Centrarchid Utilization and Attraction to Newly Remediated Habitat and Structure in an Urban Lake, Syracuse, New York

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CENTRARCHID UTILIZATION AND ATTRACTION TO NEWLY REMEDIATED HABITAT AND STRUCTURE IN AN URBAN LAKE, SYRACUSE, NEW YORK

by

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A thesis submitted in partial fulfillment of the requirements for the Master of Science Degree
State University of New York
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Syracuse, New York
April 2018

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Abstract


Onondaga Lake in Syracuse, New York, has experienced centuries of habitat degradation. A new substrate layer and habitat structures were added to enhance fish habitat. We hypothesized that centrarchids would respond to the enhancements. We examined centrarchid population size, reproduction, and recruitment relative to remediated habitat and their use of existing and new structures. The Largemouth Bass population and juvenile centrarchid catches were distributed more evenly between basins in 2017 than in previous years, and we concluded this is very likely an immediate response to new habitat availability and structure. In 2017, the whole-lake population estimate was the second highest recorded since sampling began in 1986, and the proportion of nests in remediated shoreline areas increased. Depth of the structures did not influence fish attraction; vegetated and grouped sites attracted greater richness and diversity, and more black bass visits than individual sites or structures.

Key Words: Habitat, habitat layer, habitat structure, centrarchid, remediated, Onondaga Lake, urban, vegetation, nest, camera

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Chapter 1: Historical trends and the immediate response of the Largemouth Bass population and reproduction and recruitment of centrarchids to newly remediated habitat in an urban lake

Introduction

Onondaga Lake is a medium-sized (1200 ha), urban lake located within the city limits of Syracuse, New York. The lake is oriented northwest to southwest and is, at maximum, 7.6 km long and 2.0 km wide with an average depth of 12 m. A saddle across the center of the lake divides the bathymetry into distinct north and south basins (Effler and Harnett 1996). A maximum depth of 20 m is located in the south basin. Since the late eighteenth century, the lake has undergone physical, biological and chemical changes as a result of urban development and industrialization. More than a century of municipal and industrial pollution has degraded the lake’s water quality and suitable habitat for historic and current biota.

Urban development and poorly regulated waste water treatment increased nutrient loading and reduced water quality in Onondaga Lake until the Syracuse Metropolitan Sewage Treatment Plant (METRO) received a series of upgrades from 1979 to 2004 (Effler and Harnett 1996). Excessively high N and P inputs from the city promoted algal growth and overall primary production, especially in the south basin (Matthews et al. 2001). Algal blooms caused seasonal anoxic conditions that were toxic to aquatic biota. The effects of eutrophication resulted in seasonal migration of fish species away from the system (Ringler et al. 1996). METRO was upgraded to a tertiary treatment facility by 1981 and received additional upgrades through 2004 to abide by state and federal pollution legislation (Effler and Harnett 1996; Onondaga Lake Improvement Project 1999).
In addition, water quality and physical habitat availability in Onondaga Lake was impacted by industrial pollution. For centuries, natural salt beds located in the Tully Valley region south of Syracuse were mined and exported (Perkins and Romanowicz 1996). In 1884, Solvay Process, renamed Allied Signal, established a commercial soda ash industry on the southwestern shoreline that utilized brine for production (Tully 1985). Soda ash and chlor-alkali facilities remained active until 1986 (Effler and Harnett 1996).

From 1884 to 1986, industrial waste byproducts were stored in wastebeds along Ninemile Creek and the western shoreline. Solid waste, primarily calcium carbonate, CaCO$_3$, reduced shoreline littoral habitat availability and quality by replacing natural substrate with layers of silty particulate and low-density, gravel sized, calcified oncolites. Biological effects of these pollutants included the reduction of species richness and diversity of communities (Matthews and Effler 2006; Madsen et al. 1996). The remaining effluent, including Cl$^-$, Na$^+$, Ca$^+$, mercury, and multiple organic compound pollutants, were washed directly into the lake (Effler and Harnett 1996). As a result, lake water had greater ionic conductivity and mercury accumulated in sediment and bioaccumulated in biota (Driscoll and Weng 1996; Ringler et al. 1996).

Urban and industrial development has altered the fishery of Onondaga Lake. The southern end of the lake was directly affected by warmer, flowing effluent from METRO and industrial cooling water. These inputs reduced annual ice formation, and greater ionic conductivity increased density gradients. The combination of these inputs altered the lake’s mixing regime and thermal structure (Effler and Hennigan 1996; Owens and Effler 1989). Onondaga Lake was once an oligo-mesotrophic lake with coldwater fishes such as Atlantic Salmon (Salmo salar) and Cisco (Coregonus artedi) (Rowell 1996). These species were extirpated from the system by the turn of the nineteenth century due to poorly oxygenated,
warmer water, and habitat degradation. The current fish community is dominated by warmwater species (Ringler et al. 1996; Tango and Ringler 1996; Thompson 2007; Kirby 2009). The legacy of anthropogenic pollution has drastically altered the ecology in the lake. Consequently, the lake is now managed as a warmwater fishery with remediation objectives referencing lakes in the Finger Lakes region, such as Otisco Lake.

Onondaga Lake was listed on the Federal Superfund National Priorities List and later designated an Environmental Protection Agency (EPA) Superfund site in 1994 (CNYRPDB 2010). By 2008, Allied Signal’s predecessor, Honeywell International, agreed to fund a portion of the remediation efforts and developed the Onondaga Lake Bottom Cleanup Plan under management by the New York State Department of Environmental Conservation (NYSDEC). From 2012 to 2016, remediation work included dredging and capping projects that replaced contaminated sediment with new substrate along the south and southwestern shoreline of the lake. After the dredging and capping process, continued remediation efforts were focused on ecological and recreational enhancements (Parsons 2009).

