Population Assessment and Habitat Use of Brown Trout Following Severe Overwinter Predation from Common Mergansers in a Western New York Stream

Kevin Corser[1] and Douglas A. Wilcox[1,*]

Abstract -Heavy predation by *Mergus merganser* (Common Merganser) during severe winters of 2013–2014 and 2014–2015 resulted in substantial reductions of wild *Salmo trutta* (Brown Trout) in open-water, groundwater-fed reaches of Oatka Creek in western New York State. New York State Department of Environmental Conservation considered the need for habitat manipulation to reduce the severity of future overwinter-predation by mergansers in Oatka Creek Park (OCP) but lacked data to make an informed decision. Thus, this study sought to estimate population abundance, density, and year-class distribution of Brown Trout; quantify the availability of cover and habitat; and identify habitat features used by Brown Trout in OCP. We recorded data for 100 Brown Trout (101–512 mm TL) during spring 2016, autumn 2016, winter 2017, and spring 2017. Despite the absence of mergansers in ensuing warmer winters, trout population indices decreased as the study continued, likely affected by high streamflow during sampling events. Year-class distributions typical of a small stream, however, suggest that the population is recovering. Velocity refuges and structural cover were the primary factors determining habitat selection. Large woody debris was the most favored cover type by all Brown Trout; however, boulders were also important, especially during low streamflow. Large trout (>300 mm) showed a strong preference for deepwater habitats with slow currents and high densities of woody debris and boulders, while small trout (<200 mm) preferred shallower complex habitats with slow currents, course substrates, and high cover densities. Quality trout habitat and instream cover is abundant throughout OCP, but the abundance of highly complex overwinter habitats capable of providing protection from mergansers may be limited. Adding complex structural cover to areas favored by smaller trout (<300 mm) could increase habitat complexity and likely reduce the severity of future overwinter predation.

Introduction

Oatka Creek is a small- to medium-sized stream in western New York that receives significant groundwater discharges in its downstream reaches, enabling it to support a wild *Salmo trutta* L. (Brown Trout) fishery (Sanderson 2007, Takakis 2002). Concerns about the future of the fishery surfaced in the springs of 2014 and 2015, as anglers reported poor fishing to the New York State Department of Environmental Conservation (NYSDEC), which then sampled a small section of the stream in autumn of 2015 and 2016 and reported a substantial decrease in abundance of Brown Trout compared to historical data last collected in 2003 (Sanderson 2007; M. Sanderson, NYSDEC, Avon, NY, unpubl. data).

[1]Department of Environmental Science and Ecology, The College at Brockport—State University of New York, 350 New Campus Drive, Brockport, NY 14420. *Corresponding author - dwilcox@brockport.edu.

Manuscript Editor: Jay Stauffer

NYSDEC believed that the population decrease was likely due to predation from *Mergus merganser* L. (Common Merganser)—large, fish-eating birds that had not been seen in these waters for >30 years (M. Sanderson, pers. comm.). The severe winters of 2013–2014 and 2014–2015 caused their preferred habitat (i.e., riverine wetlands and bays of large lakes) to be covered with ice, thus forcing them to search open water for food (Leonard and Shetter 1937; M. Sanderson, pers. comm.). Spring-fed reaches of Oakta Creek provided ideal overwinter habitat for mergansers during such conditions because they remained ice-free and provided an abundant supply of Brown Trout, which used the same habitat.

NYSDEC considered using habitat manipulation to help reduce overwinter predation by mergansers on Brown Trout in Oatka Creek (M. Sanderson, pers. comm.) but lacked data to make an informed management decision. The goal of this study was to provide them with additional information on habitat characteristics and changes in the population of trout to aid the decision-making process.

Distribution and abundance of stream-dwelling Brown Trout are influenced by habitat. A myriad of biotic and abiotic factors can directly and indirectly affect production of Brown Trout differently between streams and even reaches within the same stream. Winter is a stressful time for trout because they are poikilotherms whose body temperatures fluctuate with ambient water temperatures. Since activity level and swimming performance decrease with colder temperatures, stream-dwelling trout select overwintering habitat that will minimize energy expenditure (e.g., low-flow velocities, instream cover) while also providing protection from adverse physiochemical conditions (e.g., low oxygen, ice) and predators. Brown Trout use a variety of cover types, including woody debris, undercut banks, overhanging riparian vegetation, course substrate materials, aquatic vegetation, deep water, and turbulence (Boussu 1953, McMahon and Hartman 1989). 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 because smaller fish tend to use interstices in the substrate and complex bank features, while larger trout are commonly associated with deep pools and woody debris (Cunjak 1996, Cunjak and Power 1986, Johnsson et al. 2004, Mitro and Zale 2002). Factors such as food availability, competition, and predation risk may also play an important role in habitat selection (Cunjak 1996, Johnsson et al. 2004).

The effect of predation by piscivorous birds on a community of fishes varies from minor (e.g., Suter 1995, Wood 1987) to significant (e.g., Engström 2001, Power and Mitchell 1994, Stiller 2011) because not all predation is 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 mortality of 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 of age-1 and greater cohorts is likely to cause population changes (Power and Mitchell 1994), an example of a process known as additive mortality because it adds to other mortality forces. Mergansers promote additive mortality in a trout stream by selectively feeding on larger juvenile trout (Leonard and Shetter 1937, Wood and Hand 1985).

