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Seasonal habitat use and survival of brown trout (Salmo trutta) in Oatka Creek, Monroe County, New York

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by

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Dedication

I dedicate this thesis, first, to my parents for the endless love, support, and encouragement that they have given me throughout my life. I also dedicate this thesis to my girlfriend, Amanda Anderson, for her patience while I earned my degree, in addition to helping collect stream habitat data.

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Abstract

Heavy predation by common mergansers during the severe winters of 2013-2014 and 2014-2015 resulted in dramatic brown trout reductions throughout the spring-fed reaches of Oatka Creek in western New York. Management agencies are considering habitat manipulation to reduce the severity of overwinter merganser predation on the wild brown trout population in Oatka Creek Park (OCP; Monroe County) but currently lack data to make an informed decision. My study sought to 1) quantify the availability of trout cover and habitat in OCP, 2) estimate the population abundance, density, seasonal survival rate, and year-class distribution of brown trout in OCP, and 3) identify habitat features used by brown trout and evaluate the seasonal importance of each feature. Data were recorded for 100 brown trout (101-512 mm total length; TL) during spring 2016, autumn 2016, winter 2017, and spring 2017. Trout density in OCP was estimated at 10.6-11.4 trout per km^2. Despite the absence of mergansers, brown trout population metrics decreased as the study continued; however, variable sampling conditions, especially discharge, were likely responsible. Relatively normal year-class distributions suggest that the population is recovering. The relative abundance of large trout (400+ mm TL) was greater than expected, which may be a result of low trout densities (i.e., reduced competition and increased resource availability may have enhanced growth and survival rates). Velocity refuges and structural cover were the primary factors determining habitat use throughout the study. Large woody debris was the most favored cover type; however, boulders were also important, especially during low streamflow, as they provide cover in deeper

midstream channels. Large trout (300+ mm TL) showed a strong preference for slow, deep pools with high densities of woody debris and large boulders, while age-0 trout (TL < 125 mm) preferred slow, shallow-water habitats with course substrates (i.e., cobble and boulders) and high densities of complex cover (i.e., boulders, LWD, and turbulence). Quality trout habitat and instream cover is abundant throughout OCP, but the availability of complex overwinter habitats capable of providing protection from piscivorous birds may be limited. Adding structural cover to areas favored by small trout (TL < 200 mm) would increase habitat complexity and likely reduce the severity of overwinter predation.

1. Introduction

1.1. Oatka Creek brown trout fishery

Oatka Creek is a small- to medium-sized stream located in western New York. The stream receives significant groundwater discharges in its downstream reaches near the Hamlet of Mumford, Monroe County, which has enabled it to support an excellent wild brown trout (*Salmo trutta*) fishery (Tatakis 2002; Sanderson 2007; NYSDEC 2015a). However, concerns about the future of the fishery began to surface in the springs of 2014 and 2015 as anglers started reporting poor fishing to the New York State Department of Environmental Conservation (NYSDEC). The NYSDEC sampled a small section of the stream in autumn 2015 and reported a significant decrease in brown trout abundance compared to historical data last collected in 2003 (NYSDEC 2015b; M. Sanderson, NYSDEC, Personal Communication).

The NYSDEC believes that the population decline is likely due to predation from common mergansers (*Mergus merganser*). Mergansers are large, fish-eating birds that have not been seen occupying these waters in over thirty years (NYSDEC 2015b). However, the severe winters of 2013-2014 and 2014-2015 caused the preferred habitats of mergansers (i.e., riverine wetlands and bays of large lakes) to become covered with ice, thus forcing the mergansers to leave in search of open water and food (Leonard and Shetter 1937; NYSDEC 2015b). Spring-fed reaches of Oakta Creek provide ideal overwinter merganser habitat during such conditions because they remain ice-free and provide an abundant supply of brown trout, which use the same habitat.

The NYSDEC is considering using habitat manipulation to help reduce overwinter merganser predation on brown trout in Oatka Creek (NYSDEC 2015b) but lacks data to make an informed management decision. The goal of my study was to provide management agencies with additional information to aid the decision-making process. My study focused on survival and habitat use of brown trout in Oatka Creek during the winter, but sampling was also performed in the spring and autumn. My data provide trout population size estimates, size-class distributions, and stream habitat quality assessments.

1.2. Stream habitat

Distribution and abundance of stream-dwelling brown trout are determined by their habitat. Armstrong et al. (2003) defined habitat as the range of physical, chemical, and biological factors affecting the survival, growth, and reproduction of the target species. It is incredibly difficult to use habitat characteristics as a predictor of salmonid abundance because habitat-fish relationships are extremely dynamic and complex. A myriad of biotic and abiotic factors can directly and indirectly affect brown trout production differently between streams and even reaches within the same stream. Therefore, management agencies considering habitat manipulation to increase trout production must assess each site at an appropriate scale (Cunjak 1996; Armstrong et al. 2003).

Most populations of stream-dwelling brown trout are regulated by density-dependent factors, which limit production when the population is near carrying capacity (i.e., used the entire habitat) by reducing survival and growth rates (Milner et al. 2003). Habitat is a common limiting factor for trout; however, most salmonid populations reach their carrying capacities only during some portions of the year (Milner et al. 2003) followed by a period of high mortality, which is known as the critical period. In most cases, the period of high mortality during the critical period occurs within the first few months after hatching (Elliot 1994); however, it may also occur later in life (e.g., winter) (Bjornn 1971; Mitro and Zale 2002).

Winter is a stressful time for trout because they are ectothermic poikilotherms, which means their body temperatures fluctuate with ambient water temperatures. For ectotherms, metabolic rate increases as a positive function of temperature, so oxygen consumption and energy requirements decrease with lower temperatures (Diana 2003). Activity level and swimming performance also decrease with temperature, resulting in many trout becoming nocturnal throughout the winter to avoid predation (Cunjak 1996). Stream-dwelling trout faced with such challenges need to select overwintering habitat that will minimize energy expenditure (e.g., low current velocities, instream cover) while also providing protection from adverse physiochemical conditions (e.g., low oxygen, ice) and predators.

The availability of overwinter habitat, particularly cover, is a primary factor limiting abundance and recruitment for many trout populations (Elliott 1994; Cunjak 1996; Mitro and Zale 2002). Cox (2011) described cover as a channel or bank feature used by trout for energy conservation, predator avoidance, or refuge during extreme environmental events (e.g., flooding, harsh winter conditions). Brown trout use a variety of cover types throughout the year, including woody debris, undercut banks, overhanging riparian vegetation, course substrate materials, aquatic vegetation, deep water, and turbulence (Boussu 1953; McMahon and Hartman 1989; Harvey et al. 1999). However, the presence of cover becomes increasingly important during the winter months (Cunjak 1996; Mitro and Zale 2002). Body size is a major factor influencing cover preference during the winter since smaller trout tend to use interstices in the substrate and complex bank features, while larger trout are commonly associated with deep pools and woody debris (Cunjak and Power 1986; Cunjak 1996; Mitro and Zale 2002; Johnsson et al. 2004). Other factors (e.g., predation risk, food availability, competition) may also play an important role in habitat selection (Cunjak 1996; Johnsson et al. 2004).

Several studies have reported that the abundance and quality of cover in a stream are positively correlated with the distribution and carrying capacity of the trout population, along with individual survival and growth rates (Boussu 1953; Tschaplinski and Hartman 1983; Flebbe 1999; Harvey et al. 1999). Cover increases habitat complexity, which decreases competition and individual territory size by increasing food density (Diana 2003; Cox 2011) and providing visual isolation (Gowan and Fausch 1996). As territory size decreases, resources become more evenly distributed among the entire population, and stress associated with competition is reduced if visual isolation persists (Gowan and Fausch 1996). Visual isolation may also reduce predation by creating more hiding places for prey, while the physical presence of cover makes navigation more difficult for predators. Individual growth rates increase as the risk of predation is reduced because more time can be spent foraging in areas with greater prey densities (Schoener 1971; Johnsson et al. 2004).

1.3. Merganser predation

The effect of piscivorous bird predation on a community of fishes varies from minor (e.g., Wood 1987, Suter 1995) to significant (e.g., Power and Mitchell 1994; Engström 2001). This variation is observed partly because all predation is not equal in terms of the effect on the long-term population dynamics of the prey species. For example, heavy predation on a salmonid population or cohort experiencing significant density-independent mortality (e.g., trout fry) is unlikely to affect the population size because most of those individuals are likely to die anyway (Suter 1995). On the other hand, greater predation on a population or cohort not affected by density-independent mortality (e.g., age-1 and greater cohorts) is likely to cause population changes (Power and Mitchell 1994). Mortality experienced by populations with low death rates is known as additive mortality (i.e., adds to natural mortality). Mergansers promote additive mortality by selectively feeding on larger juvenile trout (~50-200 mm TL) (Leonard and Shetter 1937; Wood and Hand 1985; Feltham 1990; NYSDEC 2015b).

Physical habitat characteristics also play an important role in determining the effect of piscivorous bird predation on a trout population. Of these habitat features, water temperature is among the most important factors. The ability of trout to escape a predator is dependent on swimming ability and critical holding velocity, both of which are reduced at low temperatures (Hartman 1963; Heggenes and Traaen 1988).

Since the ability of endothermic predators (e.g., birds, mammals) to swim and capture prey is not affected by temperature, they have a distinct advantage over the fish at low temperatures (Salyer and Lagler 1940). The effectiveness of endotherms as predators is also influenced by stream size, discharge, and cover availability (e.g., trout are less vulnerable to predation in larger streams with high discharge and abundant cover) (Wood and Hand 1985; Heggenes and Borgstrøm 1988). In addition, streams with limited overwintering habitat (i.e., deep pools with cover) are also vulnerable to predation because the entire population will be forced to concentrate in a few suitable areas. The greater prey densities will increase predator efficiency and attract more predators (Heggenes and Borgstrøm 1988). Situations such as these often account for substantial overwinter trout mortality (Power and Mitchell 1994).

2. Objectives

Since quality overwinter habitat is believed to be a major factor limiting brown trout production in the Oatka Creek, I addressed the following objectives:

1) Quantify the availability of different types of cover and habitat in Oatka Creek;
2) Estimate the population abundance, density, seasonal survival rate, and year-class distribution of brown trout in Oatka Creek;
3) Identify habitat features used by brown trout and evaluate the seasonal importance of each habitat feature; and
4) Recommend potential management strategies that will increase wild brown trout production by increasing habitat quality in Oatka Creek.

3. Methods

3.1. Study Area

Oatka Creek flows for 93 km through four western New York counties (Wyoming, Genesee, Livingston, and Monroe) before merging with the Genesee River near the Town of Scottsville, New York, USA (Figure 1) (Tatakis 2002). Land use within the Oatka Creek watershed (drainage area: 559 km^2) is dominated by agriculture (73.8%), forest (21.6%), and small residential and urban areas (2.7%) (Tatakis 2002). Wetlands, which serve as important sinks for nutrients and sediments, only contribute 0.8% of the land use in the watershed (Tatakis 2002). Most natural habitats (i.e., forests and wetlands) found throughout the Oatka Creek basin are small and fragmented (Tatakis 2002). Several small towns and villages rely on Oatka Creek to provide their communities with municipal services, such as wastewater treatment and water supply. Currently, four sewage treatment facilities discharge effluent into the stream in Warsaw, Pavilion, LeRoy, and Scottsville (Tatakis 2002; Pettenski et al. 2013). Oatka Creek also provides recreational value through activities such as fishing, hiking, and boating (Tatakis 2002; Pettenski et al. 2013).

Oatka Creek flows over the Onondaga Escarpment (i.e., karst region composed mostly of limestones) near the Village of LeRoy (Genesee County), which causes surface water from the stream to flow underground through joints, fractures, and sinkholes in the bedrock. Numerous springs and seeps return groundwater to the reaches of Oatka Creek downstream from the Onondaga Escarpment (karst region ends at Buttermilk Falls near LeRoy, NY); however, the confluence with Spring Creek in the Hamlet of Mumford (Monroe County) provides Oatka Creek with the greatest groundwater input (~13 km from Genesee River confluence) (Oatka Creek Watershed Committee 2001; Tatakis 2002). The abundant groundwater discharges in the lower reaches of Oatka Creek (i.e., downstream from Spring Creek confluence) provide high quality water to the stream and moderate summer and winter temperatures (Oatka Creek Watershed Committee 2001; Tatakis 2002).

The abundant influx of groundwater has enabled the lower section of Oatka Creek to support a renowned brown trout fishery (Oatka Creek Watershed Committee 2001; Tatakis 2002). Natural reproduction is well-documented throughout the lower reaches of Oatka Creek; however, hatchery-reared brown trout are released (i.e., stocked) in this section several times each year (Tatakis 2002; Sanderson 2007; NYSDEC 2015a). In recent years, the NYSDEC has released 4,000-4,300 brown trout (200-380 mm TL) annually in the lower reaches of Oatka Creek (Monroe County) (NYSDEC 2018). Other gamefish species, such as northern pike (*Esox lucius*), largemouth bass (*Micropterus salmoides*), smallmouth bass (*M. dolomieu*), and walleye (*Sander vitreus*), may also be found in the lower reaches of Oatka Creek (Tatakis 2002).

3.2. Study Sites

Four study sites (length: 100 m) within the boundaries of Oatka Creek Park (OCP) located in the Hamlet of Garbutt (Monroe County) were randomly selected using a random number generator (Figure 2). OCP is part of the Monroe County Park system and is composed of 168 hectares of forested land, with approximately 2.25 km of stream running through the center of the park. The upstream boundary of OCP is located about 4.5 km downstream from the Spring Creek tributary. The combination of high quality water, suitable year-round water temperatures, and diverse stream habitat (i.e., varying densities of instream cover found throughout sequences of riffles, runs, pools, and glides) allows brown trout to thrive throughout the park. OCP is a favorite spot for recreational trout anglers in western New York and has been managed as a wild brown trout fishery by the NYSDEC since October 2000 to increase angler satisfaction by increasing the abundance of larger trout (TL > 356 mm) (Sanderson 2007). In doing so, special "no-kill" regulations were established (i.e., catch-and-release fishing required; artificial lures only). Three years after establishing special regulations (i.e., fall 2003), the density of large trout (TL > 356 mm) in OCP increased significantly, and reaches with special regulations had greater densities of large trout (TL > 356 mm) than reaches without special regulations (Sanderson 2007). Although hatchery-reared trout are not released directly in OCP, sections surrounding OCP are still stocked annually (203-381 mm TL) (NYSDEC 2015a). An active United States Geological Survey (USGS) gage (USGS 04230500) records stream discharge and gage height is measured at the Union Street Bridge in Garbutt at the downstream boundary of OCP (USGS 2018).

3.3. Stream habitat measurements

A series of five cross-sectional transects (length: 25 m) extending from bank to bank were used to measure the following stream habitat features along each 100-m site during base flows in December 2016 (stream discharge: 4.06 cubic meters per second; cms): stream width and depth, current velocity, substrate composition, microhabitat (riffle, run, glide, pool), and instream cover availability. Stream width was measured from bank to bank using a 50-m tape. Stream depth and current velocity were recorded at five equidistant points along each transect (Deschênes and Rodríguez 2007). Stream depth was measured from the surface of the water to the substrate with a meter stick. Current velocity was taken at 0.8 of the water depth with an acoustic digital current meter (ADC). Site area (m^2) was calculated by multiplying the site length by the mean site width. The sum of the area for all four sites was used to represent the area of OCP.

The dominant substrate type was visually estimated at 10 equidistant points (sample point radius: 25 cm) along each transect and classified using a system modified from Cummins (1962) (Table 1). The mean of the dominant substrate values was used as an index of substrate size, and the standard deviation was used as an index of substrate heterogeneity (Bain et al. 1985). Microhabitat availability was determined by classifying each transect point as a riffle (velocity $\geq$ 0.4 m/s; depth < 0.4 m), run (velocity $\geq$ 0.4 m/s; depth $\geq$ 0.4 m), glide (velocity < 0.4 m/s; depth < 0.4 m), or pool (velocity < 0.4 m/s; depth $\geq$ 0.4 m) based on depth and velocity measurements (values modified from Borsányi et al. 2004).

Categories for classifying instream cover were as follows (Platts et al. 1983): 1) turbulence, 2) undercut banks (UCB), 3) concealing water depths (CD), 4) large woody debris (LWD), 5) boulders, and 6) submerged aquatic vegetation (SAV).

Turbulence was estimated visually in eight transects per site (transect length: 12.5 m) and classified according to Stevenson and Bain (1999) (Table 2). UCBs were evaluated by measuring bank depth at 5-m intervals along both banks; bank depths greater than 10 cm were classified as a potentially useful UCB for trout. CDs were evaluated based on stream depth data; depths greater than 75 cm were classified as CDs. Nine cross-sectional transects (length: 12.5 m) were used to quantify LWD, boulders, and SAV by recording the frequency that each cover type contacts a cross-sectional transect. LWD (diameter > 5 cm) and boulders (diameter > 25 cm) contacting the transect line were counted, measured, and split into size classes based on diameter (Table 3). SAV was measured by recording the length of each patch contacting the transect line. The proportion of LWD, boulders, and SAV at each site was estimated by dividing the cumulative distance that each cover type intersected the transect by the total transect length (Stevenson and Bain 1999).

Each cover type was also categorized as *structural cover* (SC; i.e., undercut, LWD, boulders, and SAV) or *non-structural cover* (NSC; i.e., turbulence and CD). The proportions of SC and NSC were estimated by summing the individual cover types that comprised each group (maximum score: 100%). The sum of all cover types was used to estimate *total cover* (TC).