Two major objectives of the ecological and recreational improvements were to improve overall littoral aquatic habitat on the south and southwestern shoreline and to enhance the warmwater sports fishery. Aquatic habitat improvements included the implementation of a habitat layer of varying substrate size. This layer was designed to promote reestablishment of aquatic vegetation, macroinvertebrate, and fish communities (Vlassopoulos et al. 2017). Additional habitat installations included wetland plantings and structure implementation designed to provide habitat complexity for sportfish.

The urban setting of Onondaga Lake makes it highly accessible for recreational fishing. Freshwater recreational sports fishing in New York State was estimated in 1988 to exceed $284
million (Connelly and Brown 1991). Although this value is dated, the baseline economic assessment highlighted that 76% of the statewide net economic value of sports fishing came from freshwater systems. More recently, New York was designated as one of five top destination states for nonresident recreationalists (Ditton et al. 2002). The remediated habitat features in Onondaga Lake are expected to attract popular warmwater sportfish and the broader fish community (Parsons 2009).

Tango and Ringler (1996) summarized historical fish community surveys in Onondaga Lake from 1927 to 1994. Species richness increased from 10 to 12 species from 1927 to 1969 and then from 22 to 45 species from 1980 to 1994. The influx of warmwater, pollution tolerant species was suggested to be related to system connectivity to the Seneca River. The mesotrophic, warmer conditions in the lake are favorable to the Centrarchidae family of sportfish, including: Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*Micropterus dolomieu*), Pumpkinseed (*Lepomis gibbosus*), and Bluegill (*Lepomis macrochirus*). All these species were present in the lake by 1969 (Ringler and Tango 1996).

Scientists at the State University of New York College of Environmental Science and Forestry (SUNY ESF) have greatly contributed to the biological monitoring work on Onondaga Lake. SUNY ESF has conducted aquatic research independently since 1986 and in conjunction with the remediation efforts since 2008. Specific research on centrarchid reproduction, recruitment, and populations began in 1991. This research included annual population estimates for adult Largemouth Bass as well as centrarchid nest and juvenile abundance surveys that provided critical information on the centrarchid response to habitat degradation, perturbation, and enhancements over time.
From 1991 to 2016, habitat and water quality changes in Onondaga Lake have also enhanced the ability of centrarchids to carry out specific life history requirements for reproduction and recruitment. Black bass and sunfish species require protected, heterogeneous shoreline habitat for reproductive success. The aforementioned centrarchid sportfish all construct nests on sand or gravel substrates (Mraz et al. 1961). Black bass prefer the presence of vegetation or structure including stumps, logs and boulders (Cleary 1956; Hunsaker and Crawford 1964). Compared to black bass, Pumpkinseed and Bluegill sunfishes build nests in clusters and on finer gravels and sands (Keenleyside 1967). These sunfish species also nest in areas with less woody debris (Colgan and Ealey 1973). The recolonization of submerged vegetation in littoral habitat of the lake has enhanced habitat heterogeneity preferred by nesting centrarchid species.

SUNY ESF has conducted centrarchid nest surveys in Onondaga Lake since 1991. Ringler et al. (1996) and Arrigo (1998) conducted preliminary nest surveys of the entire shoreline in 1991 and 1993 through 1994. Whole-lake nest abundances ranged from 1277 to 1655 nests, and the majority (77% to 79%) of nests were located in the north basin (Arrigo 1998). Additional nest surveys were conducted in 2007, 2012, and 2014. Kirby’s (2009) 2007 nest survey was conducted for the entirety of the shoreline, while the 2012 and 2014 surveys were limited by dredging and capping activity. By 2007, water clarity in Onondaga Lake had improved and submerged vegetation recolonized much of the littoral habitat due to METRO facility upgrades. During the 2007 nesting season, 10,236, centrarchid nests were observed (Kirby 2009). Increased macrophyte abundance was determined to be causal factor for this drastic increase in total nests. Seventy-nine percent of these nests were in the north basin. Abbreviated nest surveys in 2012 and 2014 totaled 1,918 and 900 centrarchid nests, respectively.
(SUNY ESF unpublished data). Similar to 2007, the majority of these nests were in the north basin (72% and 81%, respectively).

Recruitment of juvenile centrarchid species is dependent on littoral vegetation and wetland connectivity as suitable habitat for predator avoidance. Recruitment of catchable, adult centrarchids is also dependent on habitat complexity, including submerged vegetation, for hunting and cover (Miranda and Pugh 1997). Prior to METRO upgrades, increased nutrient loading and turbidity in Onondaga Lake reduced water clarity and, thus, macrophyte diversity and growth (Thompson 2007). Kirby (2009) found reduced nutrient loading after METRO upgrades improved visibility and increased macrophyte richness and distribution. The species composition of young-of-year (YOY) from 1992 to 1994 and 2000 to 2004, were dominated by centrarchid species, primarily in the north basin (Arrigo 1998; Thompson 2007). In 2007, Kirby (2009) found similar results and suggested silt layers of CaCO$_3$ particulate and low-density, oncolite substrate in degraded areas of the southern basin continued to limited root propagation and macrophyte growth and, therefore, juvenile recruitment.

Projects that enhance littoral habitat substrate, such as muck removal to expose coarser substrate, have been found to increase nest habitat and recruitment of Largemouth Bass (Allen et al. 2003). The habitat layer implemented in remediated areas of Onondaga Lake is designed to provide loose, round gravel substrate at depths up to 9.0 m (Parsons 2009). At depths less than 2.0 m, which is preferred centrarchid nesting habitat, the habitat layer is greater in thickness (0.46 m to 0.61 m) to promote root propagation. A combination of favorable substrate and vegetation is expected to provide habitat in remediated areas to be utilized for reproduction and recruitment. Based on life history requirements of centrarchids and their dominance in the
Onondaga Lake fish community, we hypothesized this family of fish would respond to new habitat availability and enhancement.