Piscivorous bird predation on a population of trout may also be affected by physical habitat characteristics. The ability of trout to escape a predator is dependent, in part, on swimming ability and critical holding velocity, both of which are reduced at low temperatures (Hartman 1963). Since the ability of endothermic mergansers 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 and cover availability and quality (Heggenes and Borgstrøm 1988, Wood and Hand 1985). In addition, trout in streams with limited overwintering habitats (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.

Although Common Mergansers did not return to Oatka Creek in warmer winters following 2013–2014 and 2014–2015 because open water was available elsewhere, NYSDEC remained concerned about the population of Brown Trout and the potential effect of mergansers if colder winters returned. This study focused on habitat use of Brown Trout in Oatka Creek during the winter, but sampling was also performed in the spring and autumn. The objectives were to quantify the availability of different types of cover and habitat; estimate the population abundance, density, and year-class distribution of Brown Trout; identify habitat features used by Brown Trout and evaluate the seasonal importance of each habitat feature; and recommend potential management strategies that will increase production of wild Brown Trout by increasing habitat quality in Oatka Creek.

Methods

Study area

Oatka Creek flows for 93 km through 4 western counties in New York before merging with the Genesee River near the Town of Scottsville, NY (Fig. 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%); most natural habitats in the basin are small and fragmented (Tatakis 2002). The creek flows over the Onondaga Escarpment (i.e., karst region composed mostly of limestones) near the town of LeRoy, 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 downstream from the escarpment; however, the confluence with Spring Creek in the hamlet of Mumford provides Oatka Creek with the greatest groundwater input (Dowling et al. 2001, Takakis 2002). The abundant discharges of groundwater in the lower reaches of Oatka Creek maintain high quality water and moderate summer and winter temperatures in the stream (Dowling et al. 2001, Tatakis 2002).

We randomly selected 4 study sites along the creek in Oatka Creek Park (OCP), about 4.5 km downstream from the confluence with Spring Creek. 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, making OCP a favorite spot for recreational trout anglers in western New York. It has been managed as a fishery for wild Brown Trout by the NYSDEC since October 2000, with "no-kill" regulations (i.e., catch-and-release fishing required; artificial lures only) to increase angler satisfaction by increasing the abundance of larger trout (TL > 356 mm; Sanderson 2007). Three years after establishing those regulations (i.e., fall 2003), the density of trout >356 mm TL in OCP increased significantly (Sanderson 2007). Although hatchery-reared trout are not released directly in OCP, sections surrounding OCP are still stocked annually (203–381 mm TL; NYSDEC 2018). An active United States Geological Survey gage (USGS 04230500) records stream discharge and gage height at the bridge on the downstream boundary of OCP (USGS 2018).

Stream habitat measurements

We used 5 cross-sectional transects extending from bank to bank to measure the following stream habitat features along each 100-m site during base flows

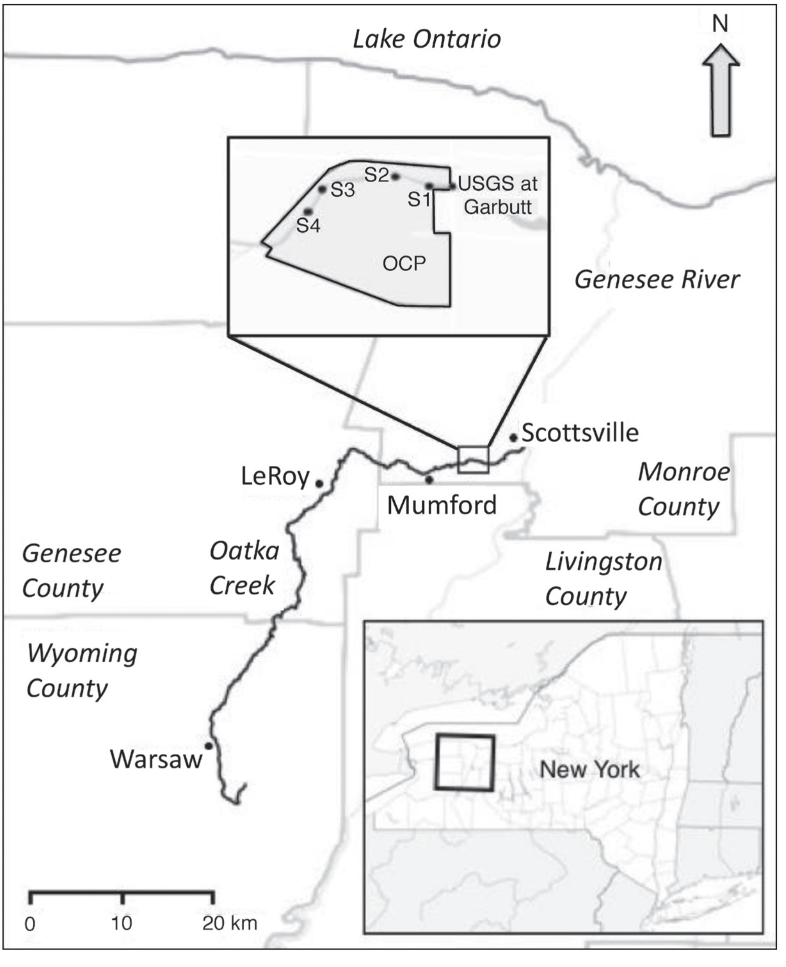

Figure 1. Oatka Creek located along the southern basin of Lake Ontario in western New York. Includes study sites (S1–S4) within Oatka Creek Park (OCP; Garbutt, Monroe County, NY) and location of an active United States Geological Survey (USGS) station at Garbutt (USGS 04230500). The hamlet of Mumford, NY, marks the location of the Spring Creek confluence (major groundwater discharge source for lower reaches) and the confluence with the Genesee River is near the Village of Scottsville, NY.

in December 2016 (stream discharge: 4.06 cubic meters per second [cms]): stream width, depth, current velocity, and substrate composition. We recorded stream depth and current velocity at 5 equidistant points along each transect. Current velocity was measured at 0.8 of the water depth with an acoustic digital current meter (ADC) to provide a good representation of the velocities available in the habitats used by the trout. We calculated site area (m^2) as the site length multiplied by the mean site width and used the sum of the area for all 4 sites to represent the area of OCP.