3.4. Trout sampling

Brown trout were collected by single-pass backpack electrofishing (Halltech HT-2000) in an upstream direction twice seasonally in spring 2016 (Sp-16), fall 2016 (F-16), winter 2017 (W-17), and spring 2017 (Sp-17). The amount of time between both seasonal samples ranged from seven to 30 days. Current was supplied at 250 volts pulsed direct current (DC) at 60 Hz, as used by Sanderson (2007) in the lower reaches of Oatka Creek. Water temperature (°C) was recorded on each sampling date at each site using a thermometer and was classified as cold (<5 °C), moderate (5-10 °C), or warm (>10 °C).

Captured trout were measured (total length; TL) and given a fin clip unique to each season (i.e., marked) immediately after capture. A steel sinker (weight: ~55 g) attached to a float with monofilament fishing line was used to mark the capture location of trout; some quick notes and diagrams were also recorded. Once sampling was completed, habitat parameters in each area where trout were captured were recorded using methods like those described in the previous section. Current velocity, stream depth, habitat type, and dominant substrate were recorded at each point of capture. Structural cover and substrate composition in the 1-m radius surrounding the point of capture were estimated visually and expressed as a percentage. Non-structural cover was reported as absent (0%) or present (100%). Fish captured within 1 m of any cover type were considered using that feature. Additional structural cover measurements are shown in Table 4. Selectivity for each cover and habitat type were calculated with Manly's α (Manly 1974):

$$\propto_i = \frac{r_i}{n_i} \bigg/ \sum_{i=1}^{k} \frac{r_i}{n_i};$$

where r_i is the proportion of fish associated with habitat i, n_i is the proportion of habitat i in the environment, and K is the total number of habitat categories. A random use of habitat types occurs when $\alpha_I = 1/K$ (Tabor and Wurtsbaugh 1991). The number of potential predators (e.g., mergansers, northern pike) encountered while sampling was also recorded.

3.5. Trout abundance and density

Population abundance was estimated each season using a modified Chapman-Petersen equation (Ricker 1975). This variation of the equation was preferred because it gives a statistically unbiased estimate for finite populations (Ricker 1975; Lockwood and Schneider 2000). The modified Chapman equation calculates the population estimate N as follows:

$$N = \frac{(M+1)(C+1)}{R+1};$$

$$Standard\ error = \sqrt{\frac{N^2(C-R)}{(C+1)(R+2)}};$$

$$95\%\ confidence\ interval = N \pm t\ (standard\ error);$$

where M is the number of fish caught and marked in the initial sample, C is the total number of fish caught during the second sample, R is the total number of marked fish caught in the second sample, and t is the Student's t for C–1 degrees of freedom (Ricker 1975). See Lockwood and Schneider (2000) for the assumptions associated with mark-recapture studies. Trout density (expressed as N/km^2) was estimated for each season and used to compensate for unequal sampling effort among sites and seasons due to differences in environmental conditions (e.g., average depth and current velocity). Density was calculated by dividing N by the product of site area

(km^2) and the proportion of the site sampled (p) that day (i.e., density = N / (km^2 * p)). The proportion of the site sampled (p) was estimated visually immediately after trout sampling was completed. Estimated trout abundance (N) was used to determine apparent survival between seasons (Mitro and Zale 2002):

$$Apparent\ survival = \frac{N_{t+1}}{N_t};$$

where N_t is the estimated trout abundance at time t. Estimated trout density (N/km^2) was also used to assess apparent survival by replacing N_t with N/km^2_t in the equation above. Apparent survival rates >1 indicate that recruitment has occurred (Mitro and Zale 2002).

3.6. Trout size class analysis

Length-frequency histograms were used to examine the size distribution of trout in the study area. Year-classes were assigned to trout based on TL: age-0 (<125 mm), age-1 (125-200 mm), age-2 (201-300 mm), and age-3+ (>300 mm) (M. Sanderson, NYSDEC, Personal Communication). Year-class distributions recorded during the study were compared to OCP year-class distributions from 2003 (i.e., pre-merganser invasion; n = 2) and 2015-2016 (post-mergansers; n = 2) provided by M. Sanderson (NYSDEC, Personal Communication). All other habitat-use analyses were performed using modified year-classes (referred to as *size classes*) to increase the number of samples in each group. Size classes were assigned as follows: 1 – small trout (ST; TL < 200 mm); 2 – medium trout (MT; 200-300 mm TL); and 3 – large trout (LT; TL >300 mm).

3.7. Watershed analysis

Geographic information system (GIS) was used to determine watershed basin characteristics (e.g., drainage area, basin slope) upstream from the bridge on the downstream boundary of OCP. StreamStats (Version 4; USGS 2017) was used to obtain watershed data. Air temperature and precipitation were recorded daily from the weather station at the Rochester International Airport (approximately 18 km from OCP); historical weather data used for comparisons were provided by the National Weather Service (2017). Gage height was recorded from the USGS station located on the downstream boundary of OCP at 12:00 a.m. every day (USGS 2018). Although the USGS gage records both stage height and discharge, stage height was preferred because ice formation during the winter may interfere with discharge values. Subsets of corresponding stage height and discharge values were recorded from the station and used to create a rating curve (i.e., discharge-stage height relationship) that allowed discharge to be estimated from stage height in OCP. On each day of sampling, stream discharge was classified as low (< 2 cubic meters per second; cms), moderate (2-8 cms), or high (> 8 cms). Stream discharge was used as an index of turbidity (i.e., water clarity) because it is positively correlated in Oatka Creek at Garbutt ($r^2 = 0.59$; Tatakis 2002). Stream and weather data (i.e., gage height and temperature) were recorded from 1 February 2016 to 1 April 2017.

3.8. Statistical analyses

Two-sample t-tests were used to detect differences in various habitat parameters (e.g., depth, velocity, cover density, substrate) between available habitat and habitat used by trout. Analysis of variance (ANOVA) was used to detect differences in several habitat and trout variables (e.g., trout habitat and total length; TL) among a variety of categorical independent variables (e.g., sites, trout size-classes, temperature and discharge groups). Data transformations were performed on variables failing to satisfy the normality requirements for parametric analyses. Non-parametric Kruskal-Wallis analysis (ANOVA equivalent) was used when normality could not be achieved. The traditional ANOVA was used when group variance was homogenous (Levene's test: $P > 0.05$), while Welch's ANOVA was used when normality was achieved but group variance was unequal (i.e., not sensitive to unequal variances). Pairwise multiple comparisons (i.e., post hoc tests) were used after significant differences ($P < 0.05$) were detected among means to identify means that differed. Tukey's HSD test was used following the traditional ANOVA (i.e., equal variances assumed), and Tamhane's test was used following Welch's ANOVA. Pearson's correlation coefficients (r) were used to evaluate trends in habitat use among various dependent variables (e.g., trout size-classes, temperature, discharge). Chi-square contingency tests were used to detect differences between habitat variables used by trout (i.e., observed) and the availability of those variables in OCP (i.e., expected), and chi-square (x^2) test for association was used to detect differences in the distributions of two categorical variables (e.g., microhabitat type, trout size-classes, sites, temperature groups).

Stepwise discriminant analysis (DA) was performed to identify major differences in the habitat used by different trout size classes and the habitat available in OCP. Four groups were used in the analysis: 1 – small trout (ST; TL < 200 mm) habitat; 2 – medium trout (MT; 200-300 mm TL) habitat; 3 – large trout (LT; TL > 300 mm) habitat; and 4 – available habitat (OCP). Significant habitat variables absent of outliers and multicollinearity were entered in the model (i.e., current velocity, stream depth, LWD density, non-structural cover density, and substrate particle size); some variable transformations were required (i.e., velocity, depth, and non-structural cover density received a square root transformation, and LWD received a log base 10 transformation). Structure coefficients were used to interpret the importance of each discriminant function. Wilks' lambda was used to determine significance, and the variables were entered in or removed from the model (entered if $F > 3.84$; removed if $F < 2.71$). All statistical analyses were performed at a 95% confidence level (alpha = 0.05), and were performed with IBM SPSS Statistics (Version 25; IBM 2017).

4. Results

4.1. Watershed characteristics

The drainage area of the watershed upstream from OCP is 531 km^2, the basin slope is 53 m/km, and the topographic relief is 435.4 m. Mean monthly discharge during the study (2016-2017) was frequently lower than normal (i.e., discharge only exceeded historic mean in January and February 2017) (Figure 3). Similarly, precipitation during the study period remained below the historic (2000-2015) mean from March to July 2016, while the amount of precipitation in August and October 2016 was greater than usual. Precipitation levels from November 2016 through

February 2017 closely reflected historical patterns, but the amount of precipitation in March 2017 exceeded historical levels considerably (Figure 4). The discharge-stage height relationship for Oatka Creek at Garbutt (USGS 04230500) includes stage height values from 0.66 to 1.56 m and discharge values from 0.57 to 40.78 cubic meters per second (cms) (r^2 = 0.9916; n = 61) (Figure 5).

4.2. Available stream habitat

Physical stream data for all sites are presented in Table 5. The total surface area of OCP sampled was 10,840 m^2 (site range: 2,590-2,860 m^2). Average site depths ranged from 50 cm at S3 to 75 cm at S1 (OCP mean: 57 cm), while mean current velocities ranged from 27 cm/s at S1 to 43 cm/s at S3 (OCP mean: 37 cm/s). The primary microhabitat types available were pools (50% of available habitat) and runs (26%) (Table 6). Riffles and glides collectively accounted for the remaining 24% of habitat (15% and 9%, respectively). A difference in the proportion of glides, riffles, runs, and pools) was not detected among sites (P = 0.446, 0.521, 0.276, and 0.084, respectively; H (3) = 2.669, 2.257, 3.869, and 6.660, respectively; n = 100); however, S1 had a greater proportion of pools and lower proportion of glides, riffles, and runs than the other sites.

The estimated mean density of total cover available in OCP was 64% (site range: 18-95%) (Table 7). The density of non-structural cover (mean density: 48%; site range: 9-68%) was much greater than the density of structural cover (mean density: 16%; site range: 9-27%). Turbulence and concealing depths (CDs) were the most abundant cover types (mean density: 25% and 22%, respectively). Boulders were the most abundant type of structural cover, followed by UCBs, and LWD (mean densities: 12%, 1.6%, and 1.4%, respectively). Submerged aquatic vegetation (SAV) was relatively uncommon (mean density: 0.7%) and only present at S3 and S4.

Boulder size-classes were inversely correlated to the proportion of boulders available ($r = -0.9279$; $n = 3$). Small boulders accounted for 81% of the boulders available in OCP, and medium-sized boulders were more abundant than large boulders (16% and 4% of boulders available, respectively). Medium-sized LWD accounted for nearly 60% of the LWD available, while small LWD contributed another 28% and large LWD accounted for the remaining 15%.

The mean dominant substrate size score in OCP was 3.8 (Table 5). A significant difference in substrate size was detected among sites ($P = 0.012$; $H(3) = 10.998$; $n = 200$). S2 had the greatest mean substrate size, and S1 had the smallest substrate particles. Similarly, S3 and S2 had the most diverse substrate composition (i.e., largest SD), while substrates at S4 were the most homogeneous.

4.3. Trout abundance, density, and survival

A total of 100 brown trout were captured throughout the study. The most trout were captured during the F-16 ($n = 47$) and Sp-16 ($n = 33$) seasons, and the fewest were captured during Sp-17 ($n = 5$). The mean population estimate (N) in OCP during the study was 66 ± 38.2 brown trout. The greatest N estimates were reported during Sp-16 ($N = 95$) and F-16 ($N = 85$), while the lowest values were recorded in Sp-17 ($N = 10$) (Table 8). Similarly, the mean estimated trout density in OCP was 8.7 trout per km^2 (Table 9). The greatest densities in OCP were recorded in Sp-16

(11.4 trout per km^2) and W-17 (10.6 trout per km^2), while the lowest density occurred during Sp-17 (2.1 trout per km^2). Overall, the number of fish captured (n), estimated N, and density decreased as the study proceeded ($r = -0.801$, -0.906, and -0.780, respectively; $n = 4$). Similarly, apparent survival decreased over the course of the study for N ($r = -0.918$; $n = 3$) and density ($r = -0.454$; $n = 3$) (Figure 6). Recruitment did not occur between any seasons based on N (apparent survival > 1.0); however, density estimates suggest that recruitment had occurred once between F-16 and W-17 (apparent survival = 1.3).

The greatest number of trout were collected at S3 and S4 ($n = 36$ and 37, respectively), while the fewest were captured at S1 ($n = 18$) and S2 ($n = 9$). Estimates of N varied considerably among sites during each season (Figure 7). Overall, average N estimates throughout the entire study were similar for S4 ($N = 19 \pm 10.8$), S3 ($N = 14 \pm 17.3$), and S1 ($N = 13 \pm 13.0$), while estimates for S2 were considerably lower ($N = 4 \pm 3.4$). N decreased throughout the study at S1, S3, and S4 ($r = -0.902$, -0.494, and -0.936; $n = 4$), whereas a minor increasing trend was observed at S2 ($r = 0.190$; $n = 4$). Mean density estimates were greatest at S1 (13.5 trout per km^2) and lowest at S2 (1.8 trout per km^2). Density decreased over the study at S1, S3, and S4, while a slight increase was observed at S2 (Table 9).

4.4. Daily sampling conditions

Stream discharge and water temperature varied considerably among sampling dates (Table 10). Mean water temperatures ranged from 0.3 to 16.5 °C, and discharge ranged from 0.3 to 11.9 cubic meters per second (cms). Water temperature and discharge categories showed a strong inverse correlation with one another (r^2 = 0.9925; n = 3) (Figure 8). Water temperatures were classified as cold for both W-17 samples and the first Sp-17 replicate (i.e., Sp-17A), while temperatures during both Sp-16 replicates and Sp-17b were considered moderate, and both F-16 samples represented warm temperatures. Similarly, discharge was categorized as low during both F-16 replicates, moderate during both Sp-16 samples, and high during all W-17 and Sp-17 samples (Table 10).

Stream discharge showed a strong negative correlation with the estimated proportion of OCP that could be sampled each day (r^2 = 0.839; n = 8), with the estimated proportion sampled ranging from 20.9% (Sp-17b; discharge = 11.9 cms) to 94.8% (F-16; discharge = 0.3 cms) (Table 10). Trout sampling was performed on approximately 69.4% of the OCP sites throughout the duration of the study (range: 21-95%). About 95 ± 5.3% of the study area was accessible for trout sampling during low discharge conditions, while 74 ± 5.9% was sampled under normal flows, and 49 ± 24.0% was sampled during high discharge. S2 had the greatest proportion sampled throughout the study (mean: 90 ± 20.7%; range: 40-100%), and experienced relatively minor variations in the proportion sampled as discharge changed. In contrast, S1 had the smallest proportion sampled under all flow conditions (mean: 35 ± 33.0%; range: 5-80%), and showed the most dramatic decrease in the proportion sampled as discharge increased (i.e., limited area sampled during normal and high discharge). The mean proportion of S3 and S4 sampled during the study was 78 ± 25.1% for both (range: 20-100%) (Figure 9).

The greatest number of trout were captured when discharge was low (n = 47) and water temperatures were warm (n = 47). Many trout were also captured during periods of normal discharges (n = 37) and moderate temperatures (n = 34), while the fewest trout were collected when discharge was high (n = 16) and temperatures were cold (n = 19). Daily trout density (n/km^2) was positively correlated with the proportion of OCP sampled ($P = 0.021$; $r = 0.786$; $n = 8$) and negatively correlated with stream discharge ($P = 0.016$; $r = -0.804$; $n = 8$). Mean water temperature also showed a positive correlation with daily density estimates ($P = 0.036$; $r = 0.740$; $n = 8$).

4.5. Trout size classes

The brown trout captured during the study ranged from 101 to 512 mm TL (mean: 236 ± 101.5 mm TL) (Figure 10). Most of the trout were placed into the age-1, -2, and -3+ year-classes (n = 34, 33, and 25, respectively) (Figure 11). Since nearly 40% (n = 7) of the fish in the age-3+ year-class were larger than 400 mm TL, a modified year-class distribution was created by reducing the range of the age-3 class (300-400 mm TL) and adding an age-4+ class (TL > 400 mm) (Figure 12).

The small trout size class (TL < 200 mm) was represented by the greatest number of individuals (n = 42), while the large size class had the smallest number (n = 25); the medium size class accounted for the remaining 33 trout. S3 and S4 supported the greatest abundance of small trout (n = 17 and 15, respectively) and medium trout (n = 14 and 15, respectively); however, several small trout were also collected from S1 (n = 9) (Figure 13). The number of large trout captured was similar among sites (range: 5-7 individuals).

4.6. Habitat use

The average depth used by brown trout in OCP was 55 ± 25.2 cm, and the average current velocity was 14 ± 15.1 cm/s. The areas occupied by trout had significantly slower current velocities than the average available velocity in OCP (37 cm/s) ($P < 0.001$; $t\ (154) = 9.014$). A difference between mean depth used by trout and available depth (57 cm) was not detected ($P = 0.510$; $t\ (177) = 0.660$).