From 2008 to 2016, there were multiple reproduction and recruitment surveys and adult Largemouth Bass population estimates before and during remediation efforts. This research synthesized long-term monitoring with 2017 sampling and analyzed the response of centrarchids to changes in habitat availability throughout the remediation timeline: before (prior to 2012), during (2012 through 2016) and after (2017). The objectives of this research were to:

1. Identify trends in adult ‘quality’ (>300 mm) Largemouth Bass population estimates from 2008 through 2017 as they relate to changes in habitat quality and availability: before, during, and immediately after remediation.

2. In addition, determine the catchability of adult Largemouth Bass in Onondaga Lake from population estimate data as a tool for future, long-term assessment.

3. Determine centrarchid nest abundances throughout the entire shoreline of Onondaga Lake during the first nesting season after remediation and to compare 2017 abundances and distribution of nests to surveys conducted before and during remediation.

4. Identify trends in average juvenile centrarchid catches in Onondaga Lake littoral habitat by year, sample site, and basin from 2010 through 2017 as they relate to changes in habitat quality and availability: before, during, and immediately after remediation.
Methods

*Largemouth Bass Population Estimates and Catchability*

Population estimates and catchability for ‘quality’ (>300 mm) Largemouth Bass were calculated by mark-recapture study methods. A 5.49 m Smith-Root electrofishing boat was used in Onondaga Lake from June 2, 2017 through July 6, 2017 and from November 8 through 17, 2017. The electrofishing boat generated 20 to 25 A by pulsing 170 V at 120 Hz.

The entire shoreline of Onondaga Lake was sampled counter clockwise in four rounds, each lasting roughly one week. Three consecutive rounds were completed in the spring and an additional fourth round in the fall to increase population estimate accuracy. The shoreline was divided into 21 sampling transects (Figure 1). Each transect was sampled in one direction and parallel to shoreline at 1.0 m in depth. This sampling depth is most effective at targeting adult Largemouth Bass utilizing littoral habitat, specifically during spring nesting activity (McInerny and Cross 2000).
Figure 1. Electrofishing sampling transects marked on the shoreline of Onondaga Lake. Center line illustrates the division of transects used by Hurley (2015) to determine population estimates and catchability in north and south basins.
A field crew consisted of one operator and two netters and would conduct sampling after sunset in calm weather conditions. Netters were instructed to collect all Largemouth Bass observed. Fish were stored in a live well for the duration of each sampling period, roughly 25 minutes, for each transect. Fish were subsequently processed and released.

Similar to past sampling methods, quality Largemouth Bass (>300 mm) were recorded as captures. Quality length is considered the total length of a Largemouth Bass considered legal size (Anderson 1978). These individuals were marked by a left half-pelvic fin clip and T-bar anchor tag containing a unique numerical code and contact information. Each tag was implanted into epaxial muscle at the third dorsal spine. Any captured fish with these markers were recorded as recaptures, re-measured, and released.

Data Analysis

SUNY ESF has made population estimates for quality (>300 mm) Largemouth Bass in Onondaga Lake since 2008. The 2017 Largemouth Bass (>300 mm) population estimates were made for the entire lake and for the north and south basins (Figure 1). As in previous years, estimates were made using the Schnabel method. The Schnabel method is used based on the assumptions that an estimated population is closed and all captured and marked fish have equal probability of survival compared to the rest of the population, return to normal behavior, and reintegrate with the population (Hayes et al. 2007).

These assumptions were made for the calculations of these population estimates. Largemouth Bass exhibit homing tendencies and stay local relative to littoral structure and vegetation, especially during the spring spawning season. This behavior keeps the population closed within the system. In addition, sampling was one directional, and individual transects were never sampled consecutively within a week-long sampling round. This allowed for
captured and marked fish to recover and reintegrate with the population. Based on these considerations, the following equation was used (Everhart 1975):

\[ \hat{N} = \frac{\sum_{t=1}^{n} C_t M_t}{(\sum_{t=1}^{n} R_t) + 1} \]

where:

- \( \hat{N} \) = the estimated population
- \( M_t \) = the number of marked fish in the population to the \( t \)th sample round
- \( C_t \) = the number of captured fish in the \( t \)th sample round
- \( R_t \) = the number of Largemouth Bass recaptured in the \( t \)th sample round
- \( n \) = the total number of rounds

Variances, \( V \), for the reciprocal of each population estimate were calculated based on the consideration that reciprocal measures are normally distributed and better used to determine confidence intervals (Everhart 1975):

\[ V\left(\frac{1}{\hat{N}}\right) = \frac{\sum_{t=1}^{n} R_t}{(\sum_{t=1}^{n} C_t M_t)^2} \]

Estimated 95% confidence intervals were made using the following equation:

\[ 1/\hat{N} \pm 1.96 \sqrt{V(1/\hat{N})} \]
Catchability was also calculated using the mark-recapture data from 2008 through 2017. This type of assessment can be used as an additional method of estimating abundance for long-term monitoring programs and helps estimate abundance while considering variation in sampling efforts over time (Yoccoz et al. 2001). Due to dredging and capping activities, individual transects were not included year to year or round to round. The following equation was used to calculate catchability:

\[ q = \frac{c}{d} \]

where:

- \( q \) = catchability
- \( c \) = total number of recaptured individuals
- \( d \) = total number of captures

Catchability values assume the same population parameters and behavior as the Schnabel method.
**Centrarchid Nest Abundance**

A centrarchid nest survey was conducted from June 8 through 15, 2017, replicating methods used by Kirby (2009). The shoreline was divided into 33 littoral zone segments measuring 500 m long (Figure 2). A survey crew consisted of one operator and one observer. The observer wore polarized sunglasses and visually counted nests overlooking the water while standing on the bow.

![Figure 2. The 2017 shoreline segments (1-33) for nest surveys derived from Kirby (2009), and the 2017 and historic seine shoreline sample sites in Onondaga Lake. Cross-sectional lines illustrate shoreline quadrants and sample sites by north and south basin.](image)
Sampling was conducted during calm, clear weather, and high water clarity. The operator drove a minimum of two transects parallel to shore at 0.5 m and 1.0 m depths per segment while the observer counted all centrarchid (black bass or *Lepomis*) nests. An additional transect 25.0 m from the 1.0 m depth transect, at roughly 1.5 m in depth, was counted in segments with deeper, visible nests. The total number of centrarchid nests was recorded, and distribution of nests was calculated for each quadrant of Onondaga Lake (Figure 2).