We visually examined the dominant substrate at 10 equidistant points along each transect and classified the types using a system modified from Cummins (1962). We used the mean of the dominant substrate values as an index of substrate size, and the standard deviation as an index of substrate heterogeneity (Bain et al. 1985).

We established the following categories for classifying instream cover (Platts et al. 1983): turbulence, undercut bank (UCB), concealing water depth (CD), large woody debris (LWD), boulders, and submerged aquatic vegetation (SAV). We visually estimated turbulence in 8 transects per site and classified this stream characteristic according to Stevenson and Bain (1999). We evaluated UCB by measuring bank depth at 5-m intervals along both banks (n = 42 per site) and classified bank depths greater than 10 cm as a potentially useful UCB for trout. We evaluated CD based on stream depth data (n = 25 per site) and classified depths greater than 75 cm as CD. We used 9 cross-sectional transects to quantify LWD, boulders, and SAV by recording the frequency that each cover type contacts a cross-sectional transect (n = 9 per site). LWD (diameter > 5 cm), boulders (diameter > 25 cm), and SAV contacting the transect line were measured and used to estimate the proportion of cover at each site according to Stevenson and Bain (1999).

We categorized each cover type as structural cover (SC; i.e., undercut, LWD, boulders, or SAV) or non-structural cover (NSC; i.e., turbulence or CD); estimated the proportions of SC and NSC by summing the individual cover types that comprised each group (maximum score: 100%); and used the sum of all cover types (i.e., SC and NSC) to estimate total cover (TC) (n = 6).

Trout sampling

We collected Brown Trout by single-pass backpack electrofishing (Halltech HT-2000) in an upstream direction twice seasonally in spring 2016, fall 2016, winter 2017, and spring 2017. Moving fish were not pursued. Time between seasonal samples varied from 7 to 30 days. We recorded water temperature (°C) on each sampling date and classified the readings as cold (<5 °C), moderate (5–10 °C), or warm (>10 °C). Captured trout were measured (total length; TL), marked (i.e., fin clip), and released. We measured stream depth and current velocity at each point of capture and visually estimated substrate composition and cover densities in a 1-m radius surrounding the point of capture. We considered fish captured within 1 m of any cover type to have been using that feature.

Trout population metrics

We estimated population abundance (N) each season using a modified Chapman-Petersen equation (Ricker 1975):

$$N = ([M + 1] \text{ x } [C + 1]) / (R + 1) \text{ and SE} = \sqrt{(N^2 \text{ x } [C - R]) / ([C + 1] \text{ x } [R + 2])},$$

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 (Ricker 1975).

We used length–frequency histograms to examine the size distribution of Brown Trout in the study area. We assigned year classes 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, pers. comm.). We performed all other habitat-use analyses using modified year classes (referred to as size classes) to increase the number of samples in each group. We assigned size classes as follows: small trout (ST; <200 mm TL), medium trout (MT; 200–300 mm TL), and large trout (LT; >300 mm TL).

Statistical analyses

We used 2-sample t-tests (alpha = 0.05) to detect differences between the proportions of habitat features (i.e., stream depth, current velocity, substrate size, and the proportion of cover) available in OCP and the proportion used by Brown Trout.

Results

Available stream habitat

Site S1 had the greatest stream depths (mean: 75 cm), slowest current velocities (27 cm/s), smallest substrate particles (score: 3.3), and greatest densities of structural, non-structural, and total cover (27, 68, and 95%, respectively) due to the abundance of boulders and CD (Table 1). Mean depth and velocity were similar

Table 1. Mean (SD) available stream habitat 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).

	Site				
Parameter	S1	S2	S3	S4	OCP
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)
Substrate (score)	3.3 (1.07)	4.6 (1.40)	4.0 (1.46)	3.6 (0.95)	3.8 (1.35)
Cover density (%)					
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	0.0	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)

for S2–S4 (min–max: 50–52 cm and 38–43 cm/s, respectively). Sites S3 and S4 had similar substrate sizes (3.6–4.0) and structural, non-structural, and total cover densities (min–max: 11–14, 52–61, and 66–72%, respectively), while S2 had considerably larger substrate particles (4.6; due to abundant slate/bedrock) and lower cover densities (9, 9, and 18%, respectively).

Overall, the estimated density of total cover in OCP was 64% (Table 1). The density of non-structural cover (48%) was 3 times greater than structural cover (16%) in OCP, as turbulence and concealing depth (CD) were widely available (25 and 22%, respectively). Boulders were the most abundant type of structural cover (12%), followed by UCB (1.6%), LWD (1.4%), and submerged aquatic vegetation (SAV; 0.7%).

Trout abundance

During the study, we captured 100 Brown Trout (Table 2). Overall, the number of fish captured (*n*) and estimated *N* decreased as the study proceeded from spring 2016 to spring 2017 (r = -0.801 and -0.906, respectively; n = 4). Capture rates and *N* estimates varied considerably among seasons (Table 2). 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). Overall, average *N* estimates throughout the study were similar for S4 ($N = 19 \pm 11$), S3 ($N = 14 \pm 17$), and S1 ($N = 13 \pm 13$), while estimates for S2 were considerably lower ($N = 4 \pm 3$).