Trout captured during high discharge periods used water depths (mean depth: 71 cm) significantly greater than those used during low and normal discharges (mean: 53 cm and 50 cm, respectively) ($P = 0.001$; $F\ (2, 47) = 8.286$). Similarly, the depths used by trout during cold water temperatures (mean: 69 cm) were significantly greater than the depths used during moderate and warm temperatures (means: 49 and 53 cm, respectively) ($P < 0.001$; $F\ (2, 57) = 9.554$). In contrast, discharge and water temperature did not have a significant impact on the current velocities used by trout ($P = 0.147$ and 0.132, respectively); however, the lowest mean current velocities were recorded when discharge was low (11 cm/s) and temperatures were warm (11 cm/s), while the highest velocities were used when discharge was high (19 cm/s) and temperatures were cold-to-moderate (17 cm/s).

4.7. Microhabitat use

Pools and glides were the most frequently used microhabitats, accounting for 65% and 28% of the sampled trout, respectively. In contrast, only 4% of the fish were captured in riffles, while 3% utilized runs. A significant difference was detected between the proportion of glides ($P < 0.001$), riffles ($P = 0.001$), runs ($P < 0.001$), and pools ($P = 0.012$) used by trout and the proportion available (Table 11). Glides were strongly preferred by trout ($\alpha = 0.65$), while preferences for pools were slightly greater than random ($\alpha = 0.27$; random use when $\alpha = 0.25$) (Table 11). A significant difference in microhabitat use was not detected among sites ($P = 0.077$; x^2 (9) = 15.56).

There was a significant difference in microhabitat use among trout size classes ($P = 0.003$; x^2 (6) = 20.03). The average TL of trout occupying pools was significantly greater than the TL of fish using glides ($P < 0.001$; F (3, 96) = 7.811). Trout from all size classes were observed using glides (range: 4-41%) and pools (range: 45-96%) (Figure 14). In contrast, riffles were only used by small and medium trout (7% and 3%, respectively) and runs were only used by 7% of small trout. The proportion of fish from each size group using pools increased with size class (r = 0.9961; $n = 3$), while the proportion of trout using glides and riffles decreased with size class (r = -0.9691 and -0.9960, respectively; $n = 3$). Daily water temperature and discharge fluctuations did not cause significant differences in microhabitat use ($P >$ 0.250; x^2 (6) = 6.59 and 7.67, respectively).

4.8. Substrate

The average dominant substrate size used by the trout (mean score: 3.0 ± 1.84) was significantly smaller than the mean available substrate size in OCP (mean score: 3.8 ± 1.35) ($P = 0.006$; t (84) = 2.823). Sand/silt was the most frequently used substrate type (used by 80% of trout). Cobble, pebble, and gravel were also widely used (70%, 68%, and 68% of trout, respectively), while the number of fish using boulders (45%) and slate (32%) was considerably lower. Sand/silt and boulders were the most preferred substrate types (α = 0.40 and 0.28, respectively; K = 6), whereas gravel was slightly preferred (α = 0.19; K = 6). The dominant substrate size used by trout showed little variation resulting from differences in discharge (P = 0.608; F (2, 42) = 0.504), temperature (P = 0.791; F (2, 46) = 0.236), and trout size class (P = 0.347; F (2, 97) = 1.070).

4.9. Cover use

Every trout collected was associated with at least one type of cover. Roughly half of these fish (52%) were associated with two or more cover types, while 14% of all trout used three types of cover. Trout used structural cover (94% of trout used at least one type of SC) more frequently than non-structural cover (44% of trout used at least one type of NSC), despite non-structural cover being approximately than three times more abundant than structural cover (Figure 15). LWD (mean max. diameter: 34 ± 27.4 cm) and boulders (mean max. diameter: 94 ± 44.9 cm) were the most utilized cover types (i.e., used by 57% and 45% of trout collected, respectively). Both non-structural cover types (i.e., turbulence – 28%; and CDs – 19%) were used more commonly than SAV (12%) and UCBs (5%). Significant differences were detected between the proportion of trout using each structural cover type (i.e., LWD, boulders, UCBs, and SAV) and the proportion of each type available in OCP (Figure

16). LWD was the most preferred cover type in OCP (α = 0.61; K = 6), but SAV was also slightly preferred (α = 0.26) (Table 12).

The average aerial density of overhead cover used by trout in OCP was 61% (Table 12). Trout used similar densities of structural cover (38%) and non-structural cover (32%) throughout the study (P = 0.197; t (198) = 1.295). LWD and CDs provided trout with the greatest mean areal cover (mean density: 20% and 19%, respectively); however, boulders and turbulence also provided considerable amounts of cover (mean density: 16% and 14%, respectively). UCBs and SAV had the lowest cover densities (mean density: 0.8% and 1.4%, respectively). The density of available LWD, UCBs, and turbulence were significantly lower than the densities used by trout (Table 12).

A significant difference between the proportion of boulder and LWD size-classes used by trout and the proportion of each size available in OCP was detected (P < 0.001; x^2 (4) = 383.416 and 77.602, respectively). Trout showed a strong preference for large boulders (α = 0.81; K = 3) and a slight preference for medium and large LWD size classes (α = 0.40 for both; K = 3).

LWD, boulders, and turbulence were used by trout at all sites. Boulders were the most commonly used cover type used at S1, while LWD was the most frequently used cover type at S2, S3, and S4; turbulence and CDs were also commonly used at some sites (Table 13). LWD was the most preferred cover type at each site (α = 0.57-0.92), but UCBs were also favored at S1 (α = 0.26), SAV at S3 (α = 0.25), and boulders at S4 (α = 0.30); selectivity for both non-structural cover types (i.e., turbulence and CDs) was low at all sites (range: 0.01-0.03 and 0.0-0.06, respectively).

4.10. Seasonal cover use

The greatest mean densities of total cover were used by trout when discharge was high (73%) and temperatures were cold (mean density: 75%), while the lowest mean densities were used when temperatures were moderate (51%) and discharge was normal (54%) (Tables 14 and 15). The difference in total cover use was significant for temperature ($P = 0.014$; $F(2, 44) = 4.702$). Although a significant difference in the density of structural cover used by trout was not detected among the discharge or temperature categories ($P = 0.060$ and 0.374, respectively), trout used the lowest densities of structural cover when discharge was high (30%). Trout captured during periods of low discharge and warm water temperature used the lowest LWD densities (11% for both) and greatest boulder densities (22% for both). The SAV density used by trout was 3% for periods with low discharge and warm water temperature, and 1% for periods of normal discharge and moderate temperature. UCBs were only used during normal discharge periods with moderate water temperatures (2% for both) (Tables 14 and 15).

The densities of non-structural cover, turbulence, and CDs used when discharge was normal (11%, 3%, and 8% respectively) and water temperatures were moderate (15%, 4%, and 12%, respectively) were considerably lower than the densities used during the other discharge and temperature regimes. A significant difference in the densities of non-structural cover and turbulence was detected among the various discharge ($P < 0.001$ and $P = 0.009$, respectively; $H(2) = 16.113$ and 9.391, respectively; $n = 100$) and temperature ($P = 0.009$ and 0.023, respectively; $H(2) = 9.517$ and 7.544, respectively; $n = 100$) categories (Tables 14 and 15).

4.11. Cover use by size class

LWD and boulders were commonly used by all brown trout size classes (i.e., LWD used by 46-64% of size classes, and boulders used by 40-49%); however, a moderate negative correlation between trout size and the proportion of each size class using boulders was identified ($r = -0.612$; $n = 3$). Turbulence was also commonly used by small and medium trout (26% and 42%, respectively), while CDs were used by 52% of large trout. The proportion of trout in each size class using CDs was positively correlated with trout size ($r = 0.929$; $n = 3$). Overall, the proportion of trout in each size class using non-structural cover increased with trout size ($r = 0.971$; $n = 3$).

All trout size classes used medium-sized LWD most frequently (range: 56-80%). Small and medium trout also commonly used smaller LWD (used by 26% and 13%, respectively), while large trout also favored the largest LWD (27%). Similarly, the proportion of small and medium trout using each boulder size class decreased as boulder size increased ($r = -0.982$ and -0.866, respectively; $n = 3$), while the proportion of large trout using each boulder size class increased with boulder size ($r = 0.778$; $n = 3$) (Table 16).

4.12. Cover and habitat use by year-class

Age-0 (or young-of-the-year; YOY) brown trout used habitats with the shallowest depths (mean: 37 cm), slowest current velocities (mean: 9 cm/s), and largest substrate particle sizes (mean score: 3.2) (Table 17). Mean depth increases linearly as year-class increases to age-4+ (mean: 82 cm) ($r = 0.9636$; $n = 5$). Except for YOY trout, current velocity decreases linearly from age-1 (18 cm/s) to age-4+ (10 cm/s) (Table 17). The proportion of each year-class using shallow-water habitats (i.e., glides and riffles) decreased steadily as age increased (YOY used glides and riffles more than any other year-class), while the proportion of each year-class using pools increased with age (all age-4+ trout used pools) (Figure 17). Runs were the least used microhabitat type in OCP (only used by 9% of the age-1 class).

Age-4+ trout used the greatest densities of structural cover (mean: 64%), followed by YOY (mean: 52%). Age-3 and age-1 trout both used similar cover densities (means: 39% and 38% respectively), while age-2 used the lowest densities of cover (mean: 30%). The age-1 class was the only age group to use all six cover types, while YOY trout used the fewest cover types in OCP ($n = 3$). YOY trout showed the greatest preference for boulders out of all the year-classes (used by 63% of YOY trout); however, LWD and turbulence were also frequently used (Table 18). Age-1 trout were associated with LWD and UCBs more than any other year-class (used by 68% and 15% of age-1 trout, respectively), while age-2 trout showed the greatest preference for turbulence and SAV (used by 42% and 24% of age-2 trout, respectively). Age-3 and age-4+ trout both used CDs considerably more than the younger age classes; however, age-3 trout used CDs most frequently (Table 18).

4.13. Stepwise discriminant analysis

Five significant habitat variables were entered in the discriminating model (Table 19). Assumptions related to sample size were satisfied (i.e., 30 to 1 ratio of valid cases to independent variables; 25 cases in smallest group) and the covariance matrix of the canonical discriminant functions was used in the classification (i.e., separate groups) because variance-covariance matrices were not equal (i.e., Box's *M* test significant; $P < 0.001$).

Stepwise DA identified two variables (i.e., velocity and depth) to discriminate habitat features among different trout size classes and available habitat (Table 20). The first two canonical discriminant functions were used in the model, and they correctly classified 65.3% of the original grouped cases (i.e., 47.6% of small trout group, 48.5% of medium trout, 56.0% of large trout, and 96.0% of available habitat). Differences between groups explain 58.4% of the variability in the two discriminant scores ($P < 0.001$; Wilks' lambda = 0.416; x^2 (6) = 127.99). The first discriminant function accounted for 74% of the between-group variance, while the second accounted for the remaining 26% (Table 21). The first discriminant function is positively contributed by velocity and the second function is contributed positively by depth (Table 22).

Group centroids plotted against the discriminant functions indicate (1) mean available current velocities were much greater than those used by all trout groups (mean velocity similar among trout groups), and (2) large trout used areas with greater mean depths than the other three groups (mean depth similar among available depth, small trout, and medium trout) (Figure 18). Significant variables were unable to discriminate the habitat of small and medium trout. Canonical discriminant function coefficients (with constant) are provided in Table 23.

4.14. Predator densities

No mergansers were observed throughout the course of the study; however, a small northern pike (~250 mm TL) was observed in a patch of SAV located along the slow-moving margin of S4 during F-16, but it was not captured. Many smallmouth bass were captured throughout the study, especially during F-16, but they were all too small (approx. 80-150 mm TL) to be considered threats to brown trout.

5. Discussion

The primary objectives of my study were to (1) assess the quality of habitat in OCP, (2) evaluate the population dynamics (e.g., abundance, density, year-class distribution) of the OCP trout population, (3) identify important habitat features used by brown trout in Oatka Creek and evaluate the seasonal importance of each feature, and (4) apply my data to recommend potential management strategies to increase brown trout production in OCP.

5.1. Seasonal trout population changes

The overall decrease in apparent survival throughout the study suggests that mortality or emigration had occurred in OCP from Sp-16 to Sp-17. Going into the study, predation from mergansers was expected to account for most of the mortality observed; however, due to their absence (or very low densities) in OCP during the winters of 2016 and 2017, they could not be responsible for considerable trout population reductions. Although several other factors (e.g., natural mortality, electrofishing-induced mortality) may have contributed to poor survival rates in OCP, I suspect that biases associated with sampling under significantly different stream conditions explain the trout population data trends.

5.1.1. Influence of stream conditions on population estimates – Stream conditions at the time of backpack electrofishing can have considerable impacts on daily capture rates (e.g., Zalewski and Cowx 1990; Reynolds 1996). For example, the extremely high discharge and turbid water in Sp-17 yielded very few trout, and resulted in population estimates with very little validity. Therefore, it can be assumed that at least some (if not most) variation among my seasonal population estimates was due to differences in sampling conditions.

A. Influence of discharge on capture rates – Among the environmental factors that may influence daily capture rates, stream discharge (and consequently, turbidity) has the greatest impact. An overall decrease in sampling efficiency was observed when discharge increased in OCP; similar results were noted by Pierce et al. (1985). Zalewski and Cowx (1990) and Reynolds (1996) reported that lower streamflow is generally beneficial for backpack electrofishing because (1) the fish are concentrated in a few areas that are easy to identify and sample, (2) most of the study area can be sampled, (3) water clarity is enhanced (stunned fish easier to see), (4) deep water refuge is limited (electrofishing efficiency increases as water depth is reduced), (5) stunned trout are easier to net in slower currents, and (6) specific conductance is greatest (i.e., water has greatest ability to carry electrical current) since the dilution of groundwater (high ion concentration) with surface water runoff is limited.

My study supports claims of capture rates increasing as discharge drops; however, there are some disadvantages of sampling during low streamflow periods (i.e., capture efficiency display bell-shaped, unimodal distributions with discharge). For example, low flows likely allow trout to detect threats (and consequently flee) much earlier since cues (e.g., vibrations, noise, shadows) released by potential predators are not as likely to be masked by current or turbidity. Suitable habitat can also become very limited during low discharge periods (Zorn and Seelbach 1995), resulting in higher fish concentrations in favorable habitats. During this study, shocking these highly productive areas were overwhelming to a single netter (i.e., multiple fish stunned at once), which allowed most trout to escape before being captured. Additionally, low streamflow reduces salmonid migration (Solomon 1978; Brenkman et al. 2001), which may be a result of limited interconnected deep-water habitats (i.e., leaving safety of deep water refuge exposes trout to natural predators). Although limiting migration does not necessarily influence capture rates, it increases the likelihood of a marked trout to be recaptured, which can have a considerable effect when calculating N (i.e., N decreases as the number of recaptures increases).

B. Influence of discharge on estimated N - Since the number of recaptures in F-16 (low discharge; most trout captured) was three times greater than Sp-16 (normal discharge), N estimates for Sp-16 surpassed those of F-16. The large number of recaptures in F-16 can be accredited to migration being limited by low streamflow because the modified Chapman-Petersen equation uses R (i.e., number of recaptures) to standardize samples of different sizes by placing R in the denominator.

In contrast, the absence of recaptures in W-17 resulted in N estimates to be inflated considerably (i.e., small denominator). Although capture rates in Sp-16 and F-16 were more than two and three times greater than those in W-17, respectively, the absence of recaptures in W-17 greatly reduced the denominator and yielded an inflated N estimate that was only slightly lower than Sp-16 and F-16 estimates. The absence of recaptures in W-17 can be attributed to the abundance of suitable habitat and ability to migrate with ease. Although N provided a valuable way to standardize population estimates recorded in considerably different discharge conditions, estimates derived from data recorded during Sp-17 likely were inaccurate since few trout were captured.

C. Influence of discharge on density estimates - Discharge can have additional influences on trout density estimates. Since density estimates compensate for the proportion of the site sampled, seasons with higher discharge (and a smaller proportion of the site sampled) density may be overestimated (assuming sampling was performed during reasonable stream conditions; i.e., does not apply to Sp-17). For example, capture rates in W-17 were low relative to Sp-16 and F-16; however, density estimates in W-17 exceeded those of F-16 and were slightly lower than Sp-16 estimates. Since swift currents associated with high discharge events makes for difficult wading, sampling effort was focused around stream banks, slow-water habitats, and current breaks (generally created by structural cover) – all of which are considered ideal trout habitat during high streamflow. In contrast, density in seasons with low discharge may be underestimated since most (if not all) of the site was sampled, but there was no compensation for the vast amount of unproductive stream habitat. Nonetheless, estimating density based on N and sampling effort was useful because it provided a way to standardize the estimates under various flow regimes; however, estimates based on the area of productive trout habitat sampled (rather than total area sampled) would be an improvement.

D. Influence of discharge on apparent survival - Assessments of seasonal survival in OCP provided little value since sampling was performed under such different stream conditions. Without two seasons sharing similar stream discharges, comparisons of population estimates cannot be made with any validity as the estimates recorded during both high and low discharge events are subject to their own unique biases. It is clear, however, that the general decreasing trends (which suggest mortality or emigration was occurring) observed throughout the study resulted from Sp-16 being the first sampling season (i.e., most favorable sampling conditions; greatest and most accurate N and density estimates) and Sp-17 being the last season (i.e., poorest conditions and estimates). At least one more seasonal population estimate would need to be recorded (preferably at a normal discharge level) to assess trout survival trends in OCP in the years following the winter merganser invasions.

All in all, the results in this section provide abundant evidence that discharge conditions can have a greater influence on estimated population metrics than the actual population size, especially during extreme events. Although some measures can be taken to compensate for certain biases, some uncertainty will always exist. Since sampling biases exist for both high and low discharge events, the most accurate OCP trout population estimates were recorded in Sp-16 (i.e., normal discharge level). These estimates could provide valuable data to future researchers or management agencies interested in tracking long-term brown trout population trends in OCP; estimates from F-16 and W-17 may also be useful if additional sampling was performed under a similar range of conditions.