**Centrarchid Juvenile Recruitment**

Assessment of the juvenile fish community have been made by SUNY ESF for Onondaga Lake since 2010. Similar to past methods and sample sites, juveniles were sampled from August 8 through August 10, 2017 at 11 shoreline sites. Sites were 30.0 m X 20.0 m in area and enclosed by a 0.5 cm stretched mesh size blocking seine. A 20.0 m long, 0.6 cm stretched mesh size, bag seine was swept three consecutive times in each enclosure. After each sweep, captured fish were held in a live well, processed, and subsequently released outside the enclosure. During processing, fish species and total length were recorded for every individual.

The total catch of centrarchid species (Largemouth Bass, Smallmouth Bass, Pumpkinseed, Bluegill, Rock bass, *Amblolites rupestris*, and Green Sunfish, *Lepomis cyanellus*) was calculated for all 2010 to 2017 sample sites (Figure 2). Due to dredging and capping activity, there was annual variation in sample site accessibility. Therefore, yearly average centrarchid catches were calculated for the entire lake and averaged by sites in the north and south basins.
Results

Largemouth Bass Population Estimates and Catchability

In 2017, 735 Largemouth Bass (>300 mm) were caught during the mark-recapture study. The whole-lake was estimated to have a population of 7,936 (95% confidence interval 5,701-13,052) individuals (Table 1; Figure 3). The estimated population based on 353 caught individuals in the north basin was 4,099 (95% confidence interval 2,577 to 10,021), and the estimated population from 382 caught individuals in the south basin was 3,759 individuals (95% confidence interval 2,467 to 7,893) (Figure 4).

Table 1. Sampling year, author, quality (>300 mm) Largemouth Bass population estimate, 95% confidence intervals and widths, and catchability based on captures (sample size) and recaptures from 2008-2017 sampling efforts. Estimates for 2010 not included due to low number of recaptures. *Sample sizes collected from limited shoreline due to dredging and capping activity.

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Sample Size</th>
<th>Recaptures</th>
<th>Population Estimate</th>
<th>Confidence Interval</th>
<th>Interval Width</th>
<th>Catchability</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Tyszko</td>
<td>339</td>
<td>9</td>
<td>4611</td>
<td>2470-9432</td>
<td>6962</td>
<td>0.026</td>
</tr>
<tr>
<td>2009</td>
<td>Tyszko</td>
<td>536</td>
<td>35</td>
<td>4752</td>
<td>3246-7244</td>
<td>3998</td>
<td>0.065</td>
</tr>
<tr>
<td>2010</td>
<td>ESF</td>
<td>199*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>ESF</td>
<td>279</td>
<td>5</td>
<td>5108</td>
<td>2837-25562</td>
<td>22725</td>
<td>0.018</td>
</tr>
<tr>
<td>2012</td>
<td>ESF</td>
<td>309</td>
<td>14</td>
<td>1930</td>
<td>1297-3777</td>
<td>2480</td>
<td>0.045</td>
</tr>
<tr>
<td>2013</td>
<td>Hurley</td>
<td>589*</td>
<td>33</td>
<td>3819</td>
<td>2858-5751</td>
<td>2893</td>
<td>0.056</td>
</tr>
<tr>
<td>2014</td>
<td>Hurley</td>
<td>444*</td>
<td>13</td>
<td>7414</td>
<td>4809-16178</td>
<td>11369</td>
<td>0.029</td>
</tr>
<tr>
<td>2015</td>
<td>ESF</td>
<td>429*</td>
<td>6</td>
<td>9636</td>
<td>5716-30674</td>
<td>24958</td>
<td>0.014</td>
</tr>
<tr>
<td>2016</td>
<td>ESF</td>
<td>359*</td>
<td>14</td>
<td>3158</td>
<td>2121-6180</td>
<td>4059</td>
<td>0.039</td>
</tr>
<tr>
<td>2017</td>
<td>Hummel</td>
<td>735</td>
<td>25</td>
<td>7936</td>
<td>5701-13052</td>
<td>7351</td>
<td>0.034</td>
</tr>
</tbody>
</table>
The 2017 population estimate was the second highest estimate since 2008. The largest estimate was 9,636 Largemouth Bass (>300 mm) in 2015, however, this estimate was made from a low number of recaptures that resulted in the largest 95% confidence interval width (5,716 to 30,674) (Table 1; Figure 3). In addition, the 2017 population estimate was the most recent estimate since 2013 derived from sampling the entire lake shoreline, and it was the first estimate after dredging and capping efforts were completed.

The whole-lake Largemouth Bass (>300 mm) population estimates and north and south basin distributions from 2017 were compared to 2013 and 2014 assessments. The whole-lake and north basin estimates from 2014 and 2017 were both similar (whole-lake: 7,414 and 7,936, respectively; north basin: 4,217 and 4,099, respectively). In contrast, the 2014 south basin estimate had roughly 1,000 fewer Largemouth Bass (>300 mm) than the 2017 south basin estimate (Figure 3; Figure 4). Both the 2013 and 2014 population distributions had higher
estimates in the north basin versus the south basin, while, the basin estimates in 2017 were more evenly distributed (Figure 4). There was high variability in the 2014 estimates, but Hurley (2015) found the basin estimates in 2013 were significantly different.

Figure 4. Hurley’s (2015) 2013 and 2014 and 2017 Largemouth Bass (>300 mm) Schnabel method population estimates (values labeled) and 95% confidence intervals for the north and south basins in Onondaga Lake.

