments will usually not form ice in the early winter stage but can form ice as the season progresses. Stable ice conditions are a hallmark of middle winter, and ice breakup defines late winter. The amount and type of ice that forms during these stages are dependent upon many physical variables including temperature, water velocity, and the structure of the stream (Huusko et al. 2007).

Some areas in rivers and streams can be considered unstable environments due to variable and fluctuating amounts of ice coverage throughout winter (Brown et al. 2011). Although some areas of faster moving water can remain ice free throughout the entire winter, other areas will be more dynamic. Ice formation during the later parts of early winter and throughout the middle winter period may be dynamic with ice forming, melting, and reforming, depending primarily on water velocity, turbulence, and temperature (Prowse and Gridley 1993; Huusko et al. 2007). The timing of this dynamic pattern may be short (day) or extended (days to weeks). These dynamic ice regimes commonly incorporate frazil ice, defined as free-floating ice crystals that form in turbulent water, and anchor ice, defined as a buildup of frazil ice that is attached to the bottom substrate (Ashton 1986).

Ice formation can be both detrimental and beneficial to the survival of brook trout during winter. If ice forms in shallow areas, the anchor ice and surface ice can physically limit the amount of space that an individual may occupy as well as alter flow characteristics causing significant habitat loss (Stickler et al. 2007). In contrast, deep areas that have surface ice cover can create stable temperatures and become refuges. In addition, ice covered areas can be used to decrease predation from terrestrial predators which is particularly important at a time when brook trout swimming performance is diminished by cold water temperatures (Alexander 1979; Heggenes et al. 1993; Cunjak 1996; Brown et al. 2011). Winter brook trout survival is, therefore, probably affected by not only the condition of the fish after spawning but also their use of ice covered areas.

Brook trout have been observed aggregating in winter pools near ground water discharge areas under some form of cover, potentially allowing fish to spend less energy maintaining their preferred position in the water column (Cunjak and Power 1986). Ground water maintains a relatively steady temperature near the stream bed throughout the year (Van Grinsven et al. 2012), providing a thermal refuge for salmonids. Such thermal refuges could provide fish an opportunity to remain close to conditions that allow for optimized metabolic rates (Cunjak and Power 1986). However, groundwater also tends to limit the development of surface ice, thus providing a stable but open habitat. The benefits of stable, relatively warm winter conditions may be sufficient to counteract the loss of surface cover and risk of predation from mammals (Alexander 1979).

Late winter occurs when ice starts breaking apart due to rising temperatures (Huusko et al. 2007). It is a complex time for brook trout as areas become flooded due to ice melt, snow melt, and additional precipitation. These changes result in increased water velocity, gradually increasing water temperatures, and possible loss of habitat that was created by ice coverage. In addition, the chemical composition of streams may change quickly when ice and snow melt due to the release of atmospherically deposited chemicals concentrated in the ice and snow (Cunjak et al. 1998). Areas that were ice covered once again become accessible to predators. Ice dams melt which may alter water depths. Late winter ends with the total disappearance of ice and the establishment of flow regimes that are not influenced by snow and ice melt.

A future challenge for brook trout in all of their range is climate change. Rising water temperatures are a threat to brook trout which typically live at temperatures between 0 °C and 22 °C and spawn at temperatures below 9 °C (Raleigh 1982). If temperature increases continue, particularly in the southern brook trout range, the available habitat may no longer be able to sustain this species. In the brook trout northern range, it is predicted that surface water temperatures will increase and ground water flow will decrease. There has already been a reduction of groundwater due to increased human water extraction in the Great Lakes region (Hall and Stuntz 2008). According to the Intergovernmental Panel on Climate Change (2014), precipitation in this region will increase in winter due to changes in the polar vortex (Champagne et al. 2019). In the Midwest region of the United States, shifts in precipitation are expected to cause an increase in late winter rainfall as opposed to snowfall (Pathak et al. 2017; Byun and Hamlet 2018). These changes are already occurring as lotic environments have experienced changes in flow regimes such as flooding (Nijssen et al. 2001; Milly et al. 2002). As a result, over the past 50 years, water levels in cold water streams have become more variable within seasons, and average water temperatures have risen (Nijssen et al. 2001; Milly et al. 2002; Mohseni et al. 2003; Bartolai et al. 2015; Pathak et al. 2017). These environmental challenges could be mitigated if brook trout behavioral traits are varied enough to allow fish to search for and find appropriate resources and new habitats for survival. Since ice is a critical component of the winter environment, understanding how brook trout relate to and use ice covered areas and other winter habitats is of interest in predicting how climate change may impact over wintering success.

Trout display different movement patterns which link to life history strategy (Gowan and Fausch 2002), and these movement patterns may affect over wintering success. Salmonids appear to become less aggressive, possibly allowing for a higher density of fish in more desirable locations (Heggenes et al. 1993; Vehanen and Huusko 2002). Variability in response at the individual or population level can offer important resiliency for the species when environmental change is unexpected or unpredicted. As climate change progresses, brook trout winter survival could be dependent on the variability of individual fish movement. Increased movement may allow brook trout to use different suitable areas as old habitats become uninhabitable. Variability in movement patterns has been observed as differences in mobility within a population (Lucas and Baras 2001). This variability could include some individual brook trout remaining within habitats that are suitable but limited in scope, while other fish are mobile and seek new suitable habitats for use. If climate change alters the environment to benefit the behavior of certain individuals over others, the survival of the population may hinge on the occurrence of individual variability in movement patterns.

Year round salmonid movement is often considered limited to a home range of <50 m as demonstrated by Gerking (1959) and Bachman (1984). However, other studies have shown that brook trout can travel well over 3,000 m for both dispersal and migration (Gowan and Fausch 1996; Cross 2013). This suggests that individuals may display different movement patterns and that this variability occurs within a population. Cunjak and Power (1986, 1987a) and Chisholm et al. (1987) studied brook trout movement and habitat use in winter. Chisholm et al. (1987) tracked brook trout throughout winter in multiple streams in Wyoming, reporting that brook trout used regions with low velocity, deep water, and sand/silt substrate in winter. However, Chisholm et al. (1987) only tracked a very limited number of brook trout which may not be representative of the majority of the population. With a limited number of brook trout being tracked, differences in responses to winter may not be observed. Cunjak and Power (1987a) studied the use of cover in winter. However, their study did not track individual trout or focus on variability in ice availability. To date, winter observations have provided only a general view of behavior in regards to habitat use and have not explored individual variability. Since ice cover has the potential to aid brook trout survival, studying brook trout at the individual level throughout winter can provide information on how individuals use winter habitat, how condition is affected by using certain habitat over others, and how individuals differ in movement.

To advance the understanding of brook trout winter ecology, this study focused on tracking brook trout to study their use of ice cover in a dynamic river system. Similar to previous studies (Cunjak and Power 1987a; Prowse and Gridley 1993; Cunjak 1996), winter was divided into three stages by photoperiod. For this study, the three hypotheses are: 1) brook trout within a riverine system will use ice covered surface areas more than open areas during winter, 2) the more mobile brook trout are, the more likely they are to use ice covered areas, and 3) the use of ice covered areas will have an impact on Fulton’s condition factor, the relationship between weight and length.

Materials and Methods

Study Site

The study was conducted on Unnamed Tributary of the Rock River in Alger County, Michigan (Fig. 1). Unnamed Tributary was selected due to its intermittent winter ice coverage and the impassable culvert that blocks further upstream brook trout migration located approximately 3,100 m from the confluence with the main stem Rock River. The tributary flows through a mixed coniferous and deciduous forest and splits into two separate channels, denoted as Unnamed A and Unnamed B, near the confluence. Unnamed B flows into a cedar (*Thuja occidentalis*) and speckled alder (*Alnus incana*) swamp that commonly floods, and this branch contains variable water levels throughout the year. Most of the water in the system flows through Unnamed A, which also flows through a mixed coniferous and deciduous forest until meeting the Rock River. Sand, various size gravel/cobble, and woody debris are common substrate. Undercut banks are present throughout, and several small habitat restoration efforts have been performed by the United States Forest Service to improve the overall quality of the tributary. Weirs have been created out of wood structures to allow for pools to form, and gravel has been added into the waterway in order to improve salmonid spawning habitat. Common fish found in the tributary are brook trout, rainbow trout (*Oncorhynchus mykiss*), coho salmon (*Oncorhynchus kisutch*), and slimy sculpin (*Cottus cognatus*). Terrestrial predators such as otter (*Lontra canadensis*) and marten (*Martes americana*) reside in the area as well.

The study site was divided into 100 m reaches using a Nikon range finder (ProStaff Laser 440, Tokyo, Japan). The start of each reach was marked and Global Positioning System (GPS) coordinates determined (Trimble, GeoXH series 7, Westminster, Colorado).

Fish Capture and Tracking

Electroshocking occurred in the fall of 2017 and 2018 and in the spring of 2018 and 2019. Shocking occurred in November before ice formation but after peak spawning season in late October. Spring shocking sessions were conducted when Unnamed Tributary was free of ice (Season 1: 4/20-21/2018 and Season 2: 3/23-24/2019). Backpack electrofishing consisted of a single pass (AbP-3TM pulsed DC, ETS Electrofishing, Madison, WI) in an upstream direction with two netters. Voltage was adjusted according to fish response.

All brook trout collected were weighed and had their total length measured. Fish were also scanned for PIT tags using an Oregon RFID handheld reader (FEF352AWF, Portland, Oregon). Any untagged brook trout ≥ 100 mm were tagged with a 23 mm PIT tag (Oregon RFID HDX tags) under NMU IACUC Protocol 308. Fish were tagged through a small horizontal incision posterior to the pelvic fins and anterior to the anal fin and then released in their reach of capture. No brook trout were tagged in the spring shocking sessions, but more fish were added to the tagged population over the summer as part of a different study. In total, 354 brook trout were tagged from 2017 to 2019.

Active tracking occurred throughout both winter field seasons (2017-2018 and 2018-2019) utilizing a portable Oregon RFID backpack single reader connected to a hand held Oregon RFID pole antenna (wand). Tracking surveys began two weeks after shocking events to avoid handling bias and were conducted during the day. The wand operator walked streamside if ice formed on top of the water surface or in the stream if open water was present. To provide some capture validation, PIT tags attached to rocks within the sampling site were used to assess detection of fish. The winter of 2017-2018 had two sample rocks with the detection probability of 75% under ice cover and 100% in open water. The number of sample rocks was increased to five during the winter of 2018-2019 with a detection probability of 68% under ice cover and 83% in open water. The detection range of the wand was approximately 60 cm which is adequate for sampling the field sight at its deepest depth of 67 cm.

Passive tracking also occurred within the field site using stationary Oregon RFID multiplex antennas. Antenna sites were constructed at the mouths of Unnamed Tributary (Fig. 1) encircling the entire stream channel, and antennas were powered by solar arrays and storage batteries. Oregon RFID tuners were adjusted to the resonant frequency of each antenna while the multiplexing reader recorded fish movement data (PIT tag number, date, time, and antenna location). During the winter of 2017-2018, Unnamed A and B antennas were active 56% and 58% of the time. Unnamed A and B antenna activity time increased to 98% and 85% for the winter of 2018-2019.