E. Influence of temperature on population estimates – The inverse correlation between discharge and water temperature was likely responsible for the correlation between water temperature and capture rates throughout this study. Although water temperature can influence capture rates by modifying (1) specific conductance of the water, (2) the metabolism of the fish (i.e., influence ability to detect and escape threats), (3) floatation rate of immobilized fish, and (4) habitat use (e.g., cold temperatures may encourage use of deep pools with slow currents = low electrofishing efficiency) (Zalewski and Cowx 1990), the influence of water temperature in the scope of this study is expected to be minor as its influences were largely overshadowed by the extreme variability of discharge (and consequently, turbidity). Ultimately, more sampling would be required under a broader range of stream conditions to understand fully the influence that temperature has on capture rates in OCP.

5.1.2. Additional factors influencing population estimates – The sampling biases associated with data collection under variable stream conditions appear to account for most seasonal population trends; however, some mortality may still have occurred in OCP during my study. This section will consider alternative factors – such as natural mortality associated with extreme environmental events, electrofishing-induced mortality, and sampling design – as potential sources of population decline throughout the study period.

A. Natural mortality – Discharge levels in OCP during summer 2016 (i.e., period separating Sp-16 and F-16) were considerably lower than normal, and a decrease in apparent survival was observed over this period. Increased competition or predation resulting from major reductions in the availability of suitable habitat may have elevated mortality rates from Sp-16 to F-16. The significant reduction in the abundance of small trout following the period of low discharge (i.e., F-16) supports this theory because small trout are most likely to be excluded from suitable habitats or preyed upon by larger trout (Bohlin 1977).

Insufficient dissolved oxygen levels resulting from the combination of low streamflow and warm summer temperatures may also account for some mortality from Sp-16 to F-16. Streams experiencing low streamflow throughout the summer are prone to more rapid and extreme water temperature increases, which consequently reduce dissolved oxygen concentrations in the stream, while also increasing dissolved oxygen requirements for trout (Raleigh et al. 1986). Additionally, Hansen (1975) suggested that streams with high groundwater contributions low in oxygen, such as

OCP during low discharge events, are even more likely to experience oxygen levels unsuitable for trout during periods of warm temperatures. Insufficient oxygen levels (coupled with warm water temperatures) have the potential to increase trout mortality rates considerably (Raleigh et al. 1986; Armstrong et al. 2003). Unfortunately, since water chemistry data were not collected, the severity (or likelihood) of such factors could not be assessed. Future researchers and management agencies should be aware of the potentially detrimental effects associated with these conditions in OCP and should be prepared to collect water chemistry data if (or when) similar events are repeated.

B. Electrofishing-induced mortality – Electrofishing is a highly invasive sampling method. Although many studies overlook the significance of electrofishing-induced harm (since most fish appear normal upon release), captured fish are prone to injuries (e.g., hemorrhages and spinal column separation) and stress that can considerably reduce survival (e.g., more vulnerable to predation, less competitive, unable to feed, reduced long-term growth rates) (Schreck et al. 1976; Mesa and Schreck 1989; Reynolds 1996; Thompson et al. 1997; Snyder 2003). Mortality (usually via respiratory failure) can also occur within hours after being captured (Reynolds 1996).

Accounts of electrofishing-induced injury (and potential mortality) were documented throughout the study. Despite efforts to limit stress, survival appeared unlikely for at least two trout released during the study (i.e., little to no operculum or body movement, unable to swim). Branding (i.e., dark spot resulting from internal hemorrhaging or fractures; generally non-lethal) was also commonly observed on captured fish. A few trout recaptured from previous seasons also appeared much skinnier than normal – similar accounts of reduced long-term growth rates were reported by Thompson et al. (1997). Additionally, Reynolds (1996) and Snyder (2003) insisted that it can be assumed other trout appearing normal upon release died later from electrofishing-induced injuries or stress.

Although the severity of electrofishing-induced damage throughout this study is uncertain, future researchers are urged to use electrofishing sparingly in OCP, as less invasive sampling methods are available (e.g., snorkel surveys, creel surveys). If electrofishing is necessary, precautions should be taken to minimize damage to the fish (e.g., use DC and limit field intensity and duration of exposure; Snyder 2003).

C. Sampling procedures – Sampling procedures may also be responsible for some inaccurate N (and, consequently, trout density) estimates. For example, the depletion method may have provided more accurate N estimates but was not practical for this study since (1) stream flows in OCP are too great for block nets to be employed, (2) handling and caring for nets would be difficult in the winter (i.e., freezing nets), and (3) the disturbance of multiple-pass depletions would cause fish constantly to move around the sample area, which would have prevented useful habitat data from being recorded.

D. Mark-recapture assumptions – Accurate population estimates from mark-recapture studies require that several assumptions be satisfied (Lockwood and

Schneider 2000). Many of these assumptions are often violated in real-world applications, and were likely not entirely satisfied during my study:

• *Mortality rates for marked and unmarked trout are equal* – This assumption was violated since electrofishing was used, which made marked fish more susceptible to mortality (Reynolds 1996; Snyder 2003).

• *Capture vulnerability for marked and unmarked trout is equal* – This assumption was likely violated since fish previously exposed to electrofishing may be more vulnerable (Grinstead and Wright 1973) or less vulnerable (Cross and Stott 1975) to recapture.

• *Marks are retained and recognizable during the sampling period* – This assumption was satisfied since marks from previous seasons were observed on several trout.

• *Random mixing occurs among marked and unmarked trout* – This assumption may have been violated since trout exposed to electrofishing may be more likely to emigrate to avoid future disturbance. It is also possible that habitat segregation between marked and unmarked trout may also occur if electrofishing-induced injuries reduce the ability of a marked trout to defend its territory or alter the habitat preferences of the trout to cope with injuries.

• *Emigration or immigration during the recapture period is negligible* – This assumption is more difficult to assess than the others; however, it is likely that it was violated at some point throughout the study, especially during the Sp-16 and Sp-17 seasons since trout were being stocked in the reaches surrounding OCP.

5.1.3. Trout population estimates by site – Site comparisons of trout capture rates and population estimates for a given day provide insight about the relative abundance of suitable trout habitat within each site for the environmental conditions at the time of sampling. It can be assumed that the sites consistently ranked among the most productive (i.e., S1 and S4) offered the greatest habitat diversity since suitable trout habitat was available under a broad range of stream conditions. Such sites were characterized as having abundant structural cover (i.e., S1 had the greatest boulder density; S4 had the greatest LWD density of all the sites), variable depth throughout stream channel, and little exposed bedrock (i.e., slate).

In contrast, S2 and S3 generally had the lowest capture rates; however, both sites provided important habitat during extreme discharge conditions (i.e., S2 provided refuge during high streamflow; S3 provided refuge during low streamflow). Limited capture of brown trout under most stream conditions suggests that S2 and S3 had relatively low habitat diversity, since suitable habitat was only available under a narrow range of conditions. I suspect that the greater abundance of slate substrate and lower structural cover densities (and complexity) account for the limited use. Similar results of salmonid abundance increasing with cover availability and complexity have previously been reported (e.g., Tschaplinski and Hartman 1983; McMahon and Hartman 1989). Nonetheless, S2 and S3 are unique habitats that increase the overall diversity of OCP and provide valuable refuges for trout during adverse environmental events.

Site density estimates were determined by habitat quality in the proportion of each site sampled. A major assumption of estimating density in this study was that the habitat quality of the proportion of the site sampled reflects the habitat quality of the entire site; however, it is likely that this assumption was frequently violated. For example, it was only possible to sample about 5% of S1 during some high discharge periods, but the quality of habitat in that small proportion of the site was likely considerably greater than the remaining site area (i.e., shallower, slower currents, greater cover densities, located along banks). Therefore, it can be assumed that density estimates under such conditions would have been overestimated.

5.2. Length-frequency and size class distributions

The length-frequency and year-class distributions for the study seem normal, other than the lack of YOY trout. Low capture rates of smaller fish are likely due to sampling biases rather than low abundance, as electrofishing is considered a size-specific sampling method. Length-frequency data derived from electrofishing samples must be regarded with caution, especially when considering the relative abundance of small fish, since capture vulnerability increases with body size. Zalewski and Cowx (1990) and Reynolds (1996) reported that larger fish are more prone to capture because they have a greater total body voltage, are more visible to netters, and are more territorial and predatory (i.e., less likely to abandon territory if threat detected).

Additionally, many YOY trout were also observed throughout the study but could not be captured due to their preference for complex habitats with dense structural cover (e.g., boulders, woody debris, UCBs) located along swift currents. Therefore, many of the smaller immobilized fish remained protected in dense cover or quickly drifted downstream with the fast current. Reynolds (1996) suggested that many other small trout were likely immobilized but not observed, as YOY are known to remain hidden in dense cover rather than rising. Unfavorable sampling conditions during W-17 and Sp-17 (i.e., high turbidity and discharge) further reduced the likelihood of providing accurate relative abundance estimates of juvenile trout, as poor visibility made detecting and capturing stunned YOY trout difficult.

Length-frequency distributions of harvestable-sized fish are, however, considered fairly accurate by Reynolds (1996). The data collected during this study show a relatively normal mean year-class distribution of age-1, -2, and -3+ trout (i.e., mean frequency decreases from age-1 to age-2, then increases slightly to age-3+); the distribution shows a linear frequency decrease as age class increases when the age-4+ year-class is included. Comparing mean year-class distributions of larger brown trout (>age-1) that were recorded during this study to those reported in OCP before (2003) and after (2015-2016) merganser predation (Figure 19; provided by M. Sanderson, NYSDEC, Personal Communication; one pass of electrofishing used in autumn), it is apparent that my data more closely resembles the pre-merganser distribution, which likely indicates that the trout population is recovering. The greater abundance of age-3+ (and age-4+) trout may also suggest that trout can reach greater sizes in OCP at lower trout densities (i.e., greater resource availability and reduced competition maximize growth rates).

5.2.1. Site size class distributions – The abundance of a given trout size class at a site is determined by the availability of quality habitat required by that specific size class. For example, the limited abundance of small trout at S2 indicates the lack of structural cover, depth and velocity variation, and non-slate substrate (i.e., limited habitat diversity and complexity) provides habitat not suitable for smaller individuals. On the other hand, S1, S3, and S4 all provided suitable small trout habitat because they all had abundant structural complexity located along swift-to-moderate current velocities with substrates composed primarily of larger pebbles and cobble.

In contrast, the frequency of large trout captured was similar among the four sites. This uniform distribution of large trout may suggest that habitat requirements of brown trout become less strict as body size increases and/or mobility increases – both of which may be attributed to a decrease in the number of potential predators. Shetter (1968) and Clapp et al. (1990) reported an increase in mobility and home-range size as brown trout size increased. The greater mobility of large trout can account for the increased abundance of large trout at S2 (which normally provides poor habitat quality with limited complexity) during high discharge events, since larger individuals can readily move among stream reaches as habitat suitability changes with streamflow. Since large stream-dwelling brown trout are piscivores (Clapp et al. 1990) and large trout habitat is abundant throughout OCP (i.e., slow, deep pools), they can occupy a greater range of habitat types because they can spend less time foraging (i.e., feeding frequency reduced as the size of prey increases) and do not have to be limited to complex habitats for food (aquatic macroinvertebrate) production like small trout, which are primarily stationary drift-feeders.

5.3. Important habitat features

Velocity refuges and structural cover were the primary factors determining brown trout habitat selection in OCP during the autumn, winter, and spring. Similar habitat preferences were described by Cunjak and Power (1987) and Heggenes et al. (1993). Many trout used current breaks on the downstream side of structural cover in areas with moderate-to-swift currents. Such areas are favored by trout because they provide an abundant supply of food without the energetic costs of maintaining position in fast currents.

Although the proportion of all structural cover types commonly used by trout is significantly greater than the proportion available in OCP, LWD was the most favored cover type. Similar observations were made by Tschaplinski and Hartman (1983) and McMahon and Hartman (1989), as a strong correlation between the volume of woody debris and the abundance of overwintering salmonids was reported. Boulders are also important for trout in OCP, especially during low streamflow, because they provide cover in deeper midstream channels during times when many cover types associated with stream margins (i.e., LWD) become too shallow for trout to occupy. Trout also favored SAV during F-16 (i.e., low discharge and warm temperatures; greatest SAV densities). It is likely that SAV also provides an important cover source throughout most of the summer as well, especially during low streamflow periods because, like boulders, it is commonly located along deeper midstream channels. Similar observations regarding the seasonal importance of SAV were reported by Vehanen et al. (2000).

In contrast, non-structural cover use in OCP reflected its availability in the environment (highly abundant throughout OCP); however, turbulence preference may increase during low discharge conditions (i.e., turbulence may also provide critical cover during warm periods throughout the summer as dissolved oxygen becomes limited and metabolism peaks). Although overlooked in this study, shade appeared to provide a critical cover source in OCP on sunny days, especially during periods of low streamflow (i.e., F-16). Shade (when combined with suitable current velocities and complex structural cover) was considered a critical factor for habitat selection for stream-dwelling salmonids by Hartman (1963), Raleigh et al. (1986), and McMahon and Hartman (1989).

Differences in mean depths and velocities used by trout under different flow regimes reflect changes in habitat availability (i.e., greater depths and velocities used as discharge increases); similar patterns were reported by McMahon and Hartman (1989) and Mäki-Petäys et al. (1997). As water temperatures drop, stream-dwelling brown trout typically become more cover-oriented and prefer habitats with greater depths and slower currents (e.g., Hartman 1963; Tschaplinski and Hartman 1983; Cunjak and Power 1986; Raleigh et al. 1986); however, the extent to which water temperature influenced habitat use in OCP could not be understood fully, as extreme discharge variations (coupled with the strong temperature-discharge correlation) masked minor water temperature differences. Ultimately, more research would be required to understand fully the extent that temperature influences habitat selection in OCP.

The importance of some habitat types may not have been well-represented due to the sampling biases associated with some areas. For example, deeper pools (i.e., CDs) with slow currents are commonly considered a primary habitat for brown trout during the winter months; however, the importance of such habitats was considerably underestimated because the efficiency of backpack electrofishing in such environments is poor (e.g., limited efficiency in deep water, slow current allows for early detection by fish, wading difficult or impossible). Similarly, the number of trout using UCBs was also underestimated. Several small trout (age-0) using UCBs were observed but could not be collected because the high habitat complexity never allowed the immobilized trout to expose itself (i.e., remained in safety of cover).

5.3.1. Substrate – The average substrate particle size commonly used by trout is smaller than the mean size available in OCP; however, this difference can be explained by trout selecting slow-water habitats (i.e., areas that accumulate small substrate particles, which have lowest ranked score) and avoiding areas dominated by slate or bedrock (i.e., substrate type with the greatest score). Although substrate composition influences habitat selection at times (e.g., gravel required for spawning; boulders provide critical low streamflow cover), little evidence suggesting that substrate had a considerable influence on habitat use was observed throughout the study, except for slate being avoided.

5.3.2. Spawning habitat – Brief spawning surveys were performed in F-16 (i.e., brown trout spawn in the autumn) by looking for redds while electrofishing. Although no redds were observed, it is likely that spawning had not started at the time sampling was conducted. Raleigh et al. (1986) supports the theory that spawning began after F-16 sampling was complete, since autumn flow rates had not yet increased and water temperatures were too warm (i.e., spawning initiated as temperatures drop below 9 ºC). Nonetheless, reports of OCP historically supporting a thriving wild brown population (e.g., Tatakis 2002; Sanderson 2007) and the presence of YOY trout during this study indicate that successful spawning (and recruitment) occurs in OCP.

5.4. Size-specific habitat preferences

Several size-specific habitat preferences were observed in OCP. As trout increase in size, their preference for deeper habitats with slower currents (and consequently, smaller substrate particles) also increased; such trends are common in stream-dwelling brown trout populations (e.g., Raleigh et al. 1986; Ayllón et al. 2010). The shift of large trout into deeper habitats resulted in a notable increase in non-structural cover use (i.e., CDs), despite small and medium trout accounting for most recorded turbulence use, which is the other non-structural cover type. The greater use of turbulence observed in the smaller trout size classes may simply be a by-product of these trout preferring shallower habitats with course substrates and/or swifter currents.

Structural cover (primarily LWD and boulders) remained important for all trout size classes, and the size of structural cover used appeared to be proportional to trout body size (i.e., largest fish used largest boulders and LWD). Using structures proportionate to body size ensures that the trout have adequate cover while remaining small enough to prevent potential predators from entering. The frequent and consistent use of LWD among all trout size classes suggests high density LWD complexes may provide the most valuable type of cover in OCP (i.e., LWD is widely available throughout OCP in a wide range of habitat types and configurations). The strong preference for boulders displayed by the smallest and largest trout (i.e., age-0 and age-4+) indicate that boulders can also provide high-quality cover; however, the overall decreasing trend in boulder use as trout size increases may suggest the availability of boulders capable of providing sufficient cover for larger trout in their desired habitat may be limited in OCP.