Daily sampling conditions

Stream discharge and water temperature varied considerably among sampling dates. The lowest mean discharge (0.3 cms) and warmest mean water temperatures (16.5 °C) occurred in Fall 2016, whereas the highest discharge rates (9.8 and 9.0 cms, respectively) and coldest temperatures (3.7 and 2.3 °C, respectively) occurred in spring 2017 and winter 2017. Stream discharge (5.7 cms) and water temperatures (8 °C) were moderate in Spring 2016. Daily trout capture rates and the estimated proportion of OCP that could be sampled each day were negatively correlated with stream discharge (r^2 = 0.816 and 0.839, respectively; n = 8). The mean proportion of S1 (the deepest site) sampled during the study (35%) was considerably lower than the other 3 sites (min–max: 78–90%).

Table 2. Seasonal values for total number of trout captured (*n*), the number of small trout (ST), medium trout (MT), and large trout (LT) captured, and estimated population abundance (*N*) with standard error (SE) in Oatka Creek Park (Garbutt, Monroe County, NY) during spring 2016 (Sp-16), fall 2016 (F-16), winter 2017 (W-17), and spring 2017 (Sp-17).

	Season				
Variable	Sp-16	F-16	W-17	Sp-17	Total
n	33	47	15	5	100
ST *(n)*	27	7	5	3	42
MT *(n)*	2	28	3	0	33
LT *(n)*	4	12	7	2	25
N (SE)	95 (44.3)	85 (25.8)	72 (48.0)	10 (5.0)	-

Trout size classes

Brown Trout captured during the study varied from 101 to 512 mm TL (mean: 236 ± 101.5 mm TL) (Fig. 2). Most of the trout were placed into the age 1, age 2, and age 3+ year-classes (n = 34, 33, and 25, respectively), and nearly 40% (n = 7) of the fish in the age-3+ year-class were larger than 400 mm TL. The size class of small trout (TL < 200 mm) was represented by the greatest number of individuals (n = 42), while the large size class had the smallest number (n = 25), and the medium size class accounted for the remaining 33 trout (Table 2). The number of large trout captured was similar among sites; however, S3 and S4 supported the greatest abundance of small trout and medium trout, while S2 supported the fewest (Fig. 3).

Habitat use

The mean stream depth used by Brown Trout (55 ± 25.2 cm) was similar to the mean available depth in OCP (57 cm; $P = 0.510$, t [177] = 0.660; Table 1). In contrast, current velocities used by trout (14 ± 15.1 cm/s) were significantly slower than mean available velocities (37 cm/s; $P < 0.001$, t [154] = 9.014; Table 1). 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; Table 1). Trout frequently used areas with sand/silt, cobble, pebble, and gravel (used by 80–68% of trout), while the number of fish using boulders (45%) and slate (32%) substrate size was considerably lower.

Every trout collected was associated with at least 1 type of cover. Roughly half of these fish (52%) were associated with 2 or more cover types, while 14% used 3 types of cover. Nearly every trout collected (94%) was associated with at least 1 type of structural cover, whereas less than half (44%) of the captured trout used at least 1 type of non-structural cover. Large woody debris and boulders were the

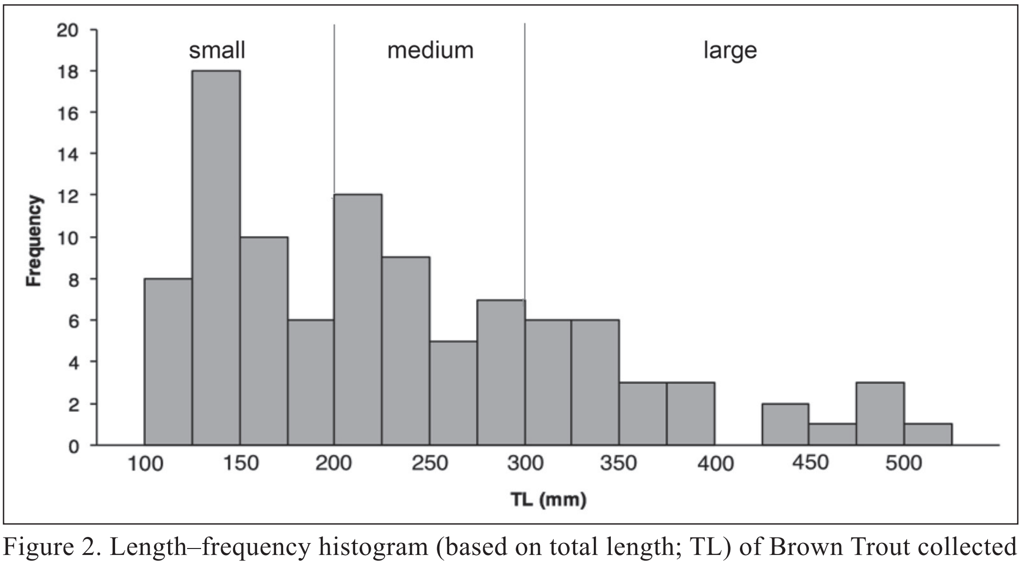

Figure 2. Length–frequency histogram (based on total length; TL) of Brown Trout collected in Oatka Creek Park (Garbutt, Monroe County, NY) from March 2016 to April 2017 (n = 100).