Habitat Sampling

Habitat analysis for stream depth, substrate analysis, dissolved oxygen, conductivity, pH, and water velocity occurred in the fall of 2018 in accordance with methods developed by Wills et al. (2006). Each reach was subdivided into five transects (20 m apart) except for Unnamed B which had eight transects. The location of each transect was recorded using GPS coordinates. The total width of the channel was measured and the width divided into five sites for data collection at 0.2, 0.4, 0.6, and 0.8 fractions of the channel width as well as the thalweg. At each point on the transect, pebble count (modified Wolman Pebble Count Procedure), depth, water velocity (Marsh McBirney 2000 flow meter, Frederick, Maryland), and dissolved oxygen (YSI Pro 20, Yellow Springs, Ohio) were measured. At the third transect in every reach, conductivity and pH were measured using an Oakton meter (PCTSTestr 50, Denver, Colorado).

During both winters, habitat features were documented when a tagged fish was located. If a fish was located in an ice free area, the identification number was recorded along with reach location, depth, and temperature. When a tagged fish was located in an ice covered section, the ice formation characteristic (clear, opaque, or snow covered) was recorded. Along with habitat features, GPS coordinates were collected for each fish (Recon and Receiver, Trimble, Corvallis, Oregon) in the first field season (2017-2018) and each fish (GeoXH, Trimble, Westminster, Colorado) in the second field season (2018-2019).

For the winter of 2017-2018, water temperature was also monitored every 30 minutes using three stationary HOBO loggers (HOBO Pendant Temperature/Light Data Logger: UA-002-xx) placed in Unnamed Tributary at reaches 1, 11, and 31. Two additional HOBO loggers were added in the winter of 2018-2019 at reaches 16 and 25. If ice formed over the temperature loggers, no attempt was made to disturb the ice to retrieve the data so as not to influence fish movement. Air temperature readings and the amount of snowfall were obtained from the National Oceanic and Atomospheric Administration National Centers for Environmental Information (NCEI) station number USC00201486 in Chatham, Michigan as this was the closest station to the field site.

Five game trail cameras, one Cuddeback (20160512, Green Bay, Wisconsin), three Moultrie (MCG-12715 GM-80xt (Gen 2), Calera, Alabama), and one Bushnell (119836C, Overland Park, Kansas) were used to document ice formation in the study site. Two cameras were placed within the field site during the first field season (2017-2018) while three more were added in the second field season (2018-2019). The five game trail cameras in the winter of 2018-2019 were stationed throughout Unnamed Tributary (reaches 2, 8, 11, 21, and 31) and covered visual sampling grids (see below) ranging in size from 2 m to 3.5 m in width and 4 m to 11 m in length. Each camera was set to photograph its section at least once during the morning and once during the afternoon. Cameras were checked and photographs downloaded biweekly.

Data Analysis

The software ImageJ (Schindelin 2012) was used to process stream surface cover images. For each day during the season, morning and afternoon images were collected and analyzed. Each image included four rebar rods that created a grid with known measurements. A template image was constructed by creating a four-sided polygon using the rebar rods as the corners. The template photograph was transformed into a new polygon resembling the true sample area shape. To correct for camera distortion, this image was used to transform all other images using the landmark correspondence tool. The area within the sampled areas in the modified image was measured and the percentage of surface cover by category recorded using the measure function. The different categories of surface cover evaluated were open water, snow covered ice, opaque ice, and clear ice.

Any tagged brook trout that was not found during the winter surveys was excluded along with any tag that remained in the same location from the prior field season (determined with GPS coordinates) or if the tag was recovered (i.e. lost tags). ArcMap 10.6.1 (*ArcMap* 2018) was used to analyze individual brook trout movement and habitat use. The study site was divided into 1 m segments. Individual brook trout GPS points were linked to the closest point that followed the river's outline. If a brook trout was found at a new location within the river, the difference between the two positions was recorded as the individual's movement. Brook trout moving equal to or over 100 m from their first detected location were classified as mobile while individuals moving less than 100 m were classified as sedentary. This technique was also used to determine the closest habitat sampling transect to brook trout GPS locations to assign the type of habitat that was present within the area.

R (R Core Team 2018) was used to perform statistical analysis. Both winter periods were analyzed to assess any overall trends. Brook trout distribution was determined in winter 2017-2018 with two shocking surveys and eight tracking surveys while winter 2018-2019 was analyzed with two shocking surveys and six tracking surveys. Individual survey reaches and the surface cover brook trout used were compared using Chi square tests to determine brook trout distribution. A similar approach was used to identify habitat use throughout winter between mobile and sedentary fish. Brook trout surface cover use was followed throughout winter. For each survey, the surface cover that brook trout used was identified to determine the use of surface cover between surveys. Two consecutive surveys were analyzed at a time. Only those individuals that were detected in both surveys were used for analysis. The surface cover that these individuals used was compared using Chi square analysis. Although individuals might not be detected throughout all surveys, they were used for analysis if they appeared in two consecutive surveys. Fish were classified into four habitat use categories consisting of open water moving to ice, remaining in open water, ice moving to open water, and remaining under ice between the two surveys. Chi square tests were used to compare the distribution of habitat use with the previous survey representing the expected values. This analysis was repeated using the next survey as a new starting location and expected values. This was repeated until all the surveys were assessed. One occurrence was added to all categories to remove any categories with zero detections in order to use Chi square analysis.

The probability of using ice cover during the three stages of winter (early, middle, late) was determined by odds ratios. The stages of winter were modified from Cunjak and Power

(1987a). Early winter was defined as the period during which photoperiod decreased from approximately 9.5 hours to 8.5 hours (November and December). After winter solstice in late December, middle winter was defined as the period when the day length increased from 8.5 hours to approximately 10.5 hours (January to mid-February). Day length afterwards continued to increase, representing late winter (mid-February until ice break out). To determine cover use during the three stages of winter, odds ratios were determined. First, the total number of brook trout using ice was divided by the number of individuals using open water in the appropriate winter stage. Then, the odds of using ice compared to open water for a stage was divided by the other winter stage odds values, creating a ratio. The three stages of winter were compared against each other, and a calculated odds ratio greater than one indicated that brook trout were more likely to use ice cover during a certain period of winter relative to the comparison period. Some brook trout were found multiple times throughout winter but were only represented once within a survey. The movement and odds ratio analysis included brook trout that were found multiple times throughout each winter, but that analysis could not account for repeated measures.

Fulton's condition factor (K) was calculated using the following equation:

$$K = \frac{weight}{length^3} \cdot 1x10^5$$

Brook trout that were recaptured during the electroshocking surveys were re-measured, allowing for comparisons between the fall and spring survey seasons. The average length and weight changes per day were also calculated.

Results

Habitat analysis showed that the dominant substrate in Unnamed Tributary was sand. A mix of various size stones ranging from 4-64 mm (pebbles) and 65-256 mm (cobble) was also present throughout the field site. Woody debris was common and scattered throughout the reaches. The average stream depth was 0.20 ±0.008 S.E.M. m while the average width was 2.28 ±0.13 S.E.M. m at the sampled transects. Undercut banks were present throughout and varied in length up to 1 m with an average horizontal length of 0.09 ±0.008 S.E.M. m. During the winter of 2017-2018, the average water temperature was 1.35 ±0.01 S.E.M. °C while the average light intensity was 70.75 ±2.51 S.E.M. $lum \cdot ft^2$. The mean water temperature and light intensity from the winter of 2017-2018 varied slightly from the winter of 2018-2019 at 0.90 ±0.005 S.E.M. °C and 19.66 ±0.42 S.E.M. $lum \cdot ft^2$ (Fig. 2). There was a significant difference in water temperature and light intensity between winters (water temperature: $t = 4.18$, $df = 319$, $P<0.001$; light intensity: $t = 5.19$, $df = 319$, $P<0.001$). Although not directly measured in this study, there was a difference in snow accumulation for each winter. The weather service at the National Oceanic and Atomospheric Administration National Centers for Environmental Information (NCEI) station number USC00201486 in Chatham, Michigan recorded an average snowfall of 0.6 m and air temperature of -6.7°C per month for the winter of 2017-2018. For the winter of 2018-2019, the average snowfall and air temperature were 0.84 m and -4.3°C per month. Compared to the 30 year average snowfall (0.70 m) per month, the winter of 2017-2018 was below average while the winter of 2018-2019 was above average per month. However, when comparing air temperature to the 30 year average (-2.4°C) per month, both winters were below average.

Throughout Unnamed Tributary, the percentage of open water varied annually and by location in the field site, exposing brook trout to different ice conditions. The percentage of open water was calculated from the two trail cameras that were placed at reaches 11 and 31. Although five trail cameras were eventually employed in this study, only cameras used at reaches 11 and 31 were used both years. The winters of 2017-2018 and 2018-2019 were compared statistically using a linear mixed model and Tukey's post hoc test to demonstrate that a difference in ice formation occurred year to year between reaches 11 and 31 (t ratio = -2.047, df = 505, $P<0.041$) (Fig. 3). Reach 31 steadily decreased in open water as winter progressed while reach 11 was more active in the formation of open water and ice cover. Reach 31 had the most ice cover for both study winters. Three other field cameras deployed in the winter of 2018-2019 demonstrated that other reaches had a similar variability in open water (Fig. 4). Although ice formation was not identical between the two study years, it was evident that in both study years, ice and open water were present and allowed different surface cover habitats to be available for fish.

For the winter of 2017-2018, 20 brook trout were recaptured in the spring by electrofishing resulting in a minimum estimate of survival rate of 11% while in the winter of 2018-2019, 19 fish were recaptured in the spring giving a minimum survival rate of 24%. For all tagged and untagged fish captured between 2017-2019, there was a significant difference in the weight and length between fall and spring (weight: KW Chi-squared = 63.077, df = 3, $P <0.001$; length: KW Chi-squared = 44.117, df = 3, $P <0.001$) (Table 1). For recaptured tagged brook trout between the fall of 2017 and the spring of 2018, 60% of them showed an increase in their initial length (t = 0.32989, df = 22, P = 0.7446) while between the fall of 2018 and spring of 2019, 74% increased in length (t = 0.502095, df = 28, P = 0.619526) (Fig. 5). Between the fall of 2017 and the spring of 2018, 55% of the recaptured brook trout had an increase from their initial weight (t = 0.27926, df = 20, P = 0.78292), 35% had a decrease from their initial weight (t = 0.55247, df = 12, P = 0.59077), and 10% had no change from their initial weight. Between the fall of 2018 and spring of 2019, 47% increased in weight (t = 0.174399, df = 16, P = 0.863739), 47% decreased in weight (t = 0.3658, df = 16, P = 0.719302), and 6% had no change in their weight. The average increase in weight and length per day when combining seasons was 0.002 ±0.007 S.E.M. g and 0.015 ±0.006 S.E.M. mm. There was no statistical difference between the two winters for average length change per day or average weight change per day (weight: t = 0.083082, df = 20.937, P = 0.9346; length: t = 0.68812, df = 21.698, P = 0.4987). The calculated Fulton's condition factor indicated that 50% of the brook trout recaptured increased in condition while 50% showed a decrease during the winter of 2017-2018 (t = 0.43381, df = 38, P = 0.6669). For the recaptured brook trout from 2018-2019, 32% showed an increase in condition factor while 68% showed a decrease (t = 1.6446, df = 36, P = 0.054). The average condition factor for fall of 2017 was 0.88 ±0.03 S.E.M. and for spring of 2018 was 0.87 ±0.03 S.E.M. while the condition factor for fall of 2018 and spring of 2019 was 0.86 ±0.21 S.E.M. and 0.81 ±0.02 S.E.M.