The microhabitats used by small trout are much less specific than those of larger trout. Small trout used the greatest range of cover and microhabitat types (despite favoring glides), while large trout appeared to select habitat primarily based on stream depth and velocity (i.e., use pools nearly exclusively). The significance of depth for providing suitable large trout habitat was emphasized by being isolated as a discriminating variable. In contrast, the lack of a discriminating factor for small- and medium-sized trout indicates that both size classes use similar habitats. Although increasing the sample size or adding additional variables into the analysis may help isolate the group centroids, a distinguishing habitat feature may not exist. Ayllón et al. (2010) reported that overlapping cohort niches (such as those observed between small and medium trout in OCP) may occur more frequently in smaller streams with limited habitat diversity. In contrast, Bohlin (1977) reported that different cohorts of brown trout had similar habitat preferences, but size segregation occurred because smaller individuals were excluded by larger fish. According to this hypothesis, similar habitat preferences for small- and medium-sized trout in OCP may be due to low fish densities. Additional research would be required to evaluate the extent (and potential cause) of overlapping cohort niches in OCP. If a niche overlap is identified and expected to be due to limited habitat diversity (as suggested by Ayllón et al. 2010), habitat manipulations focused on increasing diversity are recommended.

<u>5.4.1. YOY trout habitat</u> – The habitat preferences of YOY trout in OCP (i.e., shallow-water habitats with slower currents, course substrate particles, turbulence, and high structural cover densities – especially boulders and LWD) were similar to those published by Tschaplinski and Hartman (1983), McMahon and Hartman (1989), and Mitro and Zale (2002). Previous studies (e.g., Hartman 1963; Raleigh et al. 1986; Heggenes 1988; McMahon and Hartman 1989) reported that YOY salmonid production and survival increases with habitat complexity and cover density and diversity. Similarly, the importance of small interstitial spaces of course substrates as YOY trout habitat (especially during the winter) has been well-documented (e.g., Heggenes 1988; Maki-Petäys et al. 1997; Mitro and Zale 2002; Ayllón et al. 2010).

It was interesting that very few YOY trout were observed using SAV, which Mitro and Zale (2002) considered a major cover type for YOY salmonids during the summer and autumn. I suspect that the low discharge conditions throughout the summer limited habitat availability in OCP, which may have caused YOY trout to be excluded from higher quality habitats or experience greater predation rates from larger trout. Based on this hypothesis, it is likely that SAV provides critical cover to YOY trout in OCP under normal summer discharge conditions.

5.5. Conclusions

5.5.1. Trout abundance and year-class distributions – Despite the absence of mergansers, apparent survival according to all trout abundance indices showed decreasing trends as the study proceeded. Differences in sampling conditions, especially discharge, appear to explain most seasonal variation; however, other factors (e.g., electrofishing-induced mortality) may also account for some survival reductions. The length-frequency distribution showed that the number of YOY trout was much lower than expected; however, the size-selective nature of electrofishing, along with YOY affinity for highly complex habitats, is likely responsible. Except for YOY trout (which were not well-represented due to the limited efficiency of electrofishing on small trout), the OCP population is showing signs of recovery, as the year-class distribution resembles the pre-merganser distributions reported by NYSDEC. The population likely will continue to recover if mergansers remain absent from OCP. Although the OCP trout population has not yet returned to pre-merganser densities, the greater availability of resources may allow trout to reach greater sizes (e.g., high relative abundance of fish 400-520 mm) in the short-term.

5.5.2. Important habitat features – Current velocity refuges and the presence of structural cover (especially LWD and boulders) were the most important habitat features for trout. Deep-water habitats with slow currents were also important for large trout, while complex, shallow-water habitats with course substrates (e.g., cobble and small boulders) and slow currents were important for YOY trout. LWD was the most preferred cover type for the trout in OCP (the size of LWD used was correlated to body size), while the complexity of LWD (and the associated habitat) was inversely correlated to body size (i.e., smallest fish used most complex habitats). Boulders were also highly favored by some year-classes (especially by YOY and age-4+ trout), but the availability of boulders capable of providing sufficient cover may have been limited in suitable habitats. Midstream structures (i.e., boulders and SAV) located along deeper channels provide valuable cover for trout during low discharge periods, since many of the cover types associated with stream margins (e.g., LWD) become too shallow for trout to occupy. Current refuges located along moderate-to-fast currents were favored by trout, as they provided abundant food access without the energetic costs of maintaining position in swift currents – these slower pockets were typically created by structural cover or irregularities in the bank (i.e., seams and eddies). Overall, areas of OCP with the greatest habitat diversity and complexity provided habitat for the greatest number of trout; however, stream reaches that initially appeared unproductive provided critical refuge during periods with extreme stream conditions.

5.5.3. Availability of quality trout habitat – Quality trout habitat appears to be abundant throughout OCP; however, some sections have considerably greater potential based on the range of habitat diversity and complexity. The availability of quality habitat varies with environmental conditions (e.g., discharge, temperature), and sites with greater diversity offer the most suitable habitat under a broad range of conditions. Given that significant habitat changes have not occurred in years leading up to the dramatic population reductions in OCP, it is apparent that the stream habitat is more than capable of supporting a healthy wild trout population. During extreme winter conditions, however, complex habitats that would provide protection from endothermic predators may be limited – additional research is required to identify the specific habitat characteristics that promote winter trout survival while mergansers are present in OCP. Furthermore, evidence that habitat diversity in OCP could be improved was provided by cohort niche overlaps, but low fish densities may also be responsible. Although additional research is required to validate these hypotheses, habitat manipulations that increase habitat diversity would likely benefit the OCP trout population (e.g., reduce competition, increase carrying capacity).

5.6. Future research

5.6.1. Estimate population metrics during normal discharge – Since sampling was only performed once during normal streamflow conditions (i.e., Sp-16), additional samples should be taken and used to estimate population metrics. These data could then be used to evaluate long-term population trends (e.g., survival) in OCP without the biases associated with extreme discharge. Such information would provide necessary baseline data for any habitat manipulations that may be conducted in OCP.

5.6.2. Habitat use under a broad range of conditions – The strong correlation between discharge and temperature made it impossible to distinguish which habitat-use patterns were due to discharge, temperature, or a combination of both. Although it can be assumed that discharge was the primary force dictating habitat use (due to the extreme range of conditions in which sampling was performed), sampling would need to be conducted under a variety of conditions before definitive conclusions could be drawn. Determining habitat use is important during periods of low discharge and cold temperatures, as such conditions are relatively common during the winter and would produce the most severe merganser predation rates.

Additional sampling could also be used to determine if habitat diversity in OCP is limited (as suggested by overlapping cohort niches). If future results conclude that habitat diversity is limited in OCP, habitat manipulations (i.e., addition of structural cover) should be implemented. Future research should also examine water chemistry data (i.e., dissolved oxygen and temperature) during warm summers characterized by low streamflow to determine if such factors may be responsible for additional mortality. If warm temperatures and low dissolved oxygen levels are observed in OCP, suitable actions should be used to reduce the severity of such conditions (e.g., increase density of canopy cover by planting trees in upstream reaches).

5.6.3. Habitat use during merganser predation – Given that mergansers were absent from OCP over the course of the study, the influence of predation on habitat and cover use during the winter could not be assessed. Although previous research has shown that fish move to more structurally complex habitats to avoid predation (Savino and Stein 1982), the extent may vary among streams and trout populations. Understanding preferred trout habitat under such conditions would provide insight regarding which habitats provide the best protection from avian predators. Once the characteristics of favorable habitat types are understood, habitat manipulation projects could be performed to maximize the abundance of such habitat throughout OCP.

5.6.4. Overwinter merganser predation rate – Knowledge of merganser predation rates and favored trout year-classes in OCP could be useful for designing habitat manipulation projects to reduce predation (i.e., increase habitat for at risk cohorts). Evaluations would be based on merganser abundance, foraging patterns, and stomach content analysis. Such information could also be used to provide baseline data for evaluating the effectiveness of various bird deterrents in OCP (e.g., reflective tapes, noise makers, predator decoys). Although many of these deterrents may reduce aesthetic value in OCP during the winter, they may serve as a useful and non-lethal management approach to reduce trout predation throughout the winter.

5.7. Management recommendations

5.7.1. Increase habitat diversity with habitat manipulations – Although habitat quality is not believed to be a major limiting in OCP (under most conditions), increasing the availability of complex, diverse habitats with cover throughout OCP would help reduce merganser predation on small- and medium-sized trout (TL < 300 mm). Habitat manipulations should focus on creating and enhancing complex habitats for smaller fish because they are the preferred prey of mergansers. Increasing the abundance of habitat available for small and medium trout may also increase survival rates by reducing competition. Efforts should focus on increasing the abundance of complex LWD and boulder structures throughout diverse reaches of the stream (i.e., variable depth, velocity, and substrate composition). Areas with primarily slate substrates should be avoided as the trout in OCP rarely use such habitats due to their limited habitat complexity and food/macroinvertebrate production. Attempts to increase the abundance of YOY trout habitat should focus on enhancing riffle-glide areas with course substrates by adding complex patches of smaller diameter LWD along the stream margin or creating cobble-boulder complexes. The dead ash trees throughout OCP could provide a cost-effective approach to obtaining the LWD. Adding boulders along deeper midstream channels would also be beneficial for increasing habitat diversity and cover availability for trout of all sizes during low discharge events.

If funding is available, it may also be beneficial to construct structures in some less productive areas of OCP. Rosi-Marshall et al. (2006) reported a three-fold increase in the relative abundance of harvestable trout (TL > 250 mm) following the construction of skybooms (which imitate UCB structures; Figure 20) in a small Michigan stream. I recommend that these structures be built in relatively unproductive areas of OCP (e.g., S2 = little depth variation and available cover) because they enhance habitat complexity and diversity (e.g., cover, water depth variation) and promote the retention of woody debris and other organic matter (i.e., reduce transport distance and increase food availability). Although only a few trout were observed using UCBs throughout this study, high quality UCBs are limited in OCP (i.e., only 5.4% of UCBs in OCP have depths greater than 30 cm, and 1.2% have depths greater than 50 cm).

Ultimately, the success of habitat manipulation projects in OCP should be measured by the abundance of small trout (i.e., YOY and age-1); however, trout size-class distributions (i.e., abundance of large trout) and aquatic macroinvertebrate community diversity and abundance should also be monitored. Habitat modifications should only be made at a few areas initially; monitoring and adaptive management should then determine if, and where, additional manipulations should be performed.

<u>5.7.2. Continue current special regulations in OCP</u> – Management agencies should avoid releasing additional hatchery-reared trout in and around OCP during periods of low abundance (i.e., maintain pre-merganser stocking levels), as doing so may reduce the survival and recruitment of wild fish (e.g., degrade wild gene pool, increase competition). Wild trout provide many advantages over their hatchery-reared counterparts (e.g., greater fitness and survival, more resistant to environmental changes, less vulnerable to predation), and since streams capable of supporting wild trout are rare in the eastern United States, OCP should be embraced for being a special resource. Although the trout population will be slower to recover without additional stocking, a more sustainable and genetically diverse population that is

well-adapted to their environment will ultimately emerge. Additionally, as stocking intensity is reduced, more funding will be available for habitat enhancements and monitoring programs.

5.7.3. Continue monitoring – The trout population should continue to be monitored for several years to identify any major changes in abundance (high frequency sampling not required). Less invasive surveying techniques (e.g., snorkel and creel surveys) are recommended, and electrofishing should be used sparingly to limit unnecessary injury and mortality. Aquatic macroinvertebrate sampling may also be useful for monitoring water quality (i.e., reduce potential variables that account for trout population decline). Less invasive trout sampling procedures and invertebrate sampling are also beneficial because they can be performed by public volunteers with little training (e.g., local schools or conservation groups).

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Tables

Table 1. Substrate classification and measurement system (modified from Cummins 1962).

#	Type	Diameter (mm)
1	Sand/silt	< 2
2	Gravel	2-16
3	Pebble	17-64
4	Cobble	65-250
5	Boulder	>250
6	Slate	-

Table 2. Turbulence classification and measurement system (Stevenson and Bain 1999).

#	Classification	Broken water surface (%)
1	Negligible	< 5
2	Little	5-10
3	Minor	11-40
4	Substantial	41-70
5	Extensive	>70

Table 3. Large woody debris (LWD) and boulder size-classes based on maximum diameter (modified from Stevenson and Bain 1999).

Cover type	Size class		
	Small	***Medium***	***Large***
LWD	5-10 cm	11-50 cm	>50 cm
Boulder	25-75 cm	76-125 cm	>125 cm

Table 4. Additional measurements for each cover type present in a 1 m radius surrounding the point of trout capture. The number in parentheses following each measurement represents the number of replicates recorded.

Cover type	Measurement
Undercut bank (UCB)	Bank depth (3)
Large woody debris (LWD)	Stream depth (3) Current velocity (3) Max. diameter (1)
Boulders	Stream depth (3) Current velocity (3) Max. diameter (1)
Submerged aquatic vegetation (SAV)	Stream depth (3) Current velocity (3)

Table 5. Mean (SD) stream data available at each site (S1-S4) and overall in Oatka Creek Park (OCP) in Garbutt, Monroe County, New York. Data recorded at discharge of 4.06 cubic meters per second (cms).

Parameter	Site				OCP
	S1	***S2***	***S3***	***S4***	
Depth (cm)	75 (17.6)	52 (13.1)	50 (22.6)	52 (21.3)	57 (21.5)
Velocity (cm/s)	27 (13.1)	40 (13.9)	43 (19.2)	38 (21.4)	37 (18.1)
Width (m)	28.0 (1.44)	25.9 (1.79)	28.6 (6.21)	25.9 (1.87)	27.1 (3.40)
Area (km^2)	2.8 (0.14)	2.6 (0.18)	2.9 (0.62)	2.6 (0.19)	10.8 (0.69)
Substrate (score)	3.3 (1.07)	4.6 (1.40)	4.0 (1.46)	3.6 (0.95)	3.8 (1.35)

Table 6. Mean proportion (SD) of microhabitat available at each site (S1-S4) and overall in Oatka Creek Park (OCP) in Garbutt, Monroe County, New York. Data recorded at discharge of 4.06 cubic meters per second (cms).

Habitat type (%)	Site				OCP
	S1	***S2***	***S3***	***S4***	
Glide	1 (2.2)	12 (11.0)	8 (11.0)	16 (16.7)	9 (12.0)
Riffle	1 (2.2)	16 (26.1)	32 (33.5)	12 (17.9)	15 (24.0)
Run	11 (17.5)	36 (21.9)	24 (21.9)	32 (22.8)	26 (21.7)
Pool	87 (18.6)	36 (35.8)	36 (29.7)	40 (37.4)	50 (36.2)

Table 7. Mean density (SD) of available cover at each site (S1-S4) and overall in Oatka Creek Park (OCP) in Garbutt, Monroe County, New York (LWD = large woody debris, SAV = submerged aquatic vegetation, UCB = undercut bank, and CD = concealing depth).

Cover type	**Site**				**OCP**
	S1	***S2***	***S3***	***S4***	
Structural	27 (17.6)	9 (5.1)	11 (5.2)	14 (6.9)	16 (12.6)
LWD	1.1 (1.1)	1.0 (0.9)	0.6 (0.9)	2.9 (3.2)	1.4 (1.9)
Boulder	25 (17.5)	6 (4.8)	8 (4.7)	7 (5.7)	12 (12.3)
SAV	0	0	0.9 (0.8)	1.9 (1.9)	0.7 (1.3)
UCB	1.2 (1.5)	2.2 (1.4)	1.3 (1.8)	1.7 (1.2)	1.6 (1.4)
Non-structural	68 (54.1)	9 (10.4)	61 (30.8)	52 (36.1)	48 (40.8)
Turbulence	20 (28.4)	5 (5.4)	41 (18.6)	36 (24.9)	25 (25.7)
CD	48 (46.0)	4 (8.9)	20 (24.5)	16 (26.1)	22 (31.7)
Total cover	95 (56.9)	18 (11.6)	72 (31.2)	66 (36.7)	64 (42.7)

Table 8. Seasonal values for number of trout captured (*n*), marked and captured during first sample (*M*), captured during second sample (*C*), marked fish recovered during second sample (*R*), estimated abundance (*N*), and upper and lower limits of 95% confidence intervals (*CI*) in Oatka Creek Park, Garbutt, Monroe County, New York.

Variable	**Season**			
	Sp-16	***F-16***	***W-17***	***Sp-17***
n	33	47	15	5
M	12	22	7	4
C	21	25	8	1
R	2	6	0	0
N (SE)	**95 (44.3)**	**85 (25.8)**	**72 (48.0)**	**10 (5.0)**
CI (95%)	3-187	32-138	0-185	*

*Confidence intervals could not be calculated; df (t) = 0 (*C*-1).

Table 9. Estimated seasonal trout density (N/km^2) in Oatka Creek Park (OCP; Garbutt, Monroe County, New York), along with each individual site (S1-S4); shown with SD. Site mean (SD) provided with correlation coefficient (r).

Season	Site density (N/km^2)				OCP
	S1	***S2***	***S3***	***S4***	
Sp-16	19.0 (11.71)	1.5 (0.95)	5.1 (2.47)	14.0 (8.94)	11.4 (5.35)
F-16	11.2 (7.08)	0.4 (0.03)	13.6 (6.30)	7.7 (2.54)	8.3 (2.56)
W-17	14.3 (8.27)	3.9 (2.25)	1.4 (0.29)	10.0 (6.34)	10.6 (7.13)
Sp-17	4.8 (0.24)	1.7 (0.11)	1.4 (0.30)	3.1 (1.56)	2.1 (1.06)
Mean (SD)	**13.5 (8.25)**	**1.8 (0.83)**	**6.3 (2.75)**	**9.2 (5.03)**	**8.7 (4.12)**
r	-0.857	0.339	-0.521	-0.865	-0.780

Table 10. Daily stream conditions for each day brown trout sampling was performed throughout the study in Oatka Creek Park (OCP) in Garbutt, Monroe County, New York. The estimated proportion of the study sites sampled each day is included (% OCP sampled), along with daily estimated trout density.