most used cover types (i.e., used by 57 and 45% of trout collected, respectively), while both non-structural cover types (i.e., turbulence: 28% and CD: 19%) were used more commonly than SAV (12%) and UCB (5%) (Fig. 4). Significant differences were detected between the proportion of trout using each structural cover type

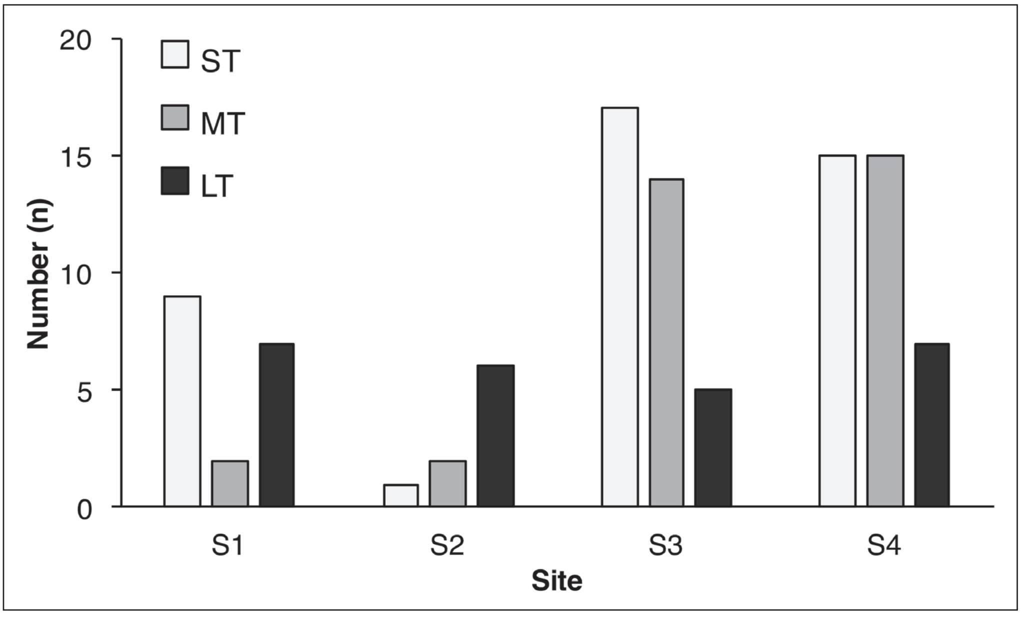

Figure 3. Frequency of small (ST), medium (MT), and large (LT) Brown Trout collected at each site (S1–S4) in Oatka Creek Park (Garbutt, Monroe County, NY) from March 2016 to April 2017 (n = 100).

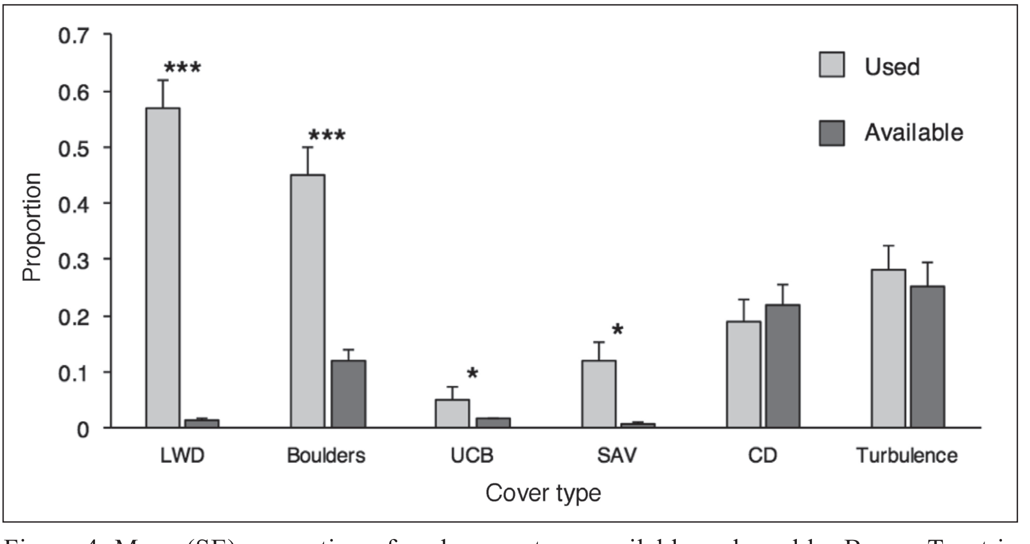

Figure 4. Mean (SE) proportion of each cover type available and used by Brown Trout in Oatka Creek Park (Garbutt, Monroe County, NY) from March 2016 to April 2017 (LWD = large woody debris; UCB = undercut bank; SAV = submerged aquatic vegetation; and CD = concealing depths). *$P < 0.05$ and ***$P < 0.001$ (2-sample t-test used to detect differences).

(i.e., LWD, boulders, UCB, and SAV) and the proportion of each type available in OCP ($P < 0.05$; Fig. 4.). Large woody debris was the most used cover type during periods with moderate-to-high stream discharge; however, boulders were the most used cover type during low discharge (Fall 2016).

Large woody debris and boulders were commonly used by all size classes of Brown Trout (i.e., LWD used by 46–64% of size classes and boulders used by 40–49%; Fig. 5). Turbulence was also commonly used by small- and medium-size trout (26 and 42%, respectively), while CD was used by 52% of large trout. The proportion of trout in each size class using CD increased with trout size ($r = 0.929$; $n = 3$).