Between the winters of 2017-2019, the relative frequency of brook trout within each reach did not change throughout winter (Fisher's test P > 0.7711) (Figs. 6 and 7). Both upstream and downstream movement occurred throughout the field site, but the middle reaches consistently held the majority of brook trout. Individuals that were found in the middle of the field site were consistently found under ice. Brook trout found in other reaches were also found under ice.

When evaluating how the distribution of tracked brook trout changed between locations over time, the individuals who moved at least 100 m were termed mobile while the other group was referred to as sedentary. 90% of tracked individuals did not move more than 100 m from their initial location, and the majority of these fish did not move more than 20 m from their initial location. Over both winters, 10% of tracked individuals moved more than 100 m (Fig. 8).

Within the mobile group of fish, 54% of the brook trout moved between 100-300 m while 46% moved over 400 m. The maximum distance traveled by an individual was 1025 m. For both winters, there was no statistical difference between the average distance traveled by individuals ($t = -0.0091$, $df = 81$, $P = 0.99236$), but the median and range varied between both years (winter 2017-2018: median = 425 m and range 926 m; winter 2018-2019: median 193 m and range 316 m). When compared to the mobile group, the sedentary group was not statistically different in average length (mobile: 141.48 ±6.19 S.E.M. mm; sedentary: 133.84 ±1.61 S.E.M. mm; $t = -1.49438$, $df = 266$, $P = 0.13$) or weight (mobile: 27.79 ±2.94 S.E.M. g; sedentary 24.87 ±1.28 S.E.M. g; $t = -1.60595$, $df = 261$, $P = 0.11$) (Fig. 9).

Within the study site, the formation of ice varied between reaches which allowed brook trout to use different surface covers (Figs. 3 and 4). For all fish (mobile and sedentary), cross tabulation between survey dates and surface cover demonstrated a significant difference among surface cover use (winter 2017-2018: Fishers test $P < 0.001$; winter 2018-2019: Fishers test $P < 0.001$; Combined: Fishers test $P < 0.001$). This was also the case for both winters for mobile and sedentary brook trout when analyzed separately (winter 2017-2018: Fishers test $P < 0.001$; winter 2018-2019: Fishers test $P < 0.05$; Combined: Fishers test $P < 0.001$) (Fig. 10). However, there was no difference in surface cover use between fish with a positive or negative change in Fulton's condition factor (winter 2017-2018: Fishers test $P > 0.8181$; winter 2018-2019: Fishers test $P > 0.5787$) (Fig. 11). Similarly, there was no significant difference in surface cover use between the recaptured brook trout and the rest of the entire tracked populations (winter 2017-2018: Fishers test $P > 0.6382$; winter 2018-2019: Fishers test $P > 0.1024$).

To determine if the presence of surface cover was favored generally, the odds ratios were calculated between use of open water compared to use of all ice surface cover types combined.

Brook trout may have been found multiple times throughout winter, and some fish may be represented within the odds ratio analysis multiple times, but they are represented in each survey only once. Surveys were combined into three stages of winter, and individuals that were found more than once were represented at different times throughout the analysis. The three stages of winter were compared to each other, and a calculated odds ratio greater than 1.0 indicated that brook trout were more likely to use ice cover during one stage of winter relative to another (Table 2). Both winters were combined to assess the different stages of winter and use of surface cover. A comparison between mobile and sedentary individuals was not included due to the low number of mobile individuals that could be included in this analysis. All tracked brook trout (mobile and sedentary combined) used ice covered areas more frequently in the middle of winter (Fig. 12). The analysis to assess movement and habitat use throughout both winters also indicated that brook trout used different surface covers (Tables 3 and 4).

Analyses were conducted to determine if physical parameters such as water temperature, air temperature, and light intensity potentially influenced brook trout mobility. There was no pattern between movement and either the averages or coefficients of variation of water temperature, air temperature, or light intensity (Tables 5 and 6). Linear regression using averages of air temperature, water temperature, and light intensity resulted in no statistical relationship between the physical parameters and the proportion of sedentary or mobile fish (sedentary: air: $P > 0.62$, water: $P > 0.55$, light: $P > 0.92$; mobile: air: $P > 0.51$, water: $P > 0.47$, light: $P > 0.87$). Linear regression using coefficient of variation values resulted in no statistical relationship between the physical parameters and sedentary brook trout (air: $P > 0.44$; water: $P > 0.39$; light: $P > 0.79$) or mobile (air: $P > 0.43$; water: $P > 0.39$; light: $P > 0.76$). There was also no statistical significance between water temperature and air temperature coefficient of variation ($P > 0.35$).

However, there was a significant relationship between the average water and air temperatures ($P < 0.001$, $r^2 = 0.81$). These results indicated that water temperature co-varied with air temperature, but other factors besides air temperature have an impact on water temperature.

Discussion

Brook trout inhabit a wide swath of northern North America including the U.S. east coast, mid-west, and some western states. Whether introduced or native to an area, adfluvial or fluvial populations of brook trout variably utilize the ecosystem. Persistence and success of a population surviving may be dependent on individual behavior. Winter in northern regions poses challenges for brook trout. With ice formation varying from year to year, brook trout response may change in response to the new conditions.

This study supports the concept that there are at least two major movement patterns that brook trout employ. A majority of individuals remain sedentary while a smaller group exhibits a more mobile pattern. Even though the colder temperatures experienced during winter in this study area resulted in a decrease in salmonid swimming performance (Alexander 1979; Heggenes et al. 1993; Cunjak 1996; Brown et al. 2011), a few individuals were still observed continuing to move within the stream with some traveling considerable distances. The mobile fish ranged in movement distance from 100 m to 1000 m. There was also movement of sedentary fish less than 100 m, but most of these movements were less than 10 m. These data demonstrated that there is a continuum of movement patterns in this population ranging from highly stationed behavior to highly mobile behavior. There was no statistical significant difference between the distance that brook trout travelled within a given winter, although this may be due to a low number of fish censured in a year. These results were similar to several other reports (Komadina-Douthwright et al. 1997; Jakober et al. 1998; Muhlfeld et al. 2001; Linnansaari et al. 2005) that indicated that winter movement is minimal on a population and individual level and that winter movement was associated with age (Jakober et al. 1998; Whalen et al. 1999; Nakamura et al. 2001; Robertson et al. 2003; Kusnierz et al. 2009). Interestingly, although this study did not directly collect age data on fish that were tagged, length which is usually related to age did not differ between these movement groups.

One aspect of this study evaluated if some abiotic factors were related to movement of fish throughout winter. Changes in light intensity can affect activity patterns of aquatic organisms (Valdimarsson and Metcalfe 2001; Finstad et al. 2004). During cold temperatures, salmonids may tend to hide more at high light intensity (Valdimarsson et al. 1997). With changes in light intensity, this may possibly result in altered foraging time and movement from concealed cover (Jakober et al. 2000; Finstad et al. 2010). The movement of fish in this study did not appear to have any relationship to light intensity, as demonstrated by using either coefficients of variations or actual averages of this parameter. It is likely since this study was conducted during relatively low light conditions that brook trout movement may not have been impacted.

This study indicated that, as with light intensity, there was no statistical significance between air or water temperature coefficients of variation or averages and fish movement patterns. Air temperature has been shown to be a covariant to water temperature (Jensen et al. 1986). Studies that observed fish movement tend to be seasonal and have indicated fish movements occur between 3°C to 6°C during the transition from fall to winter habitat (Hillman et al. 1987; Jakober et al. 1998; Nykänen et al. 2005; Bramblett et al. 2011). Temperatures during the middle of winter were relatively constant, ranging between 1°C to 4°C. With no major increase or decrease in temperature during the middle of winter, seasonal movement patterns would not be anticipated. However, temperature may indirectly influence winter movement due to ice formation. The occurrence of stable and dynamic ice is an important aspect of riverine winter habitat.

Ice formation can be a potential advantage or disadvantage depending on how much is present and where it forms. Potential disadvantages of ice formation include reducing the interaction of brook trout with bottom substrate and reducing the available space within the water column. Brook trout can either burrow into substrate such as sand or hide in coarse substrate, but these interactions can be hindered by formation of ice (Cunjak 1988, 1996; Heggenes et al. 1993; Griffith and Smith 1993; Vehanen et al. 2000). To avoid anchor ice, salmonids have been observed to move into deeper areas in winter (Jakober et al. 1998; Simpkins et al. 2000; Stickler et al. 2007, 2008). Along with anchor ice, hanging ice dams can limit the amount of space available. With the formation of hanging ice dams, deeper pockets of water may be a more suitable habitat. Brook trout within this study may have already been using deep pockets, allowing them to remain sedentary. Mobile individuals may have been forced to find new areas within the stream due to more dynamic ice conditions. Even though brook trout might have to move in response to ice formation, different areas of the stream may have ice present that could be beneficial.

The use of ice covered areas can have several advantages for brook trout. In general, ice provides cover from predators (Watz et al. 2013), decreases stress (Watz et al. 2015), provides a thermal refuge (Hicks 2009), and reduces light intensity (Finstad et al. 2004). Since brook trout swimming performance is reduced in winter, avoiding predators is more difficult (Alexander 1979; Cunjak 1996). Predators of brook trout were identified within the study site during this project by tracks and photography. Occupying habitats that allow fish to hide may help lower the risk of predation in open water, including in winter when swimming performance is reduced (Cunjak and Power 1987b; Alexander 1979; Cunjak 1996). From this study, we determined that brook trout were more likely to use areas with surface cover.

In this study, the use of ice covered areas was most extensive in the middle of winter, likely because of its increased availability. However, in early and late winter ice cover was used when present. These results aligned with other studies that demonstrate natural and artificial cover is used during winter (Cunjak and Power 1987b; Chisholm et al. 1987; Watz et al. 2016). Both mobile and sedentary fish used ice covered areas throughout winter.

Further investigation into water depth and ground water discharge where fish are located may indicate that these factors also impact fish location. When ice forms and limits available space, the water depth could become more crucial in winter habitat use. Ice formation tends to form in low velocity areas such as pools. If ice does not form in certain areas, ground water discharge may be influencing the formation of ice. Regions of ground water influx can also provide thermal stability which may help brook trout maintain optimal metabolic rates (Cunjak and Power 1986).

Winter environments can influence how a brook trout may respond physiologically. A response may be seen as a change of weight or length resulting in a shift in condition factor. When calculating the condition factor of a population, the average may not adequately represent the condition factor of individuals within that population. There was no statistical difference between the condition factor of brook trout in the fall and in the spring of either year. However, the fact that some individuals had an increase in condition while others showed a decrease suggests that some individuals were more successful at managing winter energy reserves. According to Cunjak et al. (1987), brook trout did not have a statistically significant change in condition factor from early winter to late winter. Since this study occurred during times that were comparable to our paper, our results are in agreement with their findings. Sampling may have been performed at times when brook trout may not have had major changes in condition factors, and future study dates should be expanded to capture seasonal transitions.