Season code	Rep.	Date	Temp (°C)	Discharge (cms)	% OCP sampled	Trout density (n/km^2)
Sp-16	A	23-Mar	7.8	5.6	77.0	1.4
	B	16-Apr	8.2	5.7	77.0	2.5
F-16	A	15-Sep	16.6	0.3	94.8	2.1
	B	6-Oct	16.5	0.3	94.8	2.4
W-17	A	22-Jan	4.0	8.2	64.3	1.0
	B	29-Jan	0.5	9.7	60.5	1.2
Sp-17	A	5-Mar	0.3	7.6	66.7	0.6
	B	31-Mar	6.5	11.9	20.9	0.5
Mean (SD)			*7.6 (6.31)*	*6.2 (4.16)*	*69.5 (23.52)*	*1.5 (0.81)*

Table 11. Mean (SD) proportion of microhabitat available and used by brown trout in Oatka Creek Park (Garbutt, Monroe County, New York). Habitat selectivity determined with Manly's α (Manly 1974). *Indicates preferred microhabitat type (i.e., $\alpha > 1/K$, where K = 4).

Type	**Mean proportion (%)**		***t***	**df**	**P**	**Selectivity (α)**
	Used	**Available**				
Glide	28 (45.1)	9 (12.0)	4.036	116	<0.001	0.65*
Riffle	4 (19.7)	15 (24.0)	3.305	152	0.001	0.06
Run	3 (17.1)	26 (21.7)	7.743	148	<0.001	0.02
Pool	65 (47.9)	50 (36.2)	2.391	177	0.012	0.27*

Table 12. Mean (SD) density of cover available and used by brown trout in Oatka Creek Park (Garbutt, Monroe County, New York). Habitat selectivity determined with Manly's α (Manly 1974). *Indicates preferred cover type (i.e., $\alpha > 1/K$, where K = 6).

Cover type	**Mean density (%)**		***t***	**df**	**P**	**Selectivity (α)**
	Used	**Available**				
Structural	38 (28.4)	16 (12.6)	-	-	-	-
LWD	20 (26.8)	1.4 (1.9)	6.953	102	<0.001	0.61*
Boulder	16 (25.6)	12 (12.3)	1.219	123	0.225	0.06
UCB	0.8 (3.7)	1.6 (1.4)	2.088	117	0.039	0.05
SAV	1.4 (4.0)	0.7 (1.3)	1.540	132	0.126	0.26*
Non-structural	32 (38.6)	48 (40.8)	-	-	-	-
Turbulence	14 (20.2)	25 (25.7)	2.193	44	0.034	0.01
CD	19 (39.4)	22 (31.7)	0.566	178	0.572	0.02
Total cover	61 (30.0)	64 (42.7)	-	-	-	-

Table 13. Mean (SE) cover density (%) used by brown trout at each site (S1-S4) in Oatka Creek Park (Garbutt, Monroe County, New York). (LWD = large woody debris, SAV = submerged aquatic vegetation, UCB = undercut bank, and CD = concealing depths).

Variable	**Site**				**OCP**
	S1	***S2***	***S3***	***S4***	
Structural	62 (7.3)	36 (11.2)	31 (3.4)	34 (4.5)	38 (2.8)
LWD	3 (1.6)	33 (11.3)	17 (3.8)	28 (5.0)	20 (2.7)
Boulder	57 (7.6)	2 (2.2)	9 (2.4)	6 (1.5)	16 (2.6)
SAV	-	-	4 (1.0)	-	1.4 (0.4)
UCB	2 (1.5)	-	1 (0.7)	-	0.8 (0.4)
Non-structural	62 (10.7)	24 (14.3)	18 (3.8)	33 (6.5)	32 (3.9)
Turbulence	6 (3.2)	6 (2.9)	18 (3.8)	16 (3.5)	14 (2.0)
CD	56 (12.1)	22 (14.7)	-	19 (6.5)	19 (3.9)
Total cover	84 (5.7)	58 (12.2)	49 (4.4)	63 (4.7)	61 (3.0)

Table 14. Mean (SE) cover density (%) used by brown trout during low (<2 cubic meters per second; cms), normal (2-8 cms), and high (>8 cms) discharge in Oatka Creek Park (Garbutt, Monroe County, New York). Group differences detected with Welch's ANOVA (F) or Kruskal-Wallis (H); multiple comparisons performed with Tamhane's test. (SC = structural cover, LWD = large woody debris, SAV = submerged aquatic vegetation, UCB = undercut bank, CD = concealing depth, and NSC = non-structural cover).

Variable	**Discharge category**			**Statistic**	**P**
	Low	***Normal***	***High***		
SC	36 (3.2)	45 (4.3)	30 (6.4)	F (2, 42) = 3.005	0.060
LWD	11 (3.2) [a]	32 (5.0) [b]	18 (5.3) [ab]	F (2, 42) = 11.945	<0.001
Boulder	22 (4.5)	10 (2.5)	12 (6.1)	F (2, 42) = 2.244	0.119
SAV	3 (0.7)	0.5 (0.5)	-	-	-
UCB	-	2 (1.0)	-	-	-
NSC	41 (5.6)	11 (4.5)	53 (10.3)	H (2) = 16.113	<0.001
Turbulence	21 (3.6)	3 (1.1)	20 (3.6)	H (2) = 9.391	0.009
CD	21 (6.0)	8 (4.6)	38 (12.5)	H (2) = 3.003	0.223
Total cover	63 (4.5)	54 (4.5)	73 (8.0)	F (2, 41) = 2.298	0.113

Table 15. Mean (SE) cover density (%) used by brown trout during cold (<5 °C), moderate (5-10 °C), and warm (>10 °C) water temperatures in Oatka Creek Park (Garbutt, Monroe County, New York). Group differences detected with Welch's ANOVA (F) or Kruskal-Wallis (H); multiple comparisons performed with Tamhane's T2 test. (SC = structural cover, LWD = large woody debris, SAV = submerged aquatic vegetation, UCB = undercut bank, CD = concealing depth, and NSC = non-structural cover).

Variable	**Temperature category**			**Statistic**	**P**
	Cold	***Moderate***	***Warm***		
SC	41 (7.8)	41 (3.8)	36 (4.4)	$F(2, 46) = 1.006$	0.374
LWD	31 (8.0) [b]	27 (4.2) [b]	11 (3.2) [a]	$F(2, 47) = 10.817$	<0.001
Boulder	10 (5.2)	11 (2.7)	22 (4.5)	$F(2, 50) = 2.747$	0.074
SAV	-	0.6 (0.6)	3 (0.7)	-	-
UCB	-	2 (1.0)	-	-	-
NSC	40 (9.4)	15 (5.5)	41 (5.6)	$H(2) = 9.517$	0.009
Turbulence	17 (3.4)	4 (1.2)	21 (3.6)	$H(2) = 7.544$	0.023
CD	26 (12.4)	12 (5.6)	21 (6.0)	$H(2) = 0.903$	0.637
Total cover	75 (6.9) [b]	51 (4.5) [a]	63 (4.4) [ab]	$F(2, 44) = 4.702$	0.014

Table 16. Proportion of boulder sizes available (OCP) and used by small (ST), medium (MT), and large (LT) brown trout in Oatka Creek Park (OCP; Garbutt, Monroe County, New York). Shown with correlation coefficient (*r*); *n* = 3.

Trout size	**Boulder size-class**			**r**	**P**
	Small	***Medium***	***Large***		
ST	42	32	26	-0.982	0.121
MT	75	13	12	-0.866	0.333
LT	20	10	70	0.778	0.432
OCP	*81*	*15*	*4*	*-0.928*	*0.243*

Table 17. Mean (SD) stream depth, current velocity, and substrate size used by each brown trout year-class in Oatka Creek Park (OCP) in Garbutt, Monroe County, New York.

Variable	**Year-class**				
	Age-0	***Age-1***	***Age-2***	***Age-3***	***Age-4+***
Depth (cm)	37 (13.6)	47 (18.0)	50 (22.4)	76 (26.0)	82 (28.3)
Velocity (cm/s)	9 (14.1)	18 (19.1)	14 (12.3)	11 (12.5)	10 (9.8)
Substrate (score)	3.2 (1.9)	3.2 (1.6)	3.0 (2.0)	2.5 (1.9)	2.9 (2.0)

Table 18. Percent of brown trout in each year-class using cover types in Oatka Creek Park (OCP) in Garbutt, Monroe County, New York. (LWD = large woody debris, SAV = submerged aquatic vegetation, UCB = undercut bank, and CD = concealing depth).

Cover type	**Percent of year-class (%)**				
	Age-0	***Age-1***	***Age-2***	***Age-3***	***Age-4+***
LWD	50	68	45	61	57
Boulder	63	12	48	33	57
SAV	0	9	24	0	14
UCB	0	15	0	0	0
Turbulence	38	24	42	17	0
CD	0	6	12	56	43

Table 19. Equality of group means for habitat variables entered in stepwise discriminant analysis.

Habitat variable	**Wilks' Lambda**	**$F_{(3, 146)}$**	**P**
Velocity (cm/s) [1]	0.583	34.816	<0.001
Depth (cm) [1]	0.758	15.535	<0.001
LWD (%) [2]	0.846	8.861	<0.001
Non-structural cover (%) [2]	0.847	8.805	<0.001
Substrate (score)	0.919	4.306	0.006

[1]Variable square root transformed

[2]Variable log base 10 transformed

Table 20. Habitat variables entered in stepwise statistics. Minimum partial F to enter is 3.84; maximum partial F to remove is 2.71.

Step	Entered	Wilks' lambda		Exact F		
		Statistic	***df***	***F***	***df***	***P***
1	Velocity	0.583	1, 3, 146	34.816	3, 146	<0.001
2	Depth	0.416	2, 3, 146	26.588	6, 290	<0.001

Table 21. Eigenvalues and canonical correlation for the two discriminant functions used in the analysis.

Function	Eigenvalue	% of variance	Canonical correlation
1	0.850	74.0	0.678
2	0.299	26.0	0.48

Table 22. Structure matrix for habitat variables used in stepwise discriminant analysis. Pooled within groups correlations between discriminating variables and standardized canonical discriminant functions. *Indicates largest absolute correlation between variable and any discriminant function.

Variable	Function	
	1	**2**
Velocity	0.869*	-0.494
Depth	0.192	0.981*

Table 23. Canonical discriminant function coefficients (unstandardized coefficients).

Group	Function	
	1	**2**
Velocity (cm/s) [1]	0.669	-0.131
Depth (cm) [1]	0.404	0.711
Constant	-5.773	-4.64

[1]Variable square root transformed

Figures

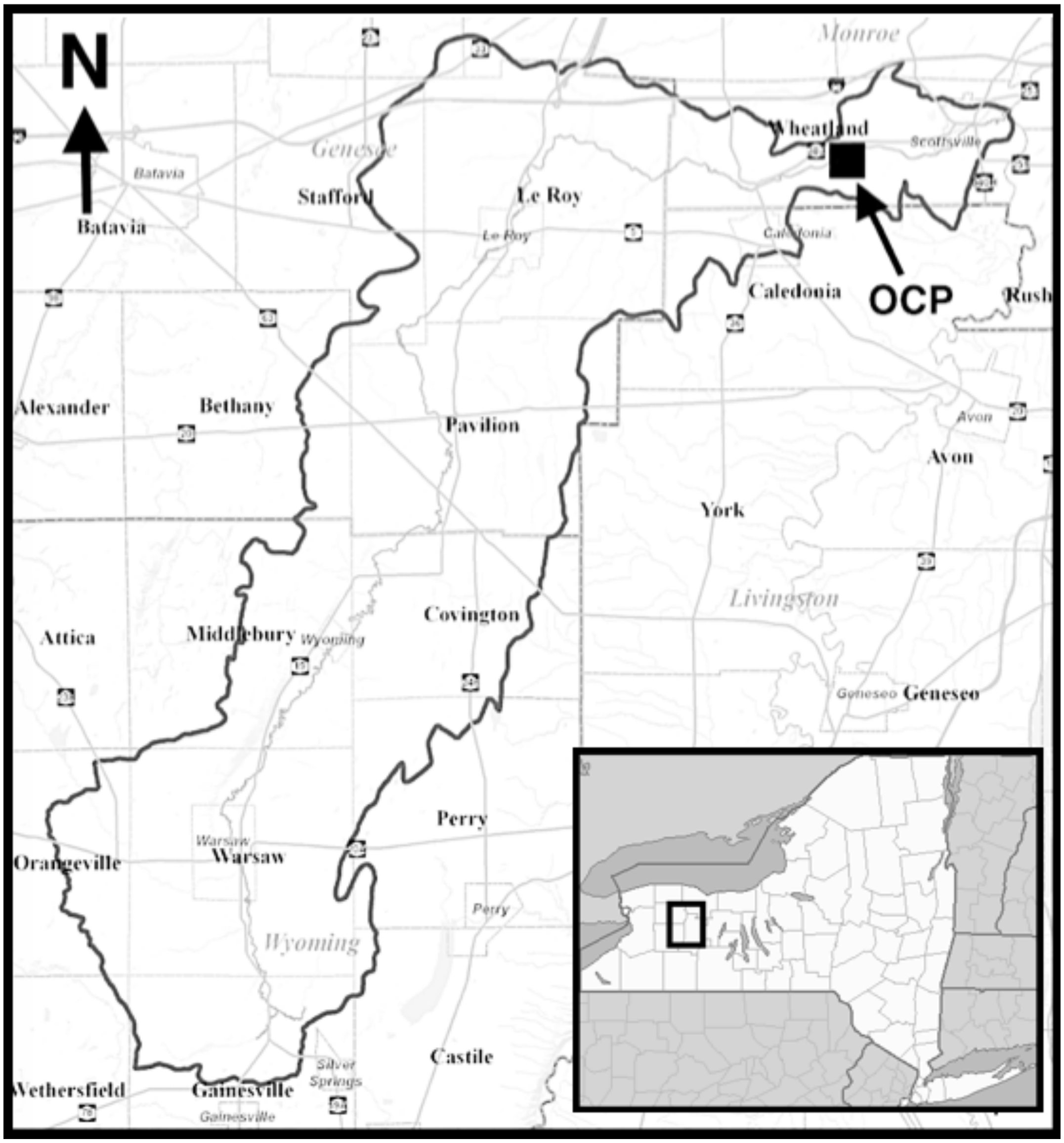

Figure 1. Oatka Creek watershed located along the southern basin of Lake Ontario in western New York, USA. Oatka Creek Park (OCP; Garbutt, Monroe County, NY) is labeled and covered by a solid black box near the Town of Wheatland (upper right corner). Map modified from Oatka Creek Watershed Committee (2001).

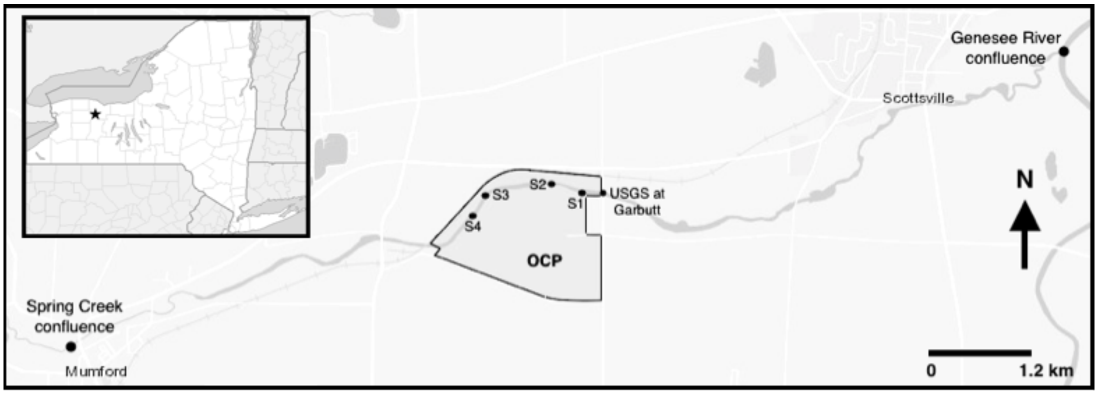

Figure 2. Lower section of Oatka Creek (Monroe County, New York) from the Hamlet of Mumford to the confluence with the Genesee River near the Village of Scottsville. Includes the four study sites (S1-S4) located within the boundaries of Oatka Creek Park (OCP) in the Hamlet of Garbutt, and location of active United States Geological Survey (USGS) station at Garbutt (USGS 04230500).