Discussion

Seasonal trout population changes

The overall decrease in apparent survival throughout the study suggests that mortality or emigration had occurred in OCP from spring 2016 to spring 2017. When the study began, 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 factors such as natural mortality may have contributed to poor survival rates in OCP, stream conditions at the time of backpack electrofishing likely had the greatest effect on daily capture rates (e.g., Reynolds 1996, Zalewski and Cowx 1990).

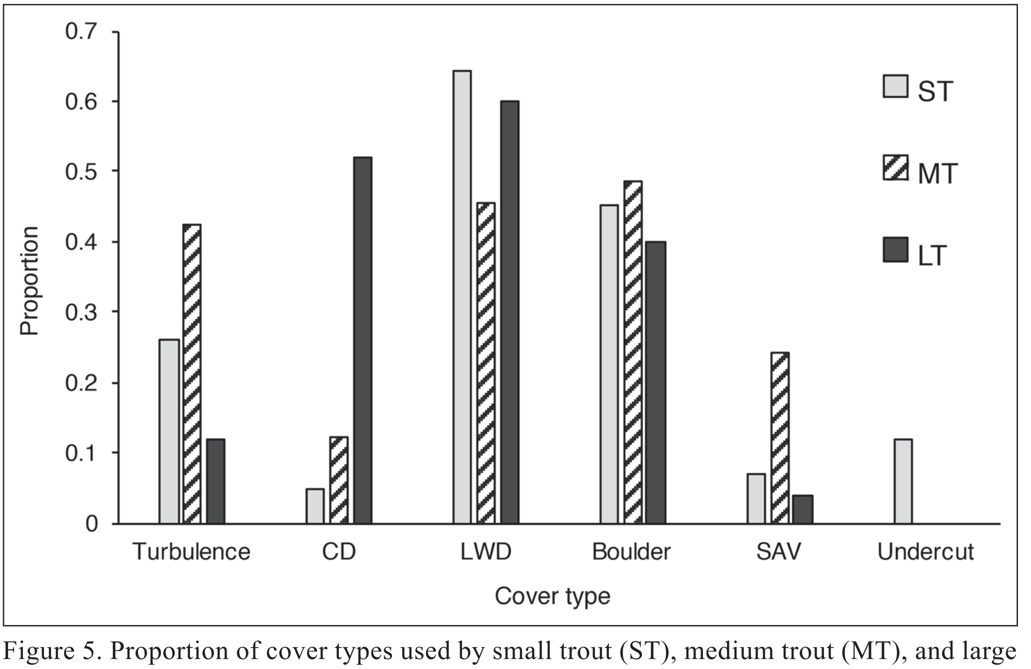

Figure 5. Proportion of cover types used by small trout (ST), medium trout (MT), and large trout (LT) in Oatka Creek Park (Garbutt, Monroe County, NY) from March 2016 to April 2017 (LWD = large woody debris; UCB = undercut bank; SAV = submerged aquatic vegetation; and CD = concealing depths).

Trout population estimates and size-class distributions vs. habitat by site

Site comparisons of trout-capture rates and population estimates for a given day provide insight about the relative abundance of suitable habitat for Brown Trout within each site for the environmental conditions at the time of sampling. Sites that consistently ranked among the most productive (i.e., S1 and S4) had the greatest habitat diversity, as suitable habitat for trout was available under a broad range of stream conditions. Those sites were characterized as having abundant structural cover (i.e., S1 had the greatest boulder density; S4 had the greatest LWD density among 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).

The abundance of a given size class was correlated with the availability of quality habitat required by that specific size class. For example, the limited abundance of small trout at S2 indicates that the lack of structural cover, depth, velocity variability, and non-slate substrate provided little habitat suitable for smaller individuals. On the other hand, S1, S3, and S4 all provided suitable habitat for small trout because they all had abundant structural complexity located along shallower habitats with variable current velocities and substrates composed primarily of pebbles, cobble, and boulders.

In contrast, the frequency of large trout captured was similar among the 4 sites. This uniform distribution of large trout suggests that habitat requirements of Brown Trout become less strict as body size increases or mobility increases (Clapp et al. 1990, Shetter 1968). Both factors likely are related to a decrease in the number of potential predators. Greater mobility of large trout could account for the increased abundance of large trout at S2, which had poor habitat quality with limited complexity during low discharge events. Also, since large, stream-dwelling Brown Trout are piscivores (Clapp et al. 1990), they can occupy a greater range of habitat types because they spend less time foraging.

Length-frequency and year-class distributions

The length–frequency and year-class distributions for the study were typical of streams of this size, other than the lack of age-0 (or young-of-the-year [YOY]) trout (TL < 125 mm). Low capture rates of smaller fish were likely due to sampling biases rather than low abundance, as electrofishing is considered a size-specific sampling method (Reynolds 1996, Zalewski and Cowx 1990). Also, many YOY trout were observed during the study that could not be captured due to their preference for complex habitats with dense structural cover (e.g., boulders, woody debris, UCB) located along swift-to-moderate currents. Therefore, many of the smaller immobilized fish remained protected in dense cover or quickly drifted downstream with the fast current. Relatively typical year-class distributions of cohorts of older trout (age-1+) likely indicate that the population is recovering and may continue to recover if mergansers remain absent. The high abundance of trout >400 mm TL may also suggest that trout can reach greater sizes in OCP at lower densities (i.e., greater resource availability, reduced competition maximize growth and survival rates, and release regulations).