This study indicates that brook trout use ice covered areas. As climate change continues to impact the environment, many scientists are concerned about the decrease in southern brook trout habitat based on increasing summer temperatures (Meisner 1990). However, this research suggests that the effects of climate change on the northern range of the species are of concern as well. Models presented in Hayhoe et al. (2010) suggest annual temperatures in the region will increase by several degrees, and precipitation in spring and winter will increase by 20% to 30% by the end of century. With climate change, northern hemisphere winters may see a shift in ice formation and flooding. For a species to survive, it is beneficial for individuals to have behaviors that vary so that a reproductively sustainable portion of the population will succeed and be able to adapt to new conditions, either on a short-term or long-term basis. Those species that can exploit a variety of habitats under different conditions are those that will have the greatest chance of survival during rapid environmental change. This study has demonstrated that a brook trout population includes important individual variation. With respect to winter movement patterns, this is likely important for winter success in streams experiencing ice formation. As global warming continues to impact the environment, understanding winter ecology of brook trout will be critical for evaluating and mitigating the impact of climate change (Bassar et al. 2016).

TABLES

Table 1. Electrofishing survey results from 2017-2019. Average length and weight were calculated along with standard error.

	Fall 2017 Survey	Fall 2018 Survey	Spring 2018 Survey	Spring 2019 Survey	Fall 2017 Tagged Fish	Fall 2018 Tagged Fish	Summer 2018 Tagged Fish	Fall 2018 Recaptures	Spring 2018 Recaptures	Spring 2019 Recaptures
Number of Brook Trout	292	155	165	167	190	78	86	9	20	19
Average Length (mm)	118.31 ±2.22	107.79 ±3.55	108.64 ±2.67	95.79 ±2.43	140.05 ±2.01	132.74 ±4.77	121.65 ±1.77	143.22 ±6.17	141.35 ±6.20	132.74 ±6.15
Average Weight (g)	19.14 ±1.07	17.15 ±2.35	14.81 ±1.12	9.27 ±0.80	29.17 ±1.67	27.20 ±4.26	18.55 ±0.87	26.20 ±3.53	28.20 ±4.62	21.33 ±3.80
Average Condition Factor (K)	0.88 ±0.02	0.85 ±0.01	0.96 ±0.04	0.79 ±0.01	0.86 ±0.01	0.85 ±0.01	0.98 ±0.01	0.89 ±0.03	0.87 ±0.03	0.81 ±0.02

Table 2. Odds ratios for surface ice cover use during the winters of 2017-2018 and 2018-2019 for all tagged fish, mobile and sedentary. The proportion of fish found under ice vs open water in each stage of winter was divided by the proportion of the other stages. A calculated odds ratio greater than one indicates that brook trout are more likely to use ice cover during a certain period of winter compared to its appropriate period. - indicates that no individuals were found in open water to compare against surface cover.

		Numerator					
		Sedentary		Mobile		All Tagged Brook Trout	
	Winter 2017-2018	Early	Middle	Early	Middle	Early	Middle
Denominator	Middle	0		-		0	
	Late	0	14.17	0	-	0	17.95
	Winter 2018-2019	Early	Middle	Early	Middle	Early	Middle
	Middle	0.44		0.50		0.44	
	Late	0.10	0.23	0.33	0.67	0.11	0.25
	Combined Winters	Early	Middle	Early	Middle	Early	Middle
	Middle	0.14		0.01		0.12	
	Late	0.55	3.94	0.47	38.05	0.56	4.75

Table 3. Surface cover use by brook trout throughout the winter of 2017-2018. Only individuals that were detected in both consecutive surveys were used for analysis.

	Comparison between Surveys													
	12/2/2017 to 1/6/2018		1/6/2018 to 1/19/2018		1/19/2018 to 2/2/2018		2/2/2018 to 2/16/2018		2/16/2018 to 3/2/2018		3/2/2018 to 3/16/2018		3/16/2018 to 3/31/2018	
	Sedentary	Mobile	Sedentary	mobile	Sedentary	Mobile	Sedentary	Mobile	Sedentary	mobile	Sedentary	Mobile	Sedentary	Mobile
Open Water to Ice	37	0	0	0	3	0	2	0	0	1	12	1	2	0
Remained in Open Water	3	0	2	0	5	0	4	0	5	1	30	3	28	4
Ice to Open Water	0	0	8	0	2	0	0	0	22	4	0	0	22	1
Remained in Ice	0	0	37	8	24	9	20	7	16	1	13	3	3	1

Table 4. Surface cover use by brook trout throughout the winter of 2018-2019. Only individuals that were detected in both consecutive surveys were used for analysis

	Comparison between Surveys									
	12/5/2018 to 12/30/2018		12/30/2018 to 1/12/2019		1/12/2019 to 1/23/2019		1/23/2019 to 2/22/2019		2/22/2019 to 3/8/2019	
	Sedentary	Mobile	Sedentary	Mobile	Sedentary	Mobile	Sedentary	Mobile	Sedentary	Mobile
Open Water to Ice	27	2	8	0	23	2	6	0	5	0
Remained in Open Water	31	1	27	2	14	0	4	0	0	0
Ice to Open Water	1	0	15	0	3	0	2	0	0	1
Remained in Ice	10	0	26	1	27	1	10	1	9	0

Table 5. Comparison of brook trout movement between abiotic factors for the winter of 2017-2018. Temperature was recorded in Celsius and converted to Kelvin to perform the calculation of the coefficient variation.

Survey	Average Water Temperature (°K)	Water Temperature Coefficient of Variation	Average Light Intensity (lum/ft^2)	Light Intensity Coefficient of Variation	Average Air Temperature (°K)	Air Temperature Coefficient of Variation	Proportion of fish that were sedentary	Proportion of fish that were mobile
1	275.34	0.22	13.33	93.88	271.06	1.38		
2	273.67	0.29	22.24	62.29	262.21	2.29	92	8
3	273.62	0.14	32.05	74.32	263.17	2.35	100	0
4	273.80	0.18	59.67	30.09	266.06	2.12	94	6
5	273.301	0.09	9.79	49.08	257.17	2.21	95	6
6	274.06	0.10	41.42	73.07	267.17	1.89	99	1
7	273.88	0.09	116.71	101.77	266.98	1.36	97	3
8	273.85	0.122	0.85	39.30	265.77	2.13	95	5

Table 6. Comparison of brook trout movement between abiotic factors for the winter of 2018-2019. Temperature was recorded in Celsius and converted to Kelvin to perform the calculation of the coefficient variation.

Survey	Average Water Temperature (°K)	Water Temperature Coefficient of Variation	Average Light Intensity (lum/ft^2)	Light Intensity Coefficient of Variation	Average Air Temperature (°K)	Air Temperature Coefficient of Variation	Proportion of fish that were sedentary	Proportion of fish that were mobile
1	274.36	0.23	224.51	47.17	267.63	1.62		
2	274.55	0.20	33.55	42.96	268.91	1.05	98	2
3	273.83	0.14	15.56	35.29	266.45	1.57	98	2
4	273.44	0.12	9.97	53.27	260.78	1.82	98	2
5	273.41	0.01	8.79	80.46	259.5	2.75	94	6
6	273.47	0.08	4.33	47.63	258.89	2.63	100	0

FIGURES

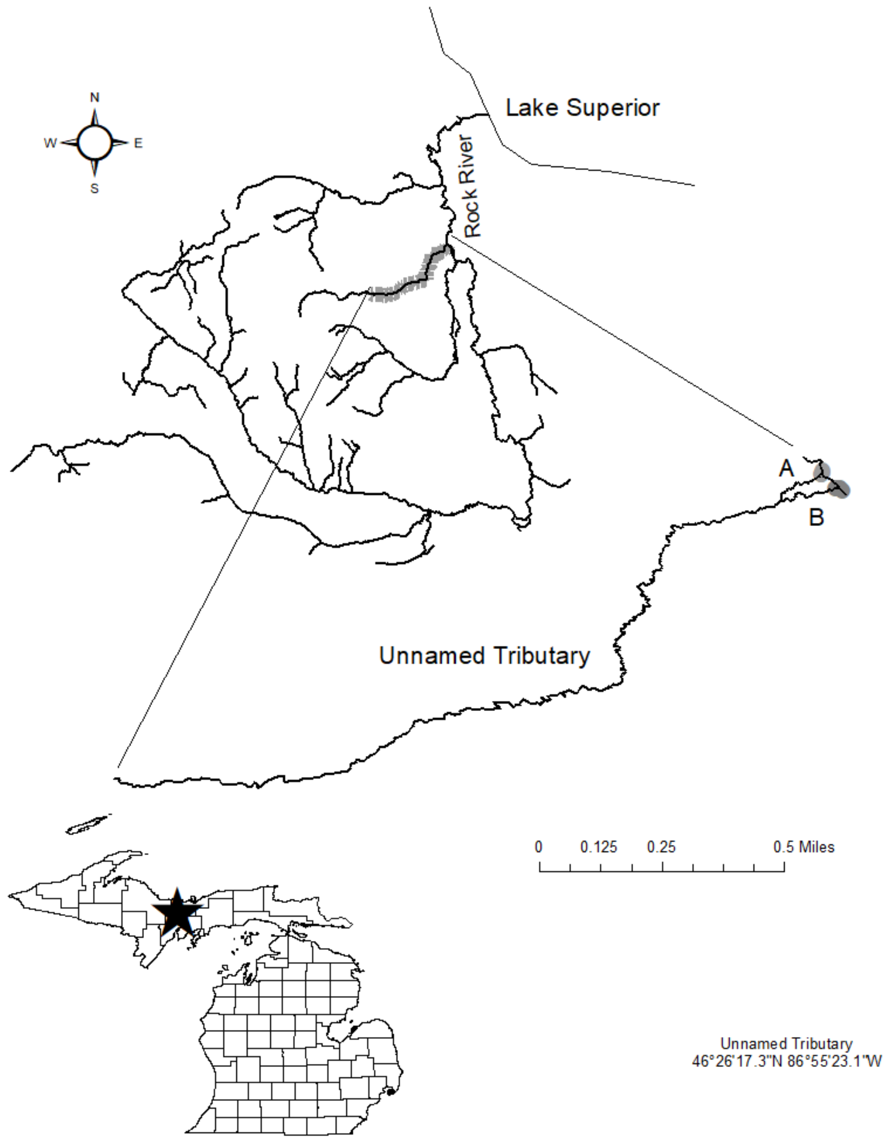

Fig. 1. Map of the Rock River watershed showing Unnamed Tributary (A and B). Approximately 3,100 m were designated as the study location (section highlighted in grey) from the mouth of Unnamed Tributary to a high pitched culvert. RFID antennas were located at the mouth of Unnamed Tributary (grey circles).