Variation in whole-lake estimates from 2008 through 2017 may be related to differences in sampling methods and shoreline accessibility. Prior to 2012, four to six complete circuits of the lake were completed once per month throughout sampling seasons (May through November). Efforts since 2012 were adjusted to target Largemouth Bass during nesting season when they have higher catchability rates. These methods were concentrated to four consecutive shoreline circuits during late spring spawning seasons (May through June) to increase the number of recaptures and population estimate accuracy (McInerny and Cross 2000).
Since 2012, the population estimates of Largemouth Bass (>300 mm) have increased, with the exception of the inaccuracy of the highest 2015 estimate and low 2016 estimate (Table 1). Variability in estimates from 2014 through 2016 may have been a result of limited shoreline access during dredging and capping activity. Due to the variation in sampling methods and available shoreline over time, catchability was estimated from total captures and recaptures each year.

The average whole-lake catchability of adult Largemouth Bass (>300 mm) in Onondaga Lake from 2008 through 2017, excluding 2010, was 0.036 with a variance of 2.9X 10^-4 (Figure 5). In 2017, there were 25 total recaptures, with 11 and 14 recaptures in the north and south basins, respectively. The 2017 whole-lake catchability was 0.034, while the north basin catchability was 0.031 and the south basin catchability was 0.037 (Table 1; Figure 5). The sample size was greatest in 2017, and the number of recaptures were greatest in 2009 and 2013. The 2009 recaptures could be correlated to a greater number of sampling circuits that occurred monthly.

![Figure 5](image-url)  
Figure 5. Whole-lake catchability, q, for 2008 to 2009 and 2011 to 2017 for Largemouth Bass (>300 mm) in Onondaga Lake. North, N, and south, S, basin catchability indicated in 2017. Mean catchability from all sample years indicated by dashed line (\(\bar{x} = 0.036; s^2 = 0.00029\)).
Since 2012, with the exception of 2016, there was an observed relationship between catchability and variability of population estimates. Catchabilities were higher when population estimate 95% confidence interval widths were smaller. Catchabilities were highest in 2009 and 2013, and lowest in 2011 and 2015. In 2016, the population estimate was nearly half of the 2017 estimate, while the catchabilities were similar (0.039 in 2016 and 0.034 in 2017) (Table 1; Figure 5). These similar catchabilities suggest that differences in population estimates may have been correlated to variation in sampling efforts. In 2016, sampling was limited by dredging and capping activity and was partially delayed to the fall due to a boat malfunction.

**Centrarchid Nest Abundance**

In 2017, there were 7,538 centrarchid nests observed in Onondaga Lake. Centrarchid species included Bluegill, Pumpkinseed, Largemouth Bass, and Smallmouth Bass. The greatest number of nests were located in the northwest quadrant of the lake (3,469 nests, 46% of total) (Table 2; Figure 6). The southwest quadrant of the lake had the least number of nests (906 nests, 12% of total). The eastern side of the lake contained the remaining 43% of nests, with greater distribution in the northeast (1769 nests, 24% of total) than the southeast quadrant (1394 nests, 18% of total) (Table 2; Figure 6).

<table>
<thead>
<tr>
<th>Quadrant</th>
<th>Centrarchid Nest Count</th>
<th>Centrarchid Nest Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest</td>
<td>471</td>
<td>877</td>
</tr>
<tr>
<td>Northeast</td>
<td>495</td>
<td>423</td>
</tr>
<tr>
<td>Southwest</td>
<td>61</td>
<td>111</td>
</tr>
<tr>
<td>Southeast</td>
<td>250</td>
<td>238</td>
</tr>
<tr>
<td>Total</td>
<td>1277</td>
<td>1655</td>
</tr>
</tbody>
</table>

Figure 6. Number of 2017 centrarchid nests in Onondaga Lake divided by quadrants created in Kirby (2009) assessment.
The majority (68% of total) of the 2017 nests was observed at the 0.5 m depth transect. All quadrants reflected this trend; the northwest (75%), northeast (62%), and southwest (74%) quadrants had a much higher proportion of nests in the shallow transect. The southeast quadrant was more evenly split with 52% of nests at the 0.5 m transect and 47% of the nests at the 1.0 m transect.

Nest counts have been conducted intermittently on Onondaga Lake by SUNY ESF since 1991. Nest counts were first made by Ringler et al. (1996) and were continued by Arrigo (1998) late spring of 1993 and 1994. Abundances ranged from 1,277 to 1,655 centrarchid nests. Since 2007, there have been four additional nesting surveys. The 2007 and 2017 nest counts sampled the entirety of Onondaga Lake shoreline and represent pre and post remediation efforts, while the 2012 and 2014 counts were limited due to capping in dredging (Table 2). These limited sampling seasons were included for comparison based on the assumption that nesting was limited no none in disturbed areas undergoing dredging and capping.

From 2007 through 2014, the highest distributions of nests were observed in the northeast quadrant, while in 2017, the highest distribution of nests was in the northwest quadrant (Table 2). Compared to 2007, the distribution of nests in the southwest quadrant was greater in 2017. The majority of these nests (75%) was observed at the 0.5 m transect. Similarly, the majority (62%) of nests observed in the southwest quadrant in 2007 was along the 0.5 m transect.
**Centrarchid Juvenile Recruitment**

In 2017, there were 4,711 individuals and 18 species sampled by seine; 29% of the total catch was juvenile centrarchid species (Figure 7). These species include: Bluegill, Green Sunfish, Pumpkin Seed, Largemouth Bass, and Smallmouth Bass. Other dominant species included 26% Round Goby (*Neogobius melanostomus*), 24% Banded Killifish (*Fundulus diaphanus*), and 17% Brown Bullhead (*Ameiurus nebulosus*). The majority of observed Brown Bullhead were sampled at new site located near Harbor Brook.