Important habitat features

Current velocity refuges and the presence of structural cover (especially LWD and boulders) were the most important habitat features for Brown Trout. Similar habitat preferences were described by Cunjak and Power (1987). 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-to-moderate currents were important for small trout. LWD was the most preferred cover type for Brown 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). Correlations between the volume of woody debris and the abundance of overwintering, stream-dwelling salmonids has been reported previously (McMahon and Hartman 1989, Tschaplinski and Hartman 1983). Boulders were also favored, but the availability of boulders capable of providing sufficient cover may have been limited in otherwise 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 appeared unproductive under normal stream conditions provided critical refuge during extreme events.

Availability of quality trout habitat

Quality habitat for Brown Trout 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 are the most suitable 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 population of wild trout. 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 (Ayllón et al. 2010), 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).

Management recommendations

The population of Brown Trout in OCP seems to be recovering from the reported predation by mergansers, and habitat quality does not seem to be a major limiting factor in OCP (under most conditions). If NYSDEC seeks to take actions, increasing the availability of complex, diverse habitats with cover throughout OCP could help reduce future predation by mergansers on small trout (<200 mm TL) because they are the preferred prey of mergansers and may 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 macroinvertebrate production. Attempts to increase the abundance of habitat for small trout should focus on enhancing areas with shallow-to-moderate depths, variable current velocities, and coarse substrates by adding complex patches of LWD along the stream margin or creating cobble–boulder complexes. Dead ash trees common 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 Brown Trout of all sizes during low-discharge events.

If funding is available, it may also be beneficial to build structures in some less productive areas of OCP. Rosi-Marshall et al. (2006) reported a 3-fold increase in the relative abundance of harvestable trout (>250 mm TL) following the construction of skybooms (which imitate UCB structures) in a small Michigan stream. Such structures should be placed 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).

Ultimately, the success of habitat manipulation projects in OCP should be measured by the abundance of small Brown Trout that can grow to the size desired by fishermen. Data provided by size-class distributions of the trout population and diversity and abundance of the aquatic macroinvertebrate community may also be useful. Habitat modifications should be made only at a few areas initially; monitoring and adaptive management should then determine if, and where, additional manipulations should be performed.

We suggest that release of additional hatchery-reared Brown Trout in and around OCP during periods of low abundance might be avoided (i.e., maintain pre-merganser stocking levels), as this could reduce the survival and recruitment of wild fish (e.g., degrade wild gene pool and increase competition). Wild salmonids have greater fitness and survival, are more resistant to environmental changes, and are less vulnerable to predation than their hatchery-reared counterparts (Chilcote 2003, Jackson and Brown 2011, Waples 1991). Although the trout population might be slower to recover without additional stocking, a more sustainable and genetically diverse population that is well adapted to the environment would ultimately emerge. Continuation of no-kill, catch-and-release regulations in OCP would obviously be beneficial, as would continued monitoring across different stream-flow conditions.

Should mergansers return, increased knowledge of their rates of predation 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 could be based on abundance of mergansers, foraging patterns, and stomach-content analyses. 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 predation on Brown Trout throughout the winter.

Acknowledgments

We thank Drs. James Haynes and Jacques Rinchard for providing valuable feedback on earlier drafts of the manuscript. Special thanks go to R.J. Sciarrone for helping collect trout each season. We also thank NYSDEC biologist Matt Sanderson and Cal Curtice from the Seth Green Chapter of Trout Unlimited for providing information about the Oatka Creek trout fishery.

Literature Cited

Ayllón, D., A. Almodóvar, G.G. Nicola, and B. Elvira. 2010. Ontogenetic and spatial variations in Brown Trout habitat selection. Ecology of Freshwater Fish 19:420–432.

Bain, M.B., J.T. Finn, and H.E. Booke. 1985. Quantifying stream substrate for habitat analysis studies. North American Journal of Fisheries Management 5:499–500.

Boussu, M.F. 1953. Relationship between trout populations and cover on a small stream. Journal of Wildlife Management 18:229–239.

Chilcote, M.W. 2003. Relationship between natural productivity and the frequency of wild fish in mixed spawning populations of wild and hatchery Steelhead (*Oncorhynchus mykiss*). Canadian Journal of Fisheries and Aquatic Sciences 60:1057–1067.

Clapp, D.F., R.D. Clark Jr., and J.S. Diana. 1990. Range, activity, and habitat of large, free-ranging Brown Trout in a Michigan stream. Transactions of the American Fisheries Society 119:1022–1034.

Cummins, K.W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. American Midland Naturalist 67:477–504.

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences 53:267–282.

Cunjak, R.A., and G. Power. 1986. Winter habitat utilization by stream resident Brook Trout (*Salvelinus fontinalis*) and Brown Trout (*Salmo trutta*). Canadian Journal of Fisheries and Aquatic Sciences 43:1970–1981.

Cunjak, R.A., and G. Power. 1987. The feeding and energetics of stream-resident trout in winter. Journal of Fish Biology 31:493–511.

Dowling, C.B., M.J. Renz, A.G. Hunt, and R.J. Poreda. 2001. The geochemistry of Oatka Creek, New York State. Report to Oatka Creek Watershed Committee. Available online at http://oatka.org/wp-content/uploads/docs/OatkaCreekGeochem.PDF. Accessed October 2019.

Engström, H. 2001. Long-term effects of cormorant predation on fish communities and fishery in a freshwater lake. Ecography 24:127–138.

Hartman, G.F. 1963. Observation of behavior of juvenile Brown Trout in a stream aquarium during winter and spring. Journal of Fisheries Research Board of Canada 20:769–787.