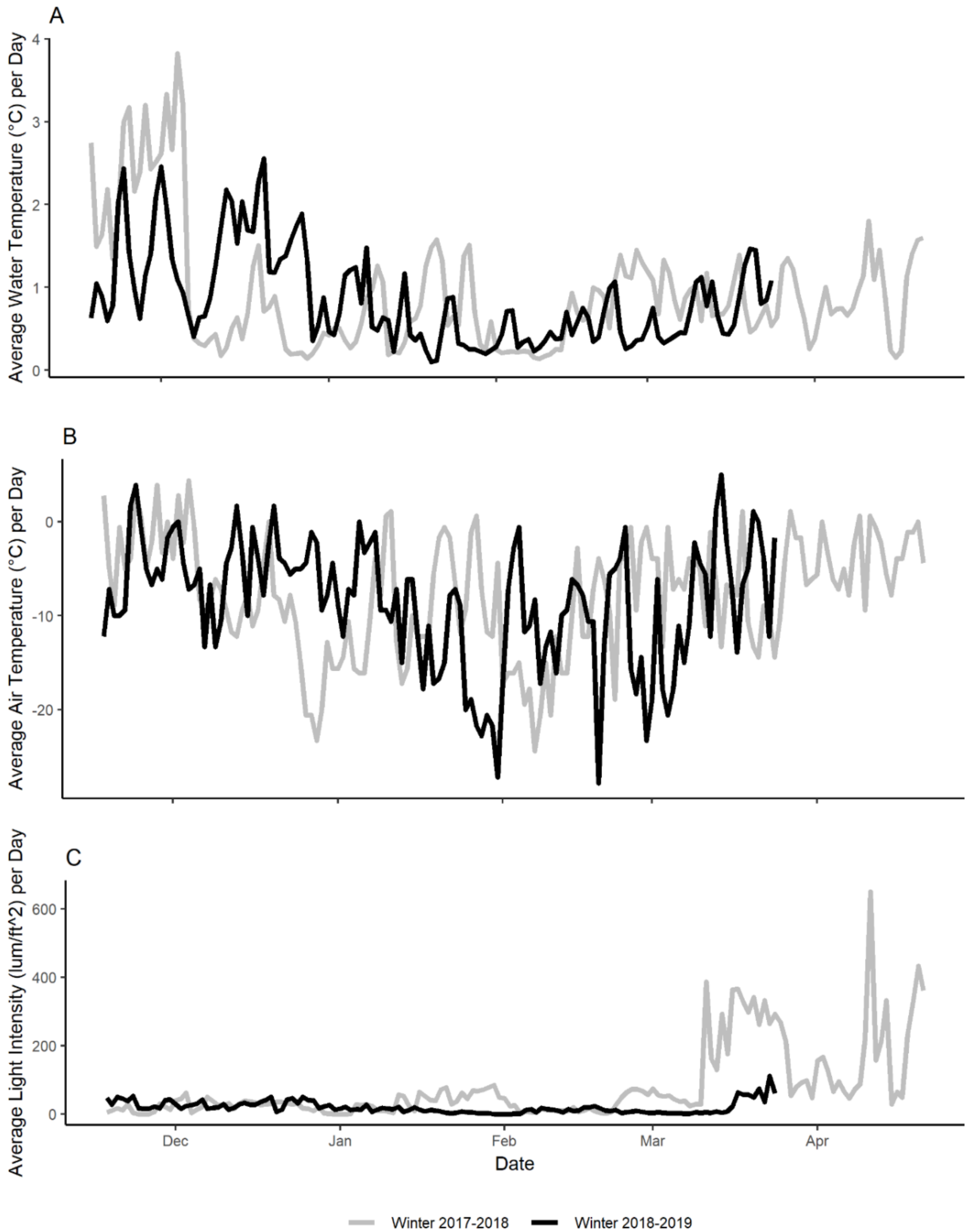

Fig. 2. Comparison of abiotic factors between winters of 2017-2018 (grey) and 2018-2019 (black). (A) Average water temperature (B) Average air temperature (C) Average light intensity. Water and light averages were based on multiple readings per day from the HOBO loggers. Winter of 2017-2018 used three HOBO loggers while winter of 2018-2019 used five HOBO loggers. Air temperature averages were obtained from the National Oceanic and Atomospheric Administration National Centers for Environmental Information (NCEI) station number USC00201486.

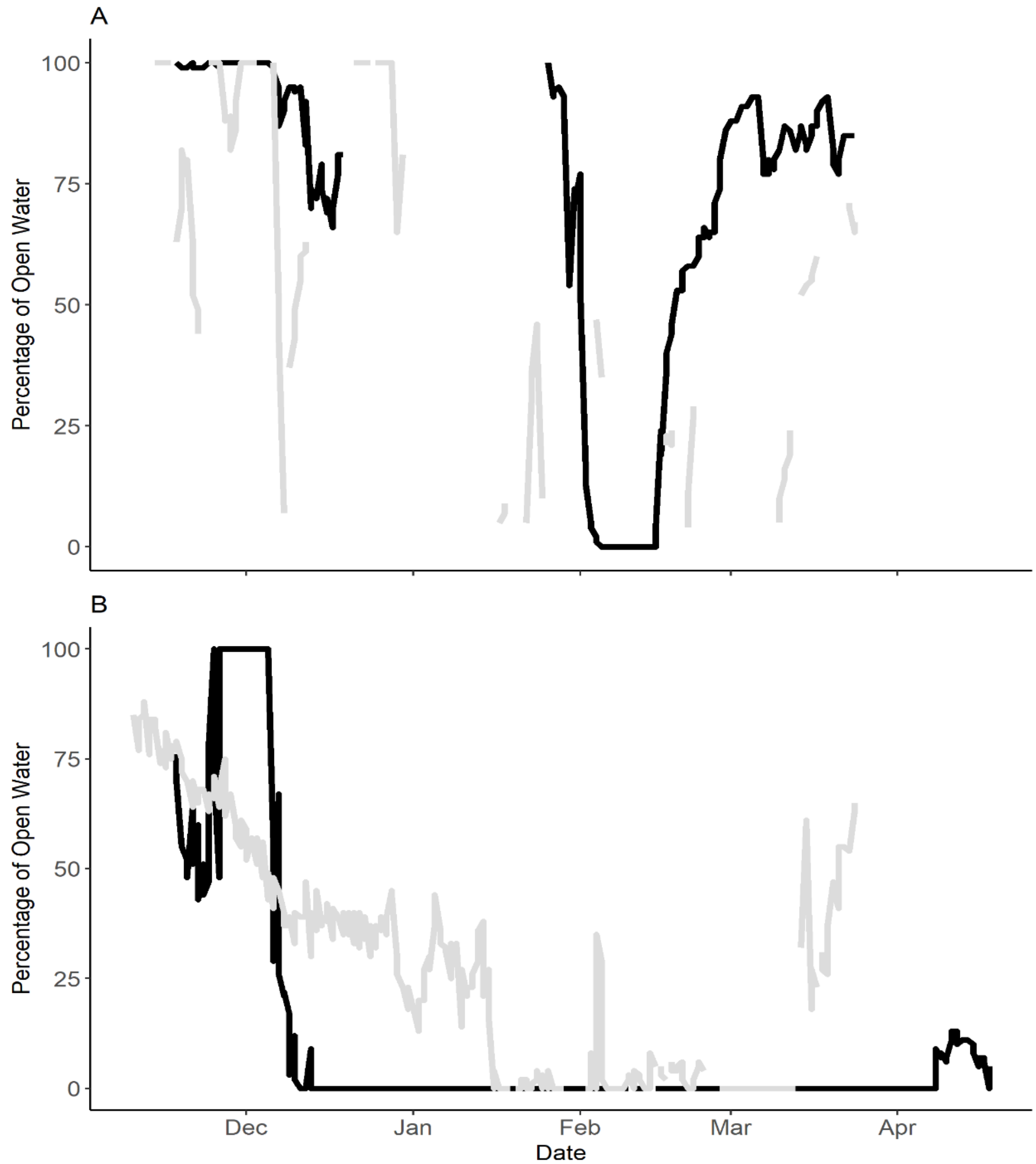

Fig. 3. Percentage of open water from winters 2017-2018 and 2018-2019. (A) Reach 11 in 2017-2018 (black) and 2018-2019 (grey) while (B) Reach 31 in 2017-2018 (black) 2018-2019 (grey). Gaps in the line indicate missing data due to camera malfunction or the lens of the camera being blocked.

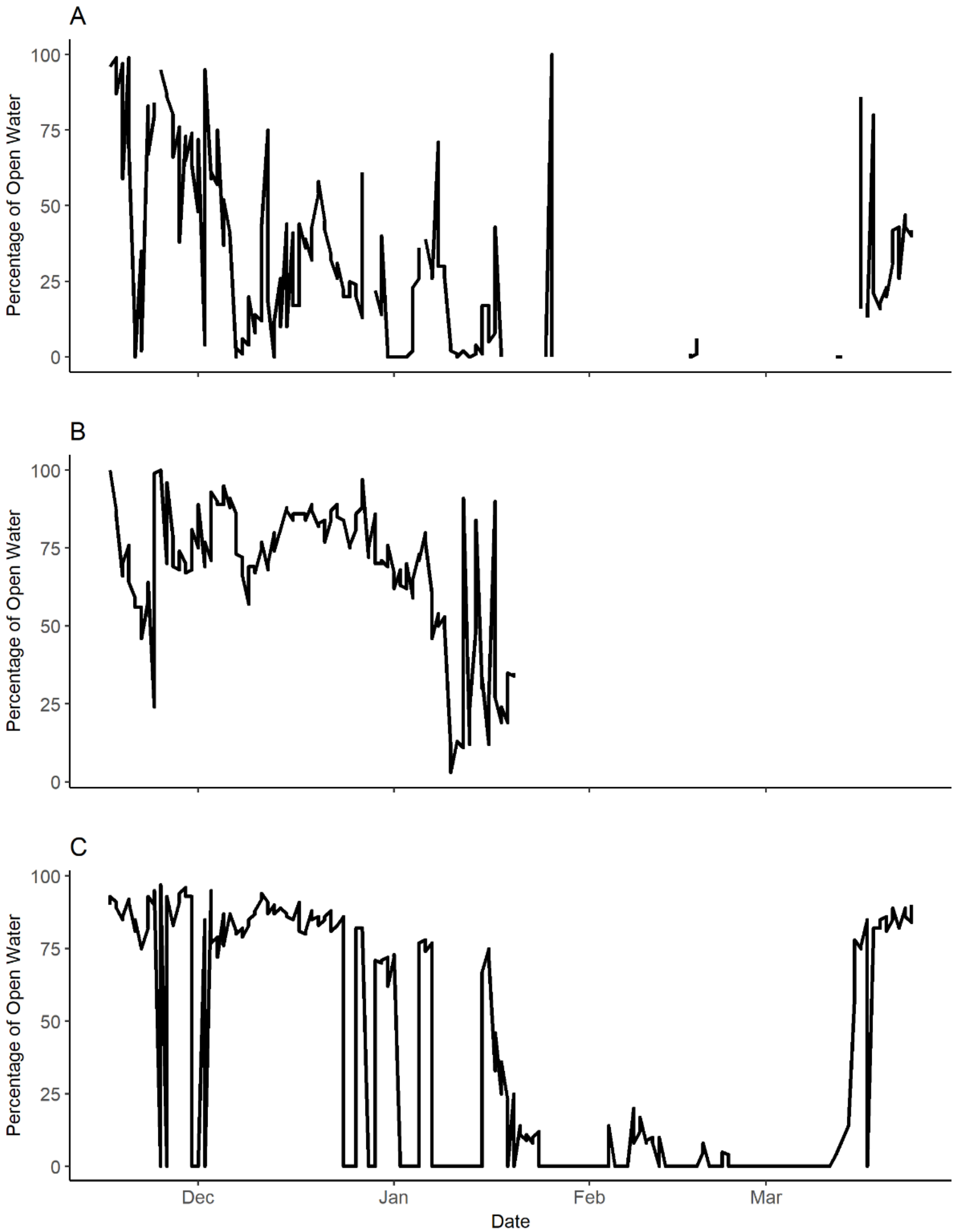

Fig. 4. Percentage of open water from additional reaches in winter of 2018-2019 showing the variability of open water among reaches within a year. (A) Reach 2 (B) Reach 8 (C) Reach 21. Gaps in the line indicate missing data due to camera malfunction or the lens of the camera being blocked.