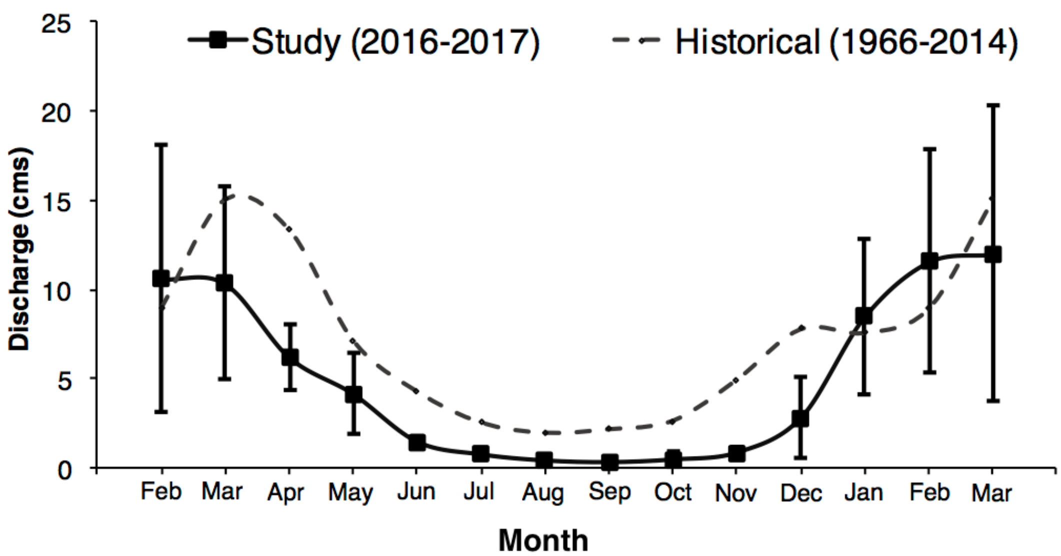

Figure 3. Mean monthly discharge (cubic meters per second; cms) for Oatka Creek at Garbutt, Monroe County, New York (USGS 04230500) during study period (2016-2017) and historically (1966-2014); standard error of the mean (SE) only reported for study period (2016-2017) (USGS 2018).

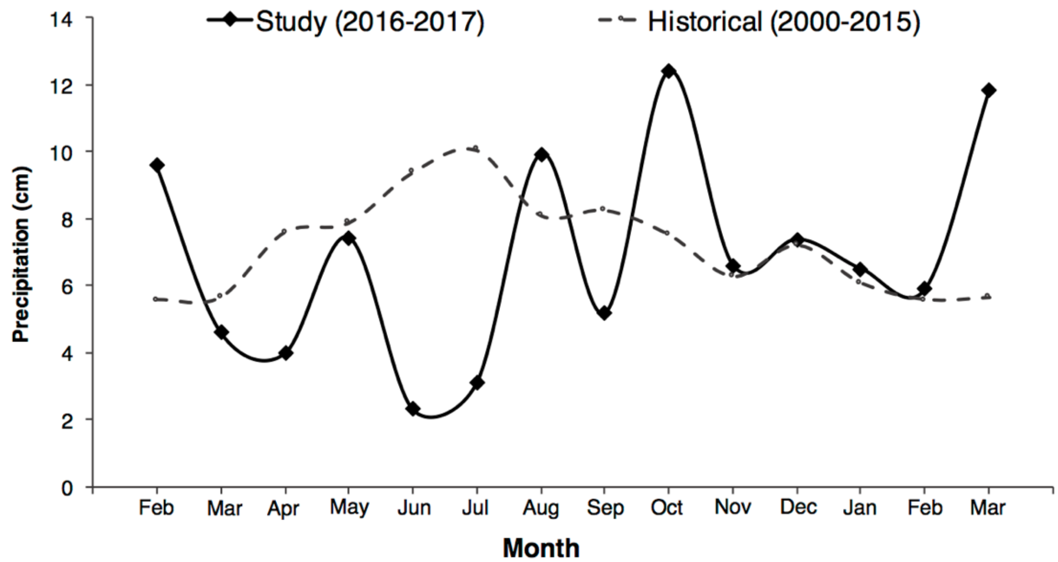

Figure 4. Monthly precipitation in Rochester, Monroe County, New York, during study period (February 2016 through March 2017), along with mean monthly precipitation from 2000-2015 (National Weather Service 2017).

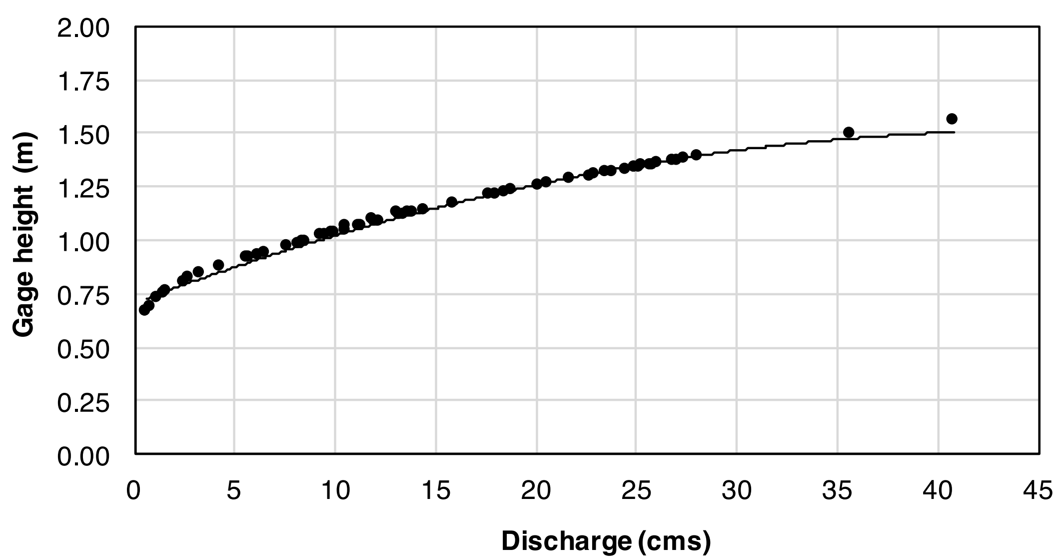

Figure 5. Rating curve (discharge-gage height relationship) for Oatka Creek at Garbutt, Monroe County, New York (USGS 04230500) shown with second order polynomial trendline ($y = -0.0004x^2 + 0.0352x + 0.7083$; $R^2 = 0.99161$; n = 61).

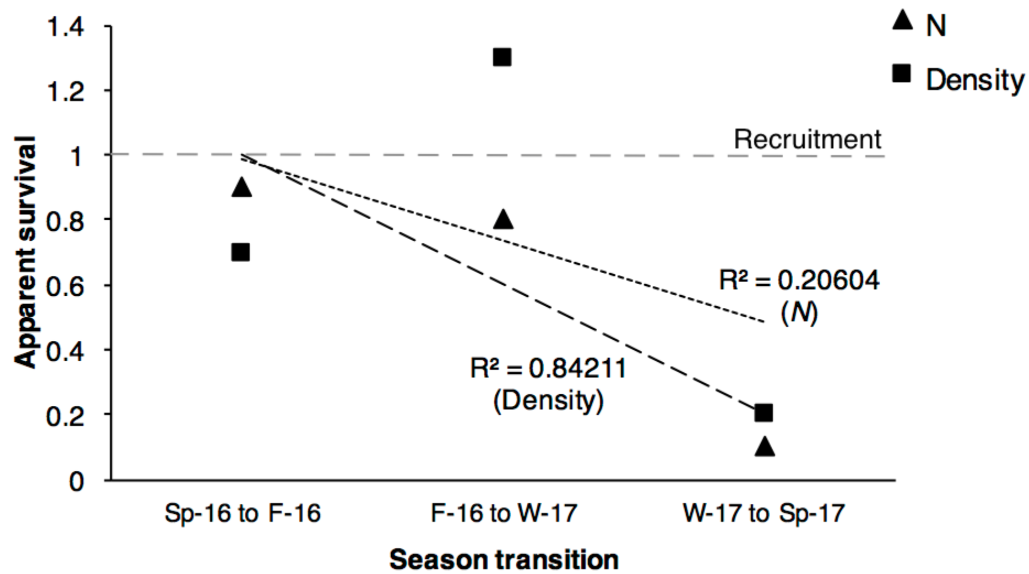

Figure 6. Apparent survival rates for estimated brown trout abundance (N) and density (N/km^2) in Oatka Creek Park in Garbutt, Monroe County, New York. Recruitment occurs when value > 1.0 (indicated by light dotted line).

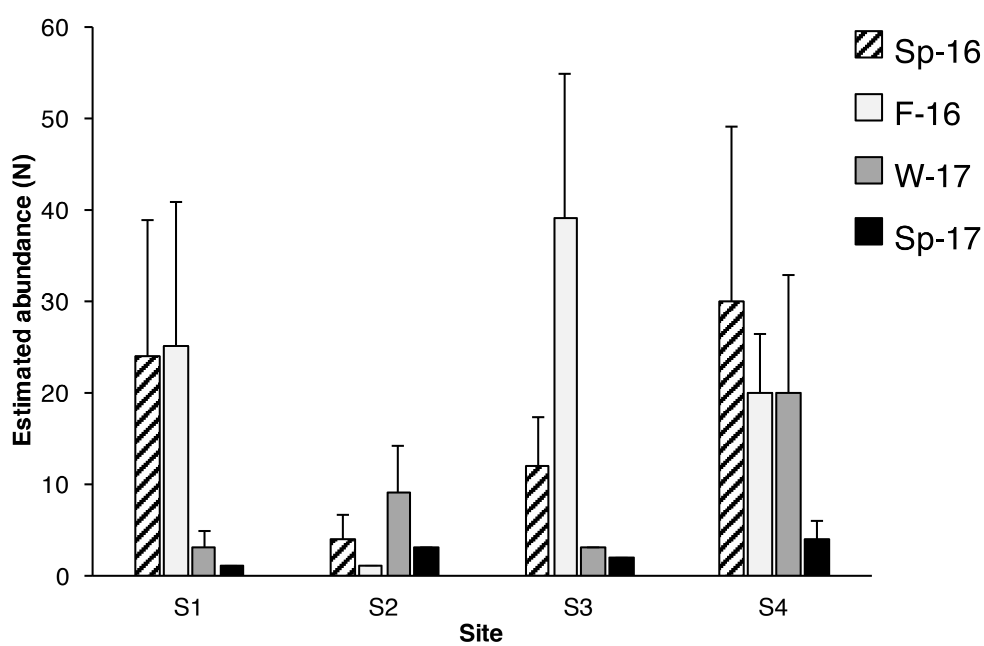

Figure 7. Seasonal estimated brown trout abundance (N ±SE) for each site (S1-S4) in Oatka Creek Park (Garbutt, Monroe County, New York).

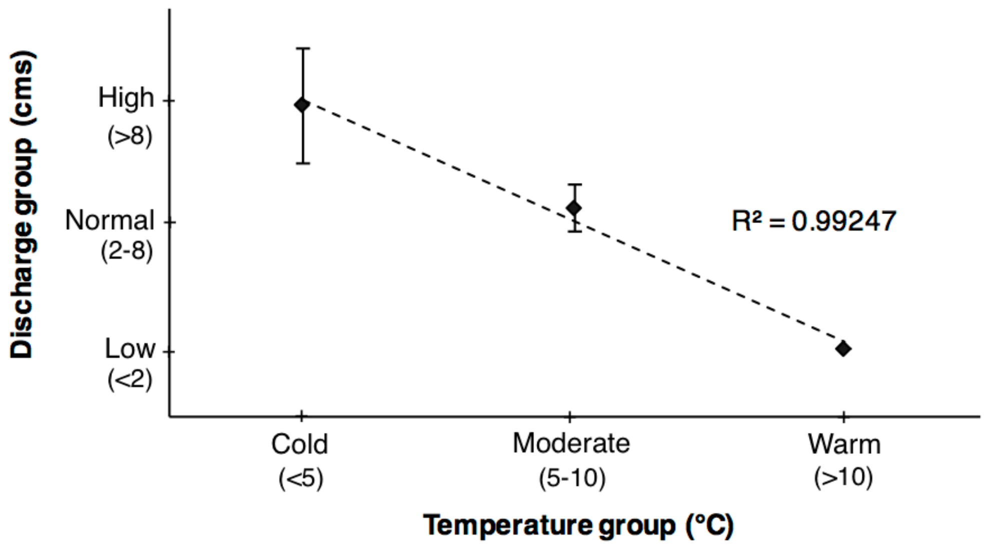

Figure 8. Relationship between temperature and discharge (cubic meters per second; cms) categories during sampling periods throughout study.

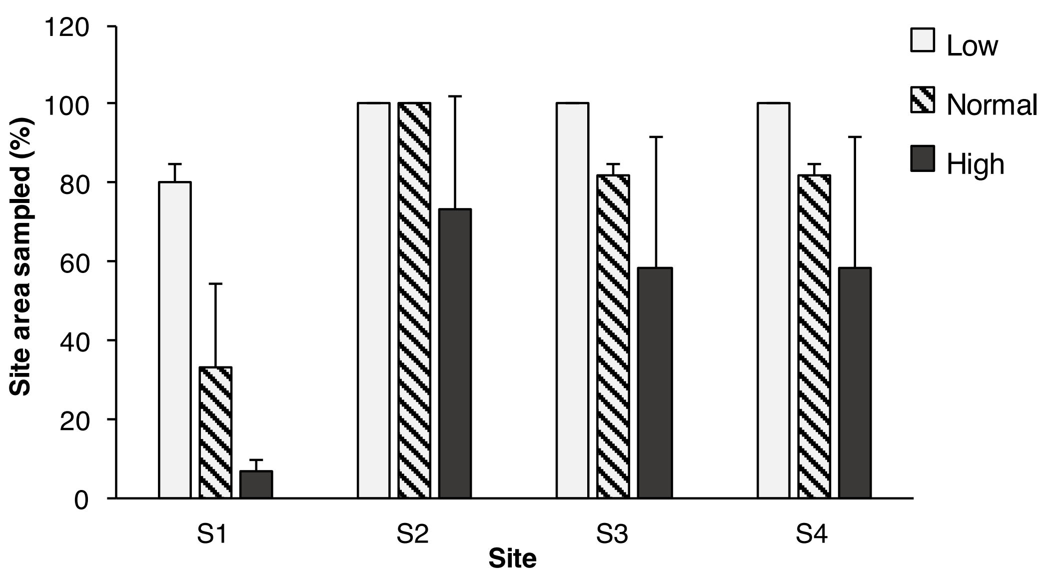

Figure 9. Mean (SD) proportion of each site sampled during periods of low (n = 2), normal (n = 2), and high (n = 4) discharge in Oatka Creek Park (Garbutt, Monroe County, New York).

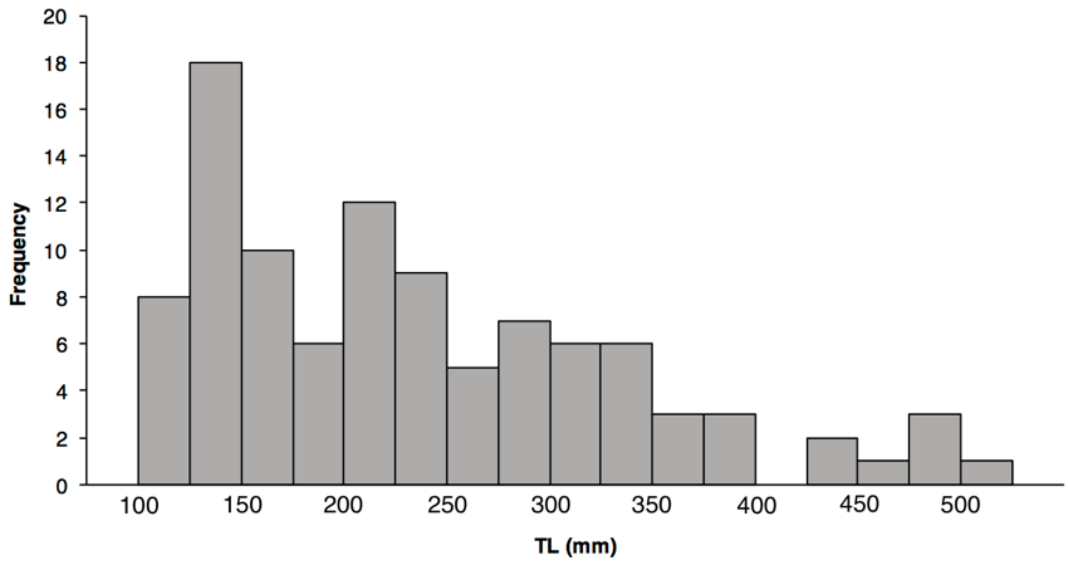

Figure 10. Length-frequency histogram (based on total length; TL) of brown trout collected in Oatka Creek Park (Garbutt, Monroe County, New York) from March 2016 to April 2017 (n = 100).

Figure 11. Year-class distribution of brown trout collected in Oatka Creek Park (Garbutt, Monroe County, New York) from March 2016 to April 2017 (n = 100). Age-classes assigned as follows: age-0: TL < 125 mm; age-1: 125-199 mm; age-2: 200-299 mm; and age-3+: TL ≥ 300 mm.

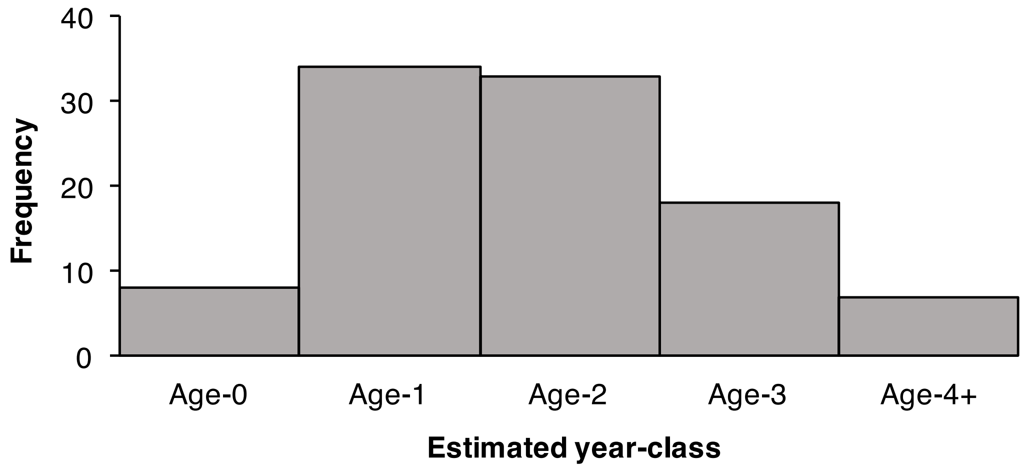

Figure 12. Modified year-class distribution of brown trout collected in Oatka Creek Park (Garbutt, Monroe County, New York) from March 2016 to April 2017 (n = 100). Age-classes assigned as follows: age-0: TL < 125 mm; age-1: 125-199 mm; age-2: 200-299 mm; age-3: 300-399 mm; and age-4+: TL ≥ 400 mm.