![Figure 7. The 2017 distribution of juvenile fish assemblages in Onondaga Lake sampled by block seine.](image-url)
Compared to the total catches each year, the greatest proportion of juvenile centrarchid species was sampled in 2011 and 2012: 45% centrarchids both years (Figure 8). The proportion of centrarchids decreased to 16% of the total catch in 2014 and has increased to 29% in 2017. However, these values may be skewed due to the variation in site accessibility over time. Sites along the western and southern shoreline had limited accessibility due to dredging and capping activity from 2012 to 2016. For example, the 2012 whole-lake proportion of centrarchids was calculated from four sample sites in the north basin, whereas all other sampling years ranged from seven to eleven lake-wide sample sites distributed throughout both basins.

Figure 8. The 2010 to 2017 percent (%) juvenile centrarchids (labeled) of total seine catches per year in Onondaga Lake.
Figure 9. The 2010 through 2017 total juvenile centrarchid seine catch for all sample sites, separated by basin, and the mean juvenile centrarchid catch per year for the entirety of Onondaga Lake and per basin black, indicated by dashed and solid lines, respectively. *The 690 Point sample site not depicted due to irregularity of sampling years. Catches from this location were included in 2010, 2016, and 2017 whole-lake and basin averages.
Due to the annual variation in sample sites, the mean catches of juvenile centrarchid species each year were calculated for all sites for the entire lake and for sample sites in each basin. Year to year, there was no single site with distinctly higher or lower centrarchid catches that potentially influenced the whole-lake and north or south basin averages (Figure 9). From 2010 through 2014, the mean centrarchid catch in the north basin was slightly greater than the whole-lake average, while the average centrarchid catch in the south basin was slightly less than the whole-lake average, with the exception of 2011 (Figure 10). From 2015 through 2017, the mean centrarchid catches for both basins were relatively equal and fluctuated from year to year. The mean centrarchid catches for both basins reached a similar peak in 2015 and 2017, and both means fell in 2016.

![Graph](image_url)

Figure 10. The 2010 through 2017 mean juvenile centrarchid catch for the entirety of Onondaga Lake and for north and south basins per year.
Discussion

The population estimates for adult Largemouth Bass (>300 mm) and reproduction and recruitment of centrarchids have increased since historical conditions and throughout 2012 to 2016 remediation efforts. Since 2014, annual population estimates were roughly 2,000 Largemouth Bass (>300 mm) greater than previous years. The 2017 whole-lake population estimate was the second largest since 2008, however, the highest estimate made in 2015 had the greatest variability, represented by the largest confidence interval, due to the low number of recaptures. In addition, the 2017 study had the highest number of captures and third highest number of recaptures, following the 2009 and 2013 studies (Tyszko 2010; Hurley 2015). These three sampling years may have had the highest number of recaptures because electrofishing rounds included the all shoreline transects, whereas other years were limited by dredging and capping.

From 2000 through 2015, catch per unit effort (CPUE) data for Onondaga Lake have been collected by the Onondaga County Department of Water Environment Protection (OCDWEP) and SUNY ESF. These assessments have also shown an increase in whole-lake catches of Largemouth Bass. CPUE is a common method of fish stock and abundance estimates made for the individuals in a population vulnerable to the selected sampling gear (Maunder et al. 2006). Since 2000, OCDWEP Ambient Monitoring Program (AMP) has calculated CPUE for adult Largemouth Bass by boat electrofishing. The 2015 AMP report showed an increase in CPUE throughout 2013 to 2015 (OCDWEP 2015). From 2008 to 2012, the CPUE ranged from 22.7 to 28.7 fish/ hour. In 2013, this value peaked at 63.4 fish/ hour and has remained greater than 43.6 fish/ hour. This increase was also reflected by SUNY ESF’s intermittent CPUE
assessment. In 2008 and 2009, the CPUE was 13.0 and 11.63 fish/hour, respectively, and in 2013 and 2014, the CPUE increased to 40.0 and 36.0 fish/hour (Tyszko 2010; Hurley 2015).

Population estimates in 2017 for Largemouth Bass (>300 mm) in the north and south were more evenly distributed than past years. Although the north basin had an estimate greater than the south in 2017 by 340 fish, the 2013 and 2014 estimates differed at the magnitude of thousands between basins. North and south basin estimates in 2013 were significantly different (Hurley 2015). Hurley (2015) also found the CPUE was greater in the north basin than the south basin during 2013 and 2014 sampling years. An even distribution of Largemouth Bass (>300 mm) estimates in 2017 is indicative of fish utilization of new suitable habitat.

These values are critical for the assessment of population responses to habitat improvements, but it is important to recognize these estimates were influenced by limitations to shoreline access during dredging and capping activity. The 2017 population estimate study was the first to include the entirety of Onondaga Lake shoreline since dredging and capping began in 2014. It is possible estimates made during sampling years when shorelines were limited are skewed. In some cases, transects also varied between sampling rounds. This leaves potential for marked fish to be inaccessible for recapture and violates Schnabel assumptions for population estimates. Likewise, it limits the accuracy of CPUE estimates. Now that dredging and capping activity is complete, a whole-lake, standardized effort will improve population estimate assessment in the future.

Catchability was calculated for each season as a method that minimizes the effects of limited shoreline accessibility and can be used as a tool for long-term assessment. During remediation from 2012 to 2016, catchability was highly variable. However, the catchabilities in 2016 and 2017 were similar and similar to the 2008 through 2017 average. In addition, the 2017
catchabilities in the north and south basins were close to the whole-lake average. We expect the similarity in catchabilities for Largemouth Bass (>300 mm) between basins is reflective of the even distribution of 2017 population estimates also found between basins.

Large variation in catchability prior to and during dredging and capping activity could be related to differences in sampling seasons. The catchability of black bass varies throughout the year, especially when compared to late spring spawning season when adults aggregate near shore (McInerny and Cross 2000). SUNY ESF sample design from 2008 through 2011 entailed boat electrofishing the shoreline once per month from May through November. Afterwards, sampling rounds were condensed to four consecutive rounds from early June through July. These annual surveys were also not consistent. In 2016, data collection was delayed to consecutive sample rounds in the fall due to boat maintenance issues. This variation in sampling season may explain why the estimate was the second lowest. Future population estimate sampling efforts should include the entire shoreline and remain condensed to May through June rounds.