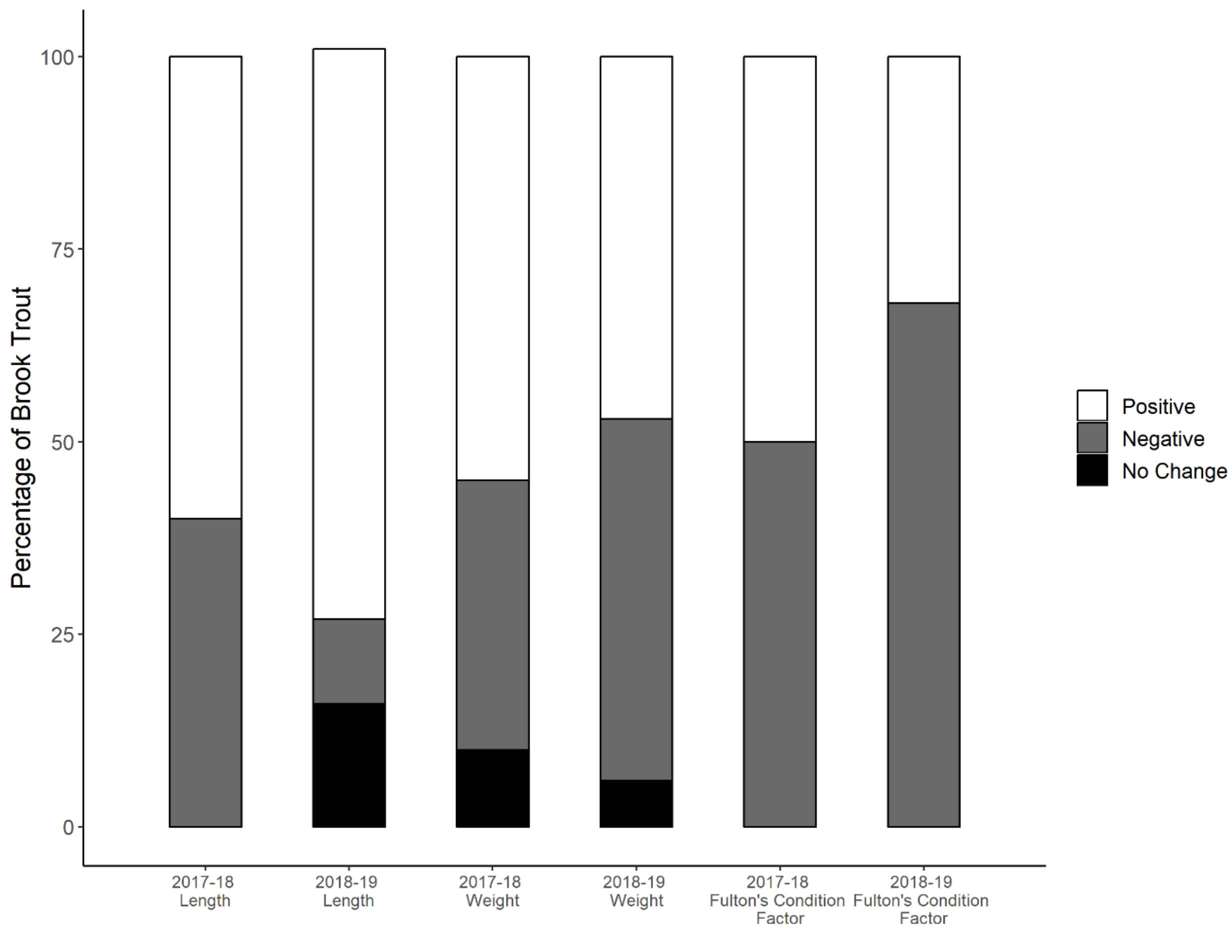

Fig. 5. Length, weight, and condition factor for recaptured brook trout between 2017-2018 and 2018-2019. Initial measurements were made in the fall and spring electroshocking sessions. Length and weight were recorded during the session while Fulton's condition factor was calculated as described in Materials and Methods.

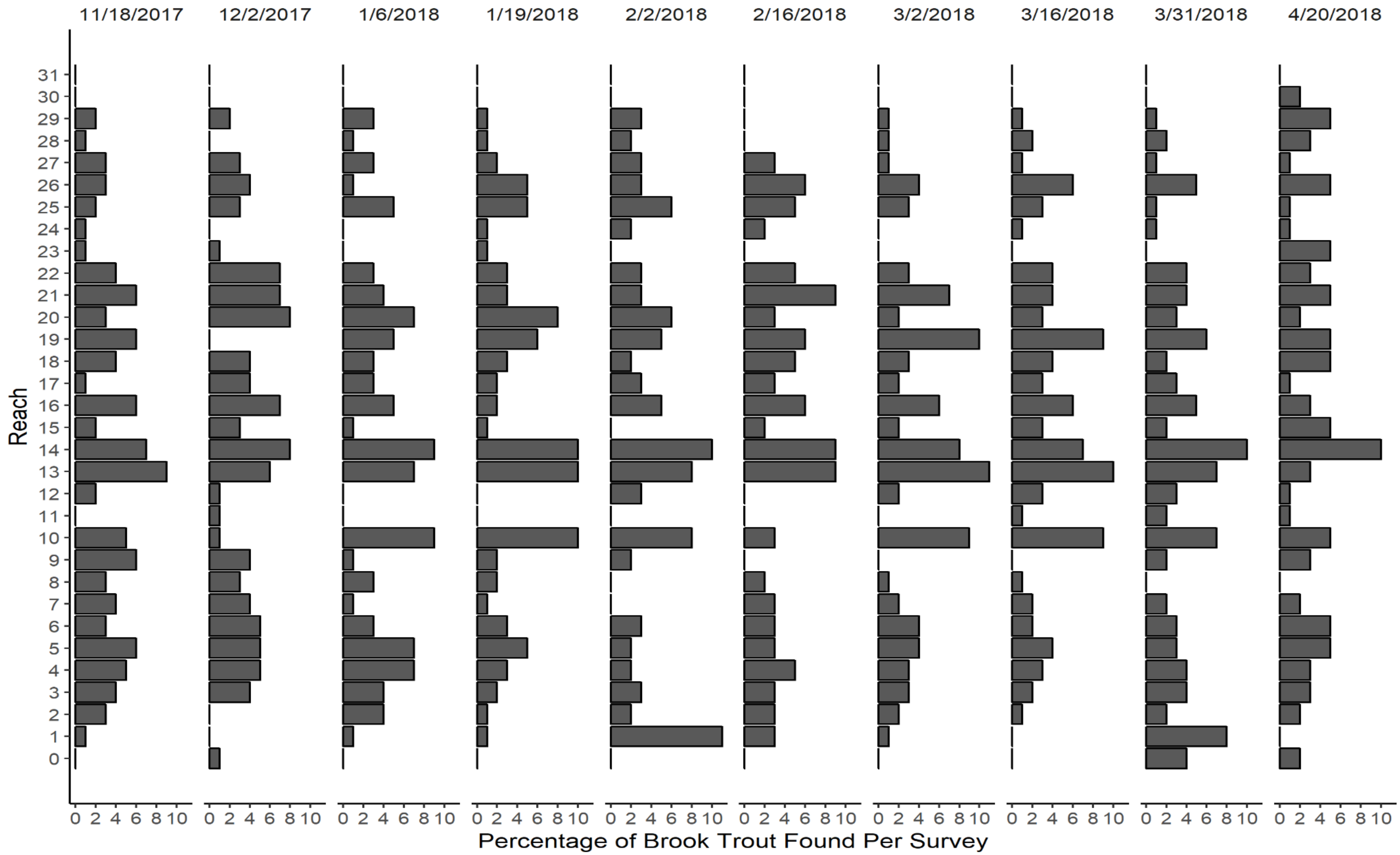

Fig. 6. Percentage of brook trout found in each reach for each survey performed in winter of 2017-2018. Distribution of brook trout per reach is represented by the total percentage of each bar. Reaches 0 and 1 are the mouths of Unnamed Tributary A and B while Reach 31 is the end of the study reach.

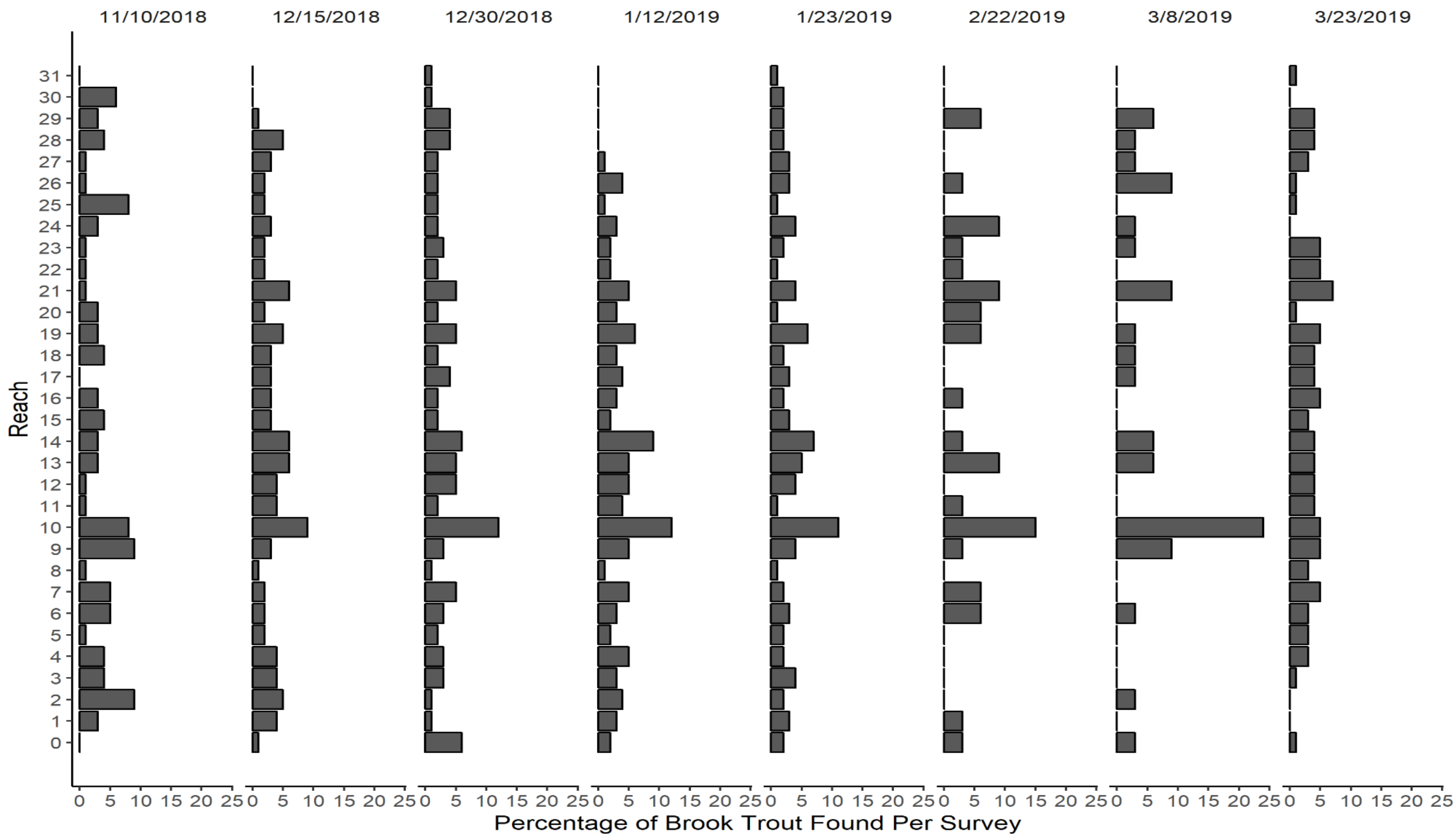

Fig. 7. Percentage of brook trout found in each reach for each survey performed in winter of 2018-2019. Distribution of brook trout per reach is represented by the total percentage of each bar. Reaches 0 and 1 are the mouths of Unnamed Tributary A and B while Reach 31 is the end of the study reach.