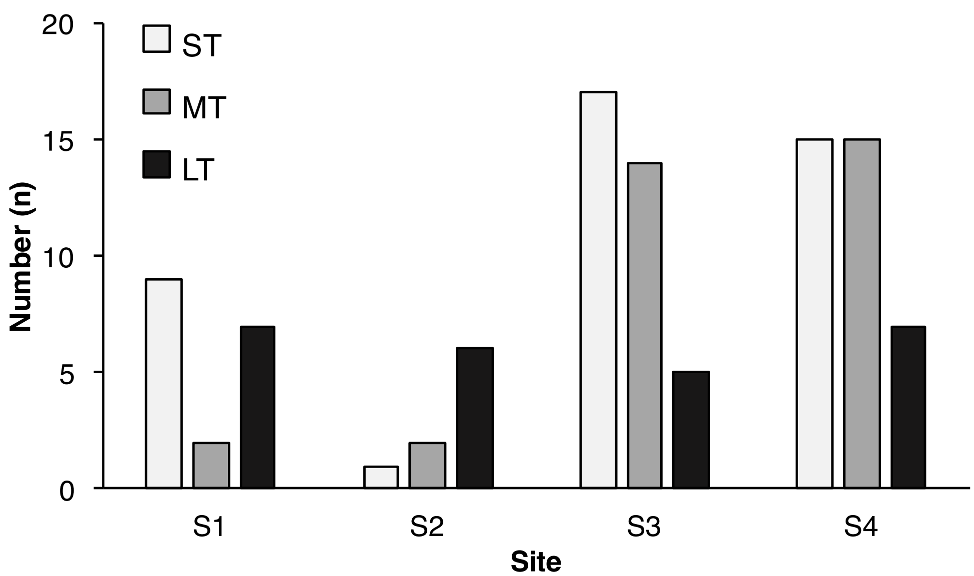

Figure 13. Frequency of small (ST), medium (MT), and large (LT) brown trout collected at each site (S1-S4) in Oatka Creek Park (Garbutt, Monroe County, New York) from March 2016 to April 2017 (n = 100).

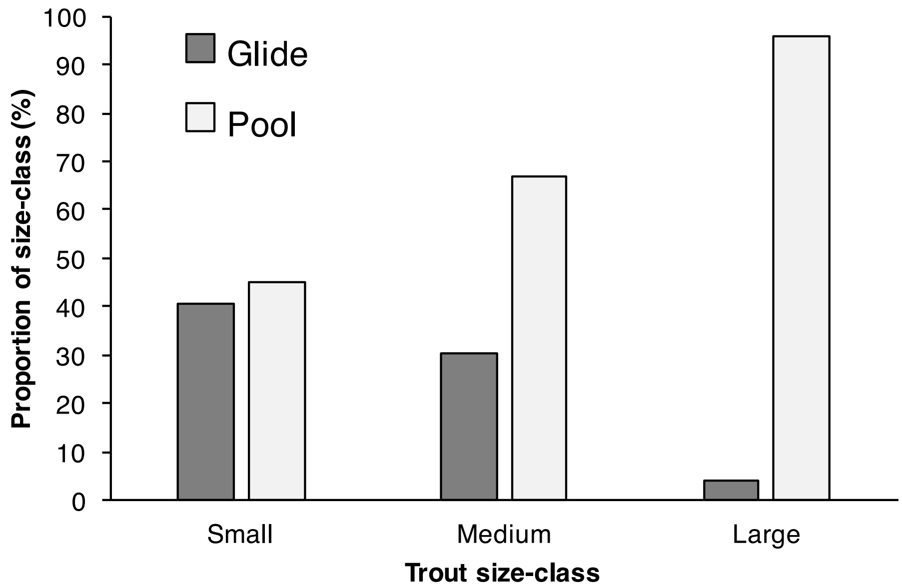

Figure 14. Proportion of small, medium, and large brown trout using glides (shallow with slow currents) and pools (deep with slow currents) in Oatka Creek Park (Garbutt, Monroe County, New York) from March 2016 to April 2017.

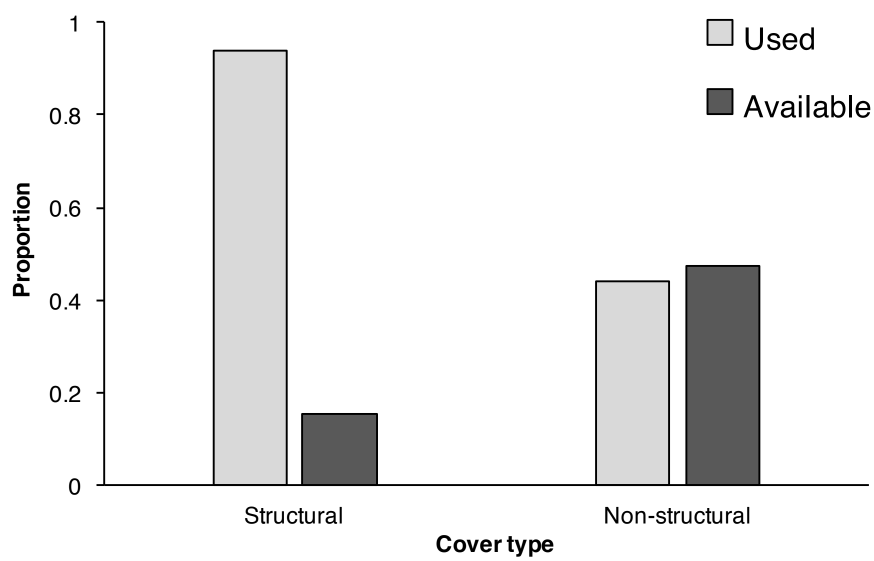

Figure 15. Proportion of structural cover (i.e., woody debris, boulders, aquatic vegetation, and undercut banks) and non-structural cover (i.e., turbulence and concealing depths) available and used by brown trout in in Oatka Creek Park (Garbutt, Monroe County, New York) from March 2016 to April 2017.

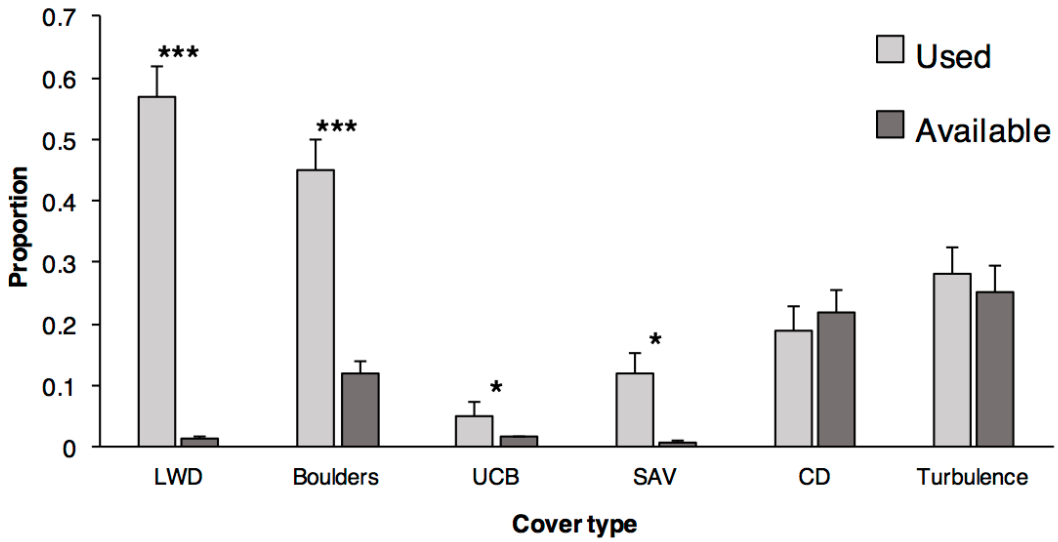

Figure 16. Mean (SE) proportion of each cover type available and used by brown trout in Oatka Creek Park (Garbutt, Monroe County, New York) from March 2016 to April 2017 (LWD = large woody debris; UCB = undercut bank; SAV = submerged aquatic vegetation; and CD = concealing depths). *P < 0.05 and ***P < 0.001 (two-sample t-test used to detect differences).

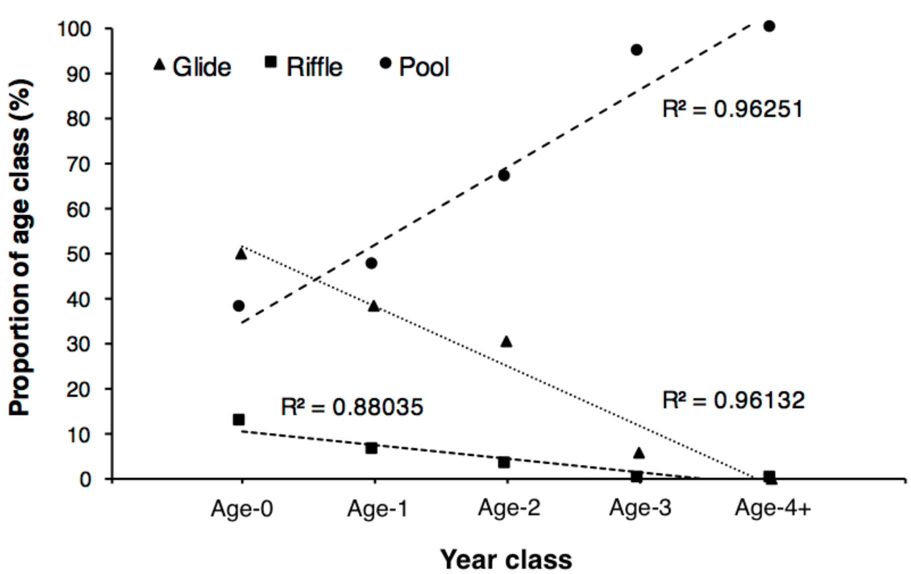

Figure 17. Proportion of brown trout in each year-class using glides, riffles, and pools in Oatka Creek Park (OCP) in Garbutt, Monroe County, New York. The other microhabitat type (runs) was excluded because it was only used by 9% of age-1 individuals.

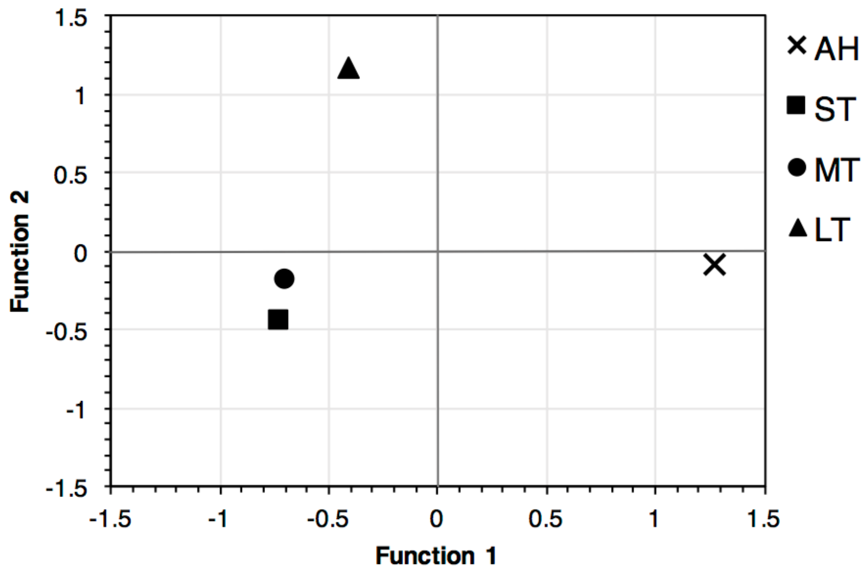

Figure 18. Mean group centroids plotted against canonical discriminant functions. Function 1 is positively contributed by current velocity, and Function 2 is positively contributed by depth. (AH = available habitat; ST = small trout, <200 mm; MT = medium trout, 200-300 mm; and LT = large trout, >300 mm).

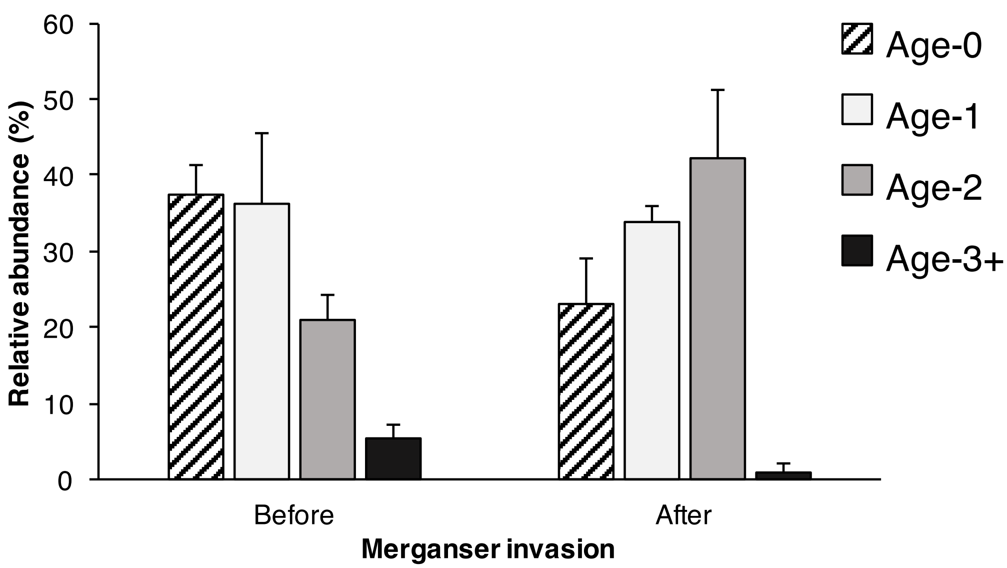

Figure 19. Mean (SE) year-class distributions of brown trout in Oatka Creek Park (Garbutt, Monroe County, New York) before (2003) and after (2015-2016) common merganser winter predation (n = 2 for both treatments). Data were provided by M. Sanderson (personal communication) and collected with single-pass electrofishing during autumn.

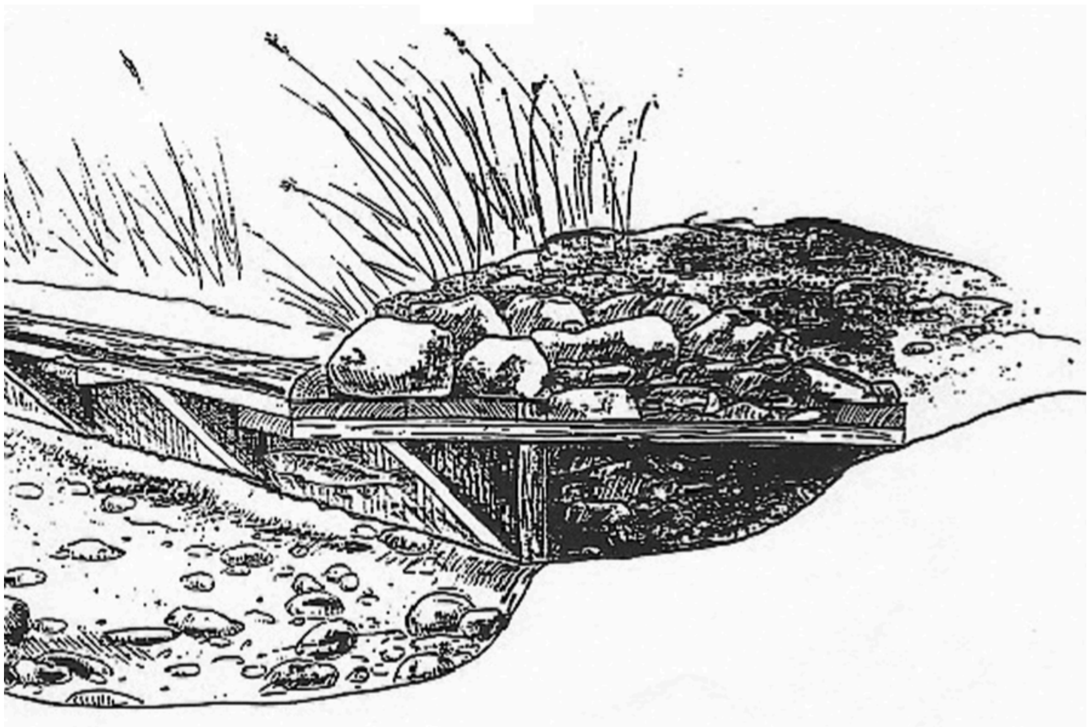

Figure 20. Illustration of recommended skyboom structure provided by USFS (1993).