Heggenes, J., and R. Borgstrøm. 1988. Effect of Mink, *Mustela vision* Schreber, predation on cohorts of juvenile Atlantic Salmon, *Salmo salar* L., and Brown Trout, *S. trutta* L., in three small streams. Journal of Fish Biology 33:885–894.

Jackson, C.D., and G.E. Brown. 2011. Differences in antipredator behavior between wild and hatchery-reared juvenile Atlantic Salmon (*Salmo salar*) under seminatural conditions. Canadian Journal of Fisheries and Aquatic Sciences 68:2157–2166.

Johnsson, J.I., A. Rydeborg, and L.F. Sundstrom. 2004. Predation risk and the territory value of cover: An experimental study. Behavioral Ecology and Sociobiology 56:388–392.

Leonard, J.W., and D.S. Shetter. 1937. Studies on merganser depredations in Michigan trout waters. Transactions of the American Fisheries Society 66:335–337.

McMahon, T.E., and G.F. Hartman. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile Coho Salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 46:1551–1557.

Mitro, M.G., and A.V. Zale. 2002. Seasonal survival, movement, and habitat use of age-0 Rainbow Trout in the Henrys Fork of the Snake River, Idaho. Transactions of the American Fisheries Society 131:271–286.

NYSDEC. 2018. Spring 2018 trout stocking for Monroe County. Albany, NY. Available online at https://www.dec.ny.gov/outdoor/23313.html. Accessed 15 March 2018.

Platts, W.S., W.F. Megahan, and W.G. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. General Technical Report INT-138. United States Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. 70 pp.

Power, G., and J. Mitchell. 1994. The influence of river ice on birds and mammals. Pp. 315–330, *In* T.D. Prowse (Ed.). Proceedings of the workshop on environmental aspects of river ice. National Hydrology Research Institute, Saskatoon, SK, Canada. 390 pp.

Reynolds, J.B. 1996. Electrofishing. Pp. 221–253, *In* B.R. Murphy and D.W. Willis (Eds.). Fisheries Techniques, Second Edition. American Fisheries Society, Bethesda, MD.

Ricker, W.E. 1975. Vital statistics from marking: single season experiments. Pp. 75–104, *In* J.C. Stevenson, J. Watson, R.H. Wigmore, and J.M. Reinhart (Eds.). Computation and Interpretation of Biological Statistics of Fish Populations. Fisheries Research Board of Canada, Bulletin 191. Department of the Environment Fisheries and Marine Service, Ottawa, ON, Canada. 382 pp.

Rosi-Marshall, E.J., A.H. Moerke, and G.A. Lamberti. 2006. Ecological responses to trout habitat rehabilitation in a northern Michigan stream. Environmental Management 38:99–107.

Salyer, C.J., and K.F. Lagler. 1940. The food and habits of the American Merganser during winter in Michigan, considered in relation to fish management. Journal of Wildlife Management 4:186–219.

Sanderson, M. 2007. The effect of a no-kill regulation on biomass, abundance, and growth of Brown Trout (*Salmo trutta*) in Oatka Creek. New York State Department of Environmental Conservation, Region 8 Bureau of Fisheries, Avon, NY.

Shetter, D.S. 1968. Observations on movements of wild trout in two Michigan stream drainages. Transactions of the American Fisheries Society 97:472–480.

Stevenson, N.J., and M.B. Bain. 1999. Cover and refuge. Pp. 105–114, *In* M.B. Bain and N.J. Stevenson (Eds.). Aquatic Habitat Assessment: Common Methods. American Fisheries Society, Bethesda, MD. 224 pp.

Stiller, J.C. 2011. Effects of Common Merganser on hatchery-reared Brown Trout and spring movements of adult males in southeastern New York, USA. M.Sc. Thesis. SUNY College of Environmental Science and Forestry, Syracuse, NY.

Suter, W. 1995. The effect of predation by wintering Cormorants, *Phalacrocorax carbo*, on Grayling, *Thymallus thymallus*, and trout (Salmonidae) populations: Two case studies from Swiss rivers. Journal of Applied Ecology 32:29–46.

Tatakis, T.A. 2002. State of the Basin Report: The Oatka Creek Watershed. Rochester Area Community Foundation, Rochester, NY.

Tschaplinski, P.J., and G.F. Hartman. 1983. Winter distribution of juvenile Coho Salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. Canadian Journal of Fisheries and Aquatic Sciences 40:452–61.

US Geological Survey (USGS). 2018. National Water Information System: Web interface. USGS 04230500, Oatka Creek at Garbutt, NY. Available online at https://waterdata.usgs.gov/usa/nwis/uv?site_no=04230500. Accessed 11 February 2018.

Waples, R.S. 1991. Genetic interactions between hatchery and wild salmonids: Lessons from the Pacific northwest. Canadian Journal of Fisheries and Aquatic Sciences 48:124–133.

Wood, C.C. 1987. Predation of juvenile Pacific salmon by the Common Merganser (*Mergus merganser*) on eastern Vancouver Island. I: Predation during seaward migration. Canadian Journal of Fisheries and Aquatic Sciences 44:941–949.

Wood, C.C., and C.M. Hand. 1985. Food-searching behavior of the Common Merganser (*Mergus merganser*). I: Functional responses to prey and predator densities. Canadian Journal of Zoology 63:1260–1270.

Zalewski, M., and I.G. Cowx. 1990. Factors affecting the efficiency of electric fishing. Pp. 89–111, *In* I.G. Cowx and P. Lamarque (Eds.). Fishing with Electricity: Applications in Freshwater Fisheries Management. Fishing News Books, Oxford, UK. 248 pp.