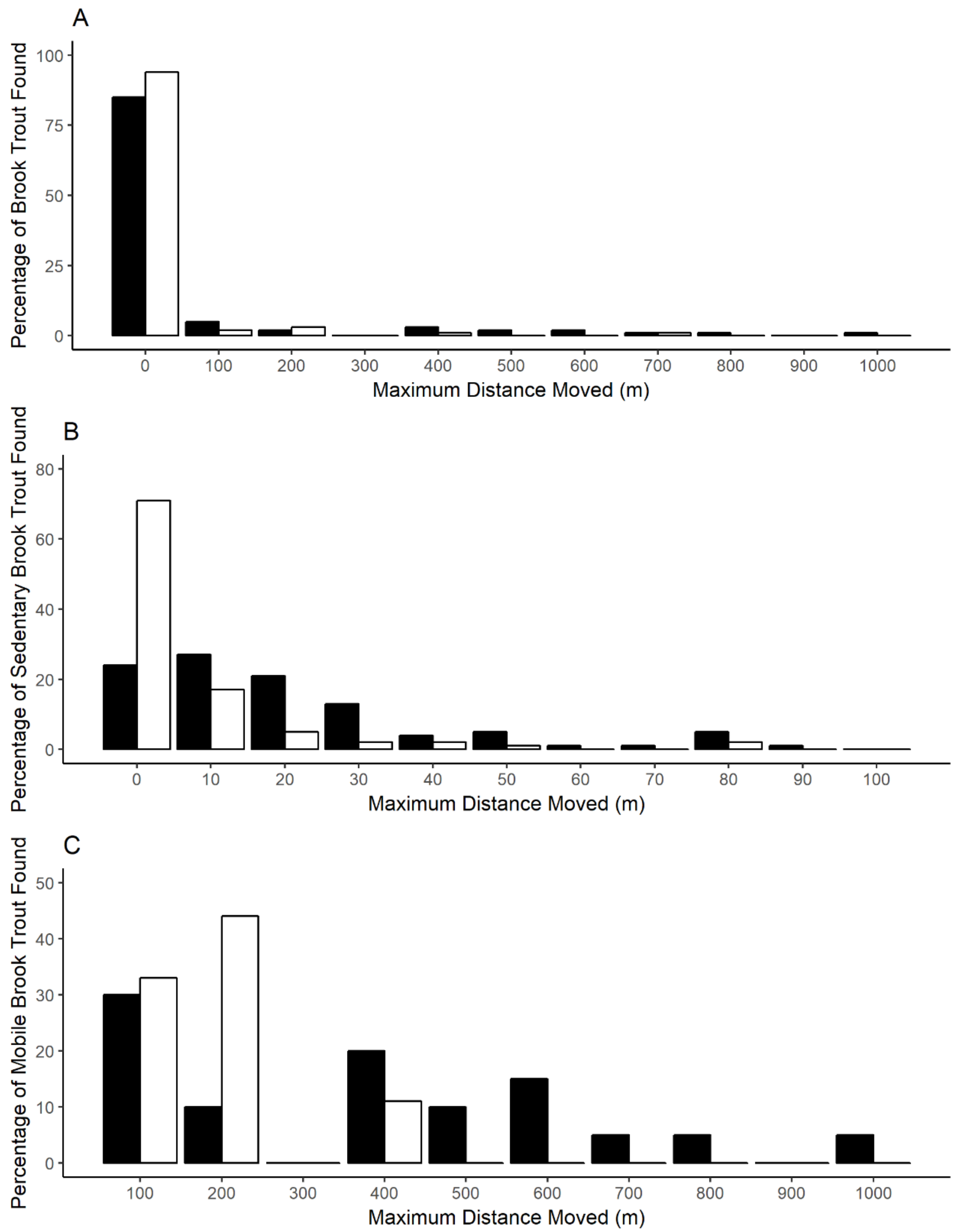

Fig. 8. Brook trout maximum distance moved from winter 2017-2018 (black) and winter 2018-2019 (white). (A) All tagged brook trout found once in winter 2017-2018 or 2018-2019 (B) Brook trout that moved less than 100 m from home range (C) Brook trout that moved 100 m or greater from home range. Maximum distance was calculated as how far a brook trout moved from its original starting position**.**

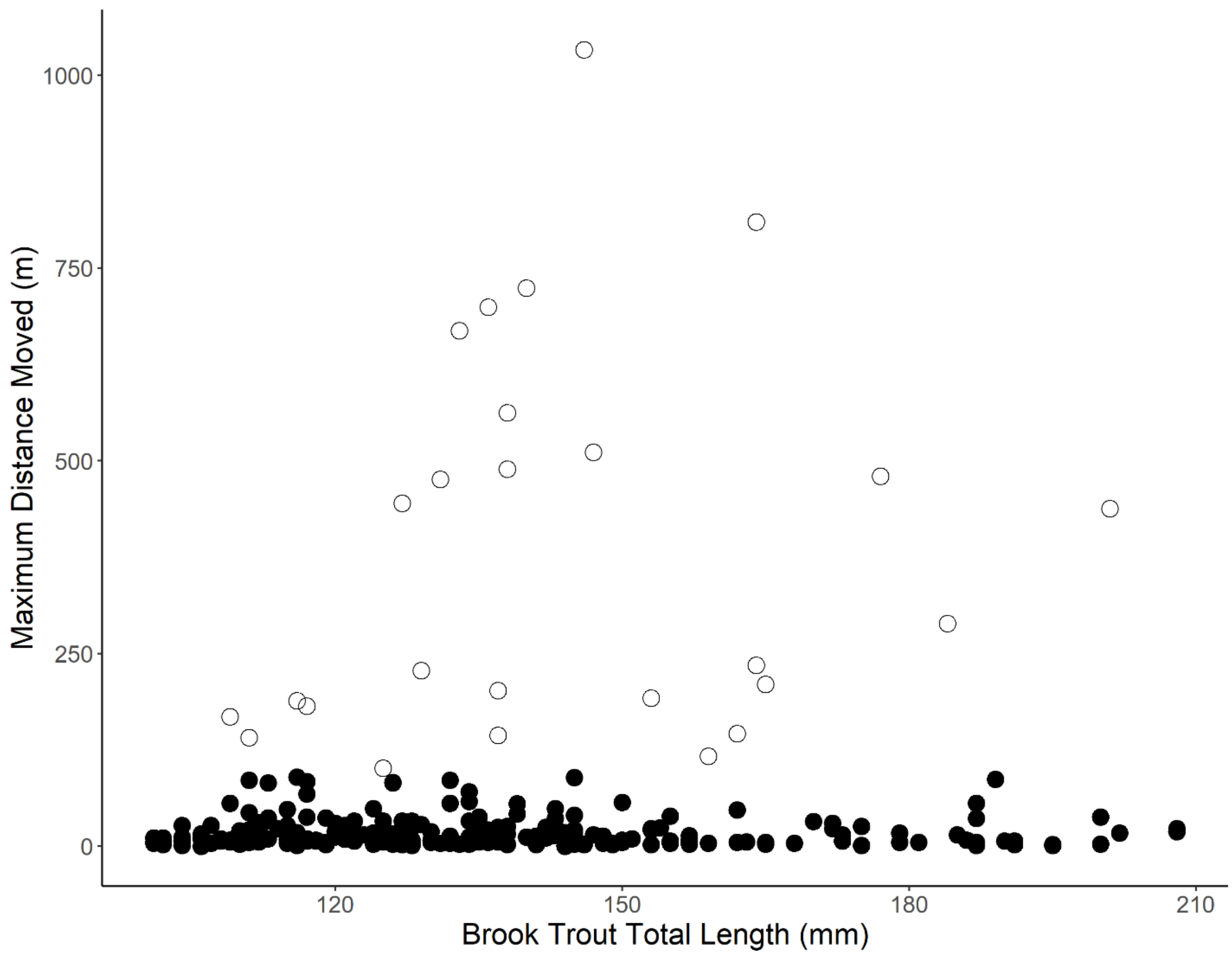

Fig. 9. Comparison of brook trout total length (mm) and maximum distance traveled from 2017-2019. Brook trout that moved 100 meters or more are indicated as white circles while sedentary brook trout are represented by black circles.