Standardizing these efforts will increase accuracy of Onondaga Lake’s Largemouth Bass (>300 mm) catchability, and this value can be used as a long-term management tool. The catchability value for specific bodies of water can be used to determine the state of the fishery, or changes in population densities (Arreguin-Sanchez 1996). Unlike the Schnabel estimator, the Peterson estimator of mark-recapture population assessment requires a single-round in which fish are marked, followed by collection of a single sample examined for recaptures (Ricker 1975). Onondaga Lake’s Largemouth Bass (>300 mm) mean catchability can be used to estimate assumed sample recaptures from single-round catch, and then the Peterson method can be used to estimate the population. This type of assessment simplifies sampling efforts and can be used for cost-effective, long-term monitoring.
The nest abundances and distributions for Onondaga Lake were also influenced by shoreline availability and weather. More than 7,500 centrarchid nests were observed throughout the entirety of the lake. While this total abundance was less than the 2007 nest count, whole-lake abundances remain much greater than surveys of roughly 1,500 centrarchid nests in 1993 and 1994 (Arrigo 1998; Kirby 2009). The difference in total abundance between 2007 and 2017 is likely not indicative of decreased levels of reproductive activity. Annual variation in spawning activity is caused by abiotic conditions such as water temperature and photoperiod (Gross et al. 2002). Black bass and sunfish typically spawn in late April through July at water temperatures between 12°C to 20°C (Miller and Storck 1984). These temperatures are influenced by late winter and early spring snowmelt and precipitation.

Unusually high levels of precipitation from early to mid-June 2017 decreased water temperature and increased turbidity in Onondaga Lake. From May 1 through June 7, 2017, 18 out of the 20 days of precipitation were above the historic, monthly average of 0.11 inches per day (NOAA Weather Data). Spawning surveys were delayed to June 8, 2017 because of heavy precipitation and water clarity. The Upstate Freshwater Institute Ambient Monitoring Program (UFI AMP) implements monitoring equipment for near-real-time water quality data from the epilimnion at the point of maximum depth in the south basin of the lake. During our assessment from early to mid-June 2017, epilimnion temperature was 1°C to 4°C below the 17-year average of 17°C to 19°C. However, temperatures recorded near shore while sampling were between 17°C to 24°C and overlapped the preferred range for spawning. We suspect turbidity from excess precipitation may have influenced our nest counts. UFI AMP data showed spikes in turbidity in the south deep epilimnion ranging from 3 NTU to 5 NTU greater than the 17-year average during our assessment (UFI 2017, unpublished data). The 2017 nest survey was
conducted on days with clear, calm weather and high shoreline visibility, but it is possible we missed nests at greater depths.

Due to annual variation of spawning activity, the distribution of nests by basin and quadrant may be a useful measurement for long-term assessment and monitoring of centrarchid reproduction. Compared to previous nest surveys, the 2017 data showed an increase in the proportion of nests in the southwest quadrant of the lake. Kirby (2009) found nest sites were correlated with varying substrate size composition prior to remediation and implementation of the new habitat layer. Precipitates associated with CaCO$_3$ pollution have resulted in a silty to gravel-sized, low-density substrate throughout Onondaga Lake. These oncolites are present in sediment throughout the lake. This substrate limits colonization of submerging vegetation preferred for nest construction, but centrarchids have been observed nesting on substrate containing gravel-sized oncolites (Thompson 2007; Kirby 2009).

The new habitat layer in southern and western remediation zones consists of round gravel substrate that can be manipulated for nesting and root propagation (Parsons 2009). Kirby (2009) found the majority of centrarchid nests in Onondaga Lake on substrate comprised of 40% gravel or 50% gravel and pebble mixture. In contrast, Thompson (2007) found high nest densities on finer gravel (primarily oncolites), sands, and clays. While black bass prefer gravel substrate, Bluegill and Pumpkinseed sunfish prefer finer gravel and sands (Colgan and Ealey 1973; Keenleyside 1967). However, Bluegill nests have also been observed in proximity to gravel substrate. Gravel substrate provides interstitial space for YOY protection from predation (Bain and Helfrich 1983). While degraded substrate composed of low-density gravel has been utilized for nests, we suspect the recolonization of vegetation in areas limited by root propagation will increase habitat heterogeneity preferred by nesting centrarchids.
The remediation efforts and new habitat layer in the south basin littoral zone of Onondaga Lake are likely influenced the recruitment of juvenile centrarchids. Prior to 2014, there were observed differences in the mean juvenile centrarchid catches between basins. With the exception of 2011, the south basin had fewer mean catches of juvenile centrarchids than the whole-lake average, while the north basin had greater average mean catches. After 2014, mean catches of centrarchids for the entire lake and basins were very similar. This trend suggests that mean centrarchid recruitment is more evenly distributed between the north and south basins, similar to the even distribution of population estimates of adult Largemouth Bass (>300 mm) in 2017. From 2010 through 2017, we also observed an annual fluctuation in mean centrarchid catches for all of Onondaga Lake and by basins. These fluctuations became more distinct from 2014 through 2017.

Centrarchid recruitment is heavily influenced by littoral and wetland connectivity and water levels. Successful recruitment of juvenile centrarchids is positively correlated to increased macrophyte cover and connectivity to wetland vegetation (Pratt and Smokorowski 2003). In Onondaga Lake, Kirby (2009) found there was a positive correlation between nesting and recruitment of centrarchids and increased macrophyte growth. We suspect the observed even distribution of mean juvenile centrarchid catches since 2014 was related to increased macrophyte abundance throughout the lake. Additionally, Miranda et al. (1984) found a positive relationship between increased water levels and survival of YOY Largemouth Bass. Higher water levels were determined to increase nursery habitat connectivity, carrying capacity, and food availability for juveniles. The observed annual fluctuation in mean juvenile centrarchid catches in Onondaga Lake may have been influenced by water level. In 2017, there was heavy precipitation in May and June that potentially influenced the corresponding peak in the mean juvenile centrarchid
catch in August. Moreover, in 2016, central New York experienced below average precipitation in the spring and summer. This drought may have caused the corresponding low mean juvenile centrarchid catch in August 2016.