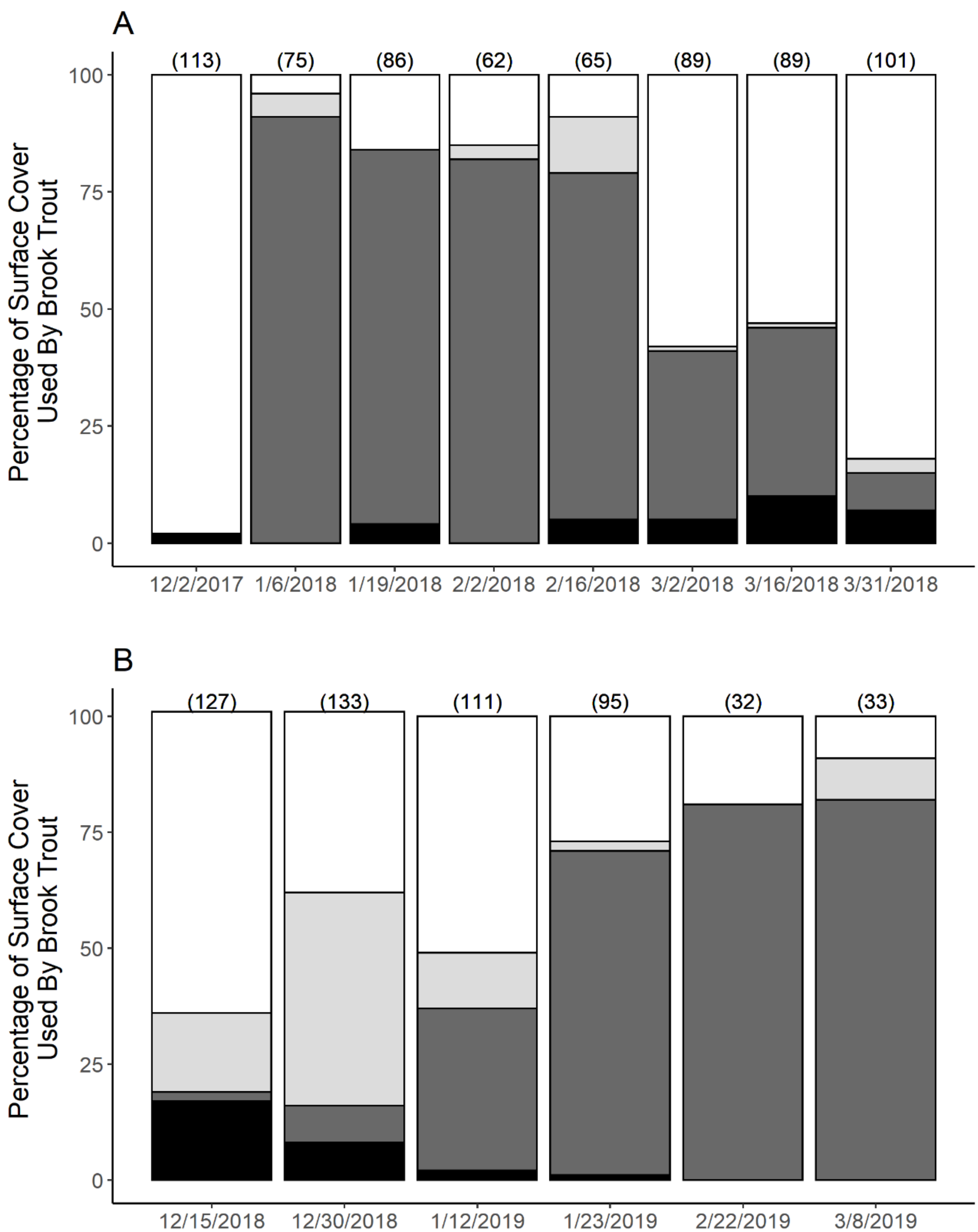

Fig. 10. Proportion of brook trout found under different surface covers between (A) winter 2017-2018 and (B) winter 2018-2019. The possible surface covers were ice (light grey), open water (white), snow covered ice (dark grey), and undercut bank (black). Numbers in parenthesis represent the total number of fish used for each analysis. The surface cover used by brook trout from both seasons was significant (winter 2017-2018: Fishers test, $P < 0.001$; 2018-2019: Fishers test, $P < 0.001$).

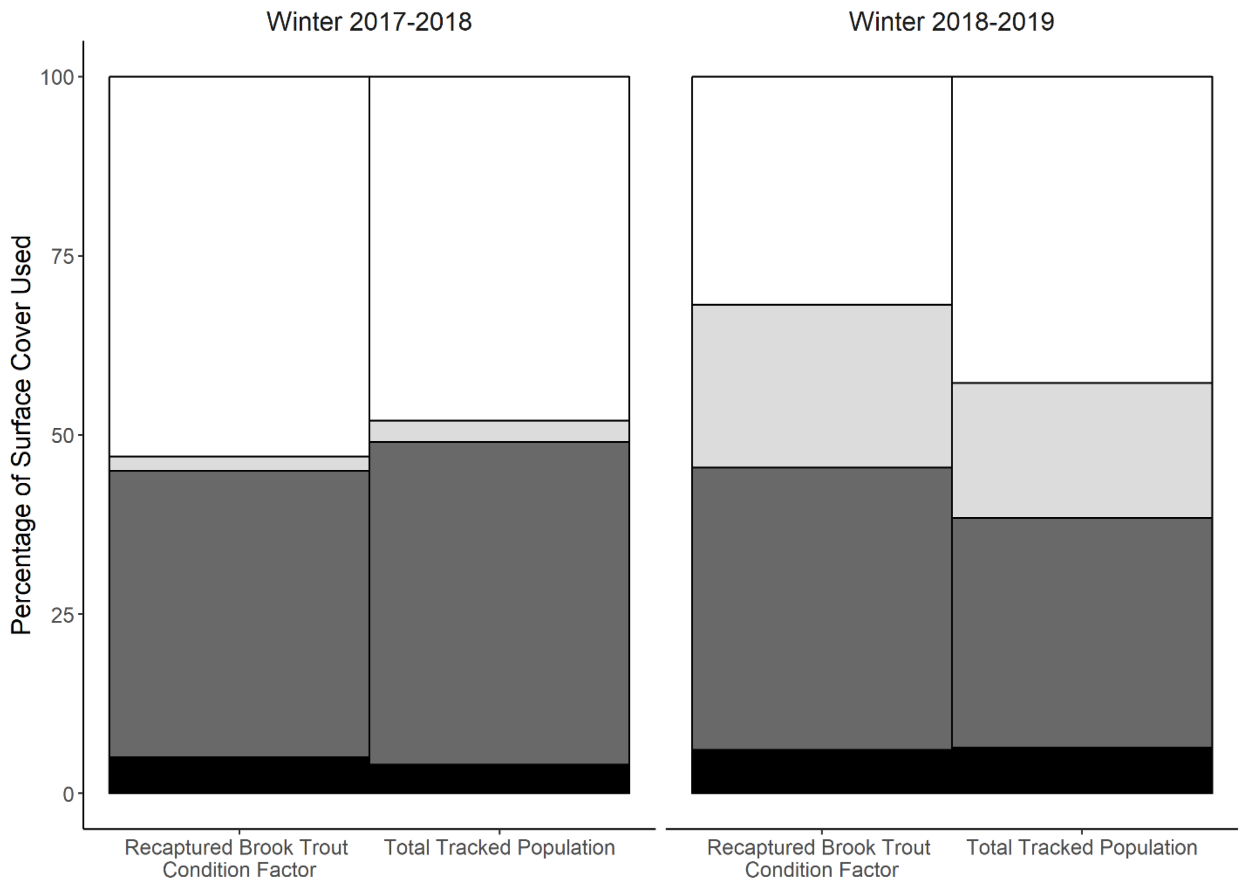

Fig. 11. Surface cover use compared against recaptured brook trout condition factor and entire tracked population during winters of 2017-2018 and 2018-2019. The colors of the bars indicate the percentage of fish using each type of cover and include ice (light grey), open water (white), snow covered ice (dark grey), and undercut bank (black).

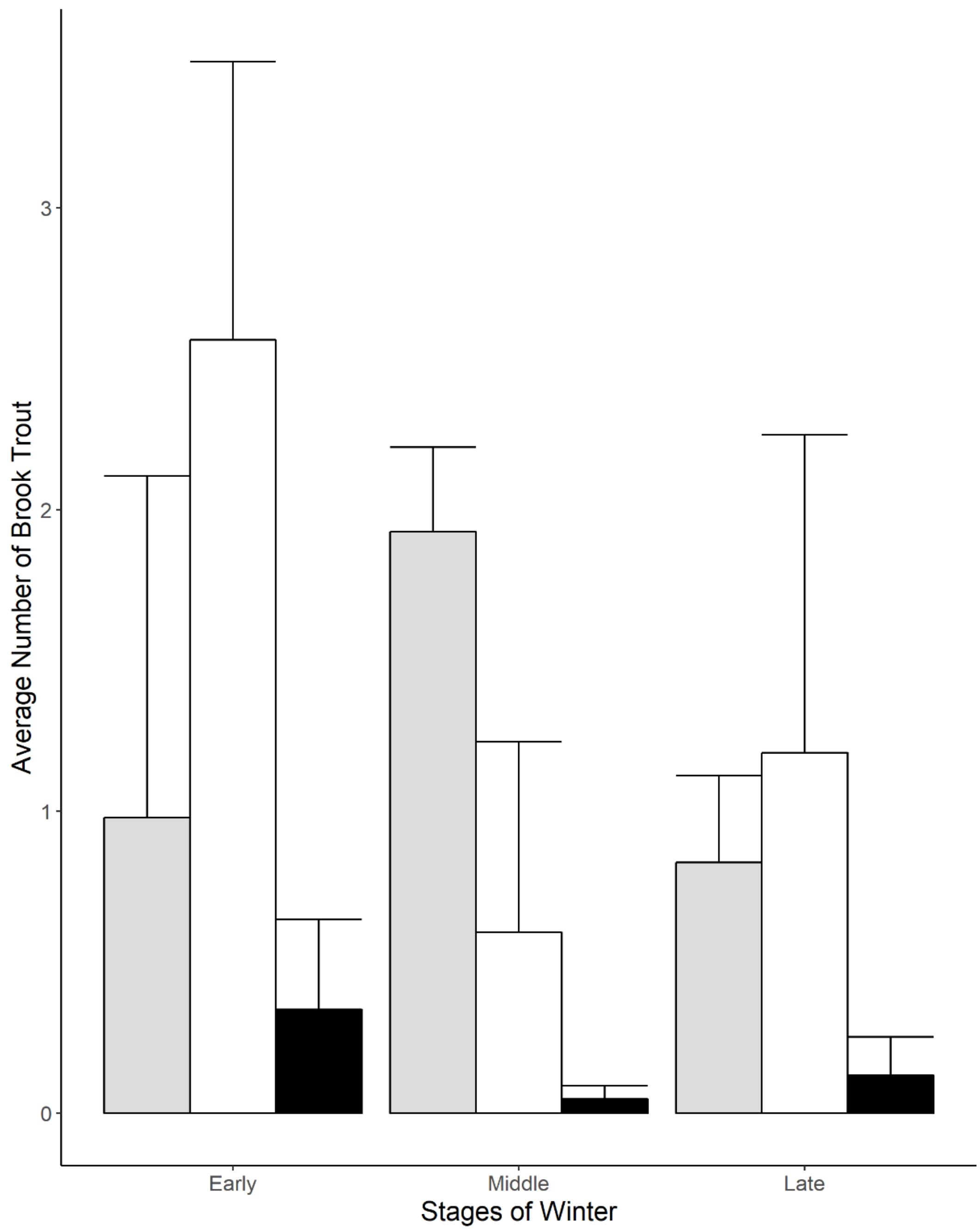

Fig. 12. Use of surface cover by brook trout over the three stages of winter. Data for both the 2017-2018 and 2018-2019 winters were combined for analysis. Ice (grey), open water (white), and undercut bank (black) were the possible surface covers available. Error bars represent ± standard deviation.

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Application to Use Vertebrate Animals in Research, Testing or Instruction

NORTHERN MICHIGAN UNIVERSITY

Project Title (If using external funds, enter the title used on the grant application): Physiological drivers of movement phenotypes in brook trout (*Salvelinus fontinalis*) within the Rock River drainage.

General Instructions

Please check the IACUC website to ensure you are using the current version of the form. All parts of this form *must be submitted electronically* to the Institutional Animal Care and Use Committee (email: IACUC@nmu.edu) and the relevant Department Head or other departmental designee. Review of this application will commence upon receiving the electronic application, but the project may not begin until all required approval signatures are obtained via Right Signature. Please contact the IACUC chair (email: IACUCChr@nmu.edu) if you have any questions.

Review Dates:

Designated Member Review of applications (appropriate for USDA Use Categories B and C) will be completed within two weeks after receipt of the electronic application.

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Application Number: 308
Date Application Received: April 10, 2017
☒ **Approved** ☐ **Denied on April 28, 2017**

I. Principal Investigator (Must be a faculty member or Department Head): Jill B. K. Leonard

Co- Investigator: Jacob E. Bowman

Department: Biology

Phone number: 227-1619

II. Funding Sources/Course Information and Dates

If the proposed work is for a course, please include the number of the course and title of the course

Funding Sources (External & Internal, if applicable) Faculty grant
Additional Funding Pending (click on the correct box)? ☒ Yes ☐ No