Within the first year after remediation, we identified a more even distribution of littoral habitat uses by centrarchid species between Onondaga Lake’s north and south basins. We expect the new habitat substrate will continue to promote macrophyte growth and macroinvertebrate recolonization in the future. These habitat enhancements will provide littoral complexity and connectivity preferred by centrarchid species.
References


Chapter 2: Centrarchid utilization and attraction to existing and newly implemented habitat structure in an urban lake

Introduction

Artificial habitat structure, in addition to substrate and vegetation enhancement and shoreline stabilization, is a commonly used component of aquatic habitat improvement projects (Pegg et al. 2015). Implementation of structure is a timeless method of attracting fish for sustenance. The first artificial reef structure was documented in the eighteenth century in Japan and was used to increase commercial harvests (Meier 1989). Habitat structure installation projects have proliferated to various coastal and freshwater systems worldwide and include a broad range of types and materials. Structures have been made of woody debris (whole trees, stumps, logs, stake beds, porcupine cribs, log cribs, hay bales, brush piles), rocky debris (boulders, rock reefs, rock piles), and other various materials (cars, tires, PVC piping, plastic tubing, cement blocks) (Bassett 1994; Bolding et al. 2004; Feger and Spier 2010; Hunt and Annett 2002; Richards 1997; Tugend et al. 2002). Richards (1997) determined fish are attracted to structure within hours after installation. Although this observation was likely identified prior to Richards’ (1997) assessment, it is formally used to justify the implementation of habitat structure as a means to meet recreational and ecological management objectives.

Recreational fishery management objectives are focused on attracting sportfish and increasing angler catch per unit effort (CPUE). The Michigan Department of Fish and Game was first to document installation of structure in a freshwater impoundment in the 1930s. These artificial structures included brush piles and rocky debris (Hazzard 1937). Largemouth Bass, Smallmouth Bass, Rock Bass, Bluegill, and Pumpkinseed, are popular structurally- oriented
sportfish recreationally managed to optimize angler CPUE. Angler catches at installed structure sites are often studied in lakes and impoundments lacking natural structure and are managed to provide recreational opportunities. Johnson and Lynch (1992) determined CPUE in reservoirs was greater at woody debris structures, such as evergreen trees, stake beds, and brush piles, compared to non-structure sites. Evergreen tree sites were found to provide a mean catch rate of 18.9 Largemouth Bass or Crappie (Pomoxis spp.)/hour versus less than 1 fish/hour at control sites (Richards 1997). Johnson and Lynch (1992) also found evergreen and stake bed sites resulted in greater mean catch rates of 2.0 to 11.0 Bluegill/hour compared to other structure sites. Rocky debris, such as shoreline rip rap, has also been found to increase angler catch rates of Smallmouth Bass and Rock Bass (Paxton and Stevenson 1979).

By the 1990s, the conceptual model for habitat enhancement management and research emphasized the ecological significance of habitat structure for fish communities (Basset 1994; Tugend et al. 2002). Structure provides habitat heterogeneity necessary for fish to grow and reproduce (Patton and Lyday 2008). Natural structures in lakes are aged by decomposition and degraded by sedimentation and erosion. Global development and fragmentation of forested and aquatic ecosystems have threatened the natural replenishment of littoral structure in lentic freshwater systems (Saunders et al. 1991). The unique morphometric characteristics of lakes and reservoirs influence the effectiveness of habitat structure (Wills et al. 2004). Pardue and Nielsen (1979) found that added structure was less effective at providing habitat for fish in lakes with complex bathymetry. Current research is focused on determining what physical attributes of artificial structure are successful at providing long-lasting habitat complexity and connectivity, as well as the composition of fish assemblages attracted to structure and their specific utilization of the created habitat (Allen et al. 2014; Bolding et al. 2004; Bassett 1994; Kovalenko et al. 2014).
Additionally, structure enhancement projects are assumed to increase fish production, but research has yet to successfully determine a direct correlation (Miranda 2017).

Centrarchid species utilize structure for reproduction, protection, and forage. Woody structures and rocky debris provide cover and are preferred nesting habitat for black bass (Hoff 1991; Vogele and Rainwater 1975). Studies have determined centrarchids show preference for structure but not between artificial and natural structure of the same material. Hunt and Annett (2002) determined nearshore (< 2.0 m in depth) large woody debris (LWD) had significantly more Largemouth and Smallmouth Bass nests than single boulder and non-structure sites. They found no difference nest site preference between naturally occurring LWD and implemented, supplementary LWD sites. Bassett (1994) found higher abundances of adults utilizing deeper log cribs, the parameters of structures, and rocky reefs as forage and hunting habitat. There was no difference in Smallmouth Bass counts utilizing deeper (>2.0 m in depth) artificial rocky reefs versus natural reefs. Nearshore LWD, such as evergreen trees, is also preferred by a larger diversity of juvenile centrarchid species as forage habitat and cover from predators (Bassett 1994).

Centrarchid preference for habitat is influenced by complexity and connectivity of littoral habitat structure. In addition to providing juvenile habitat, the interstitial complexity provided by evergreen trees was found to attract more Bluegills than hardwood trees (Johnson and Lynch 1992). Eadie and Keast (1984) found macrophytes also provide complexity. Greater species richness and diversity were found in vegetated areas (Eadie and Keast 1984). In the absence of adequate LWD structure, Largemouth Bass were found to utilize vegetation (Sammons et al. 2003). Vegetation also provides supplementary forage habitat when rocky substrate is lacking.
(Beauchamp et al. 1994). Additionally, grouped structure provides habitat connectivity used by larger fish. Lynch and Johnson (1988a) found angler catch rates of Bluegills at grouped offshore woody structure sites were over four times greater than catch rates at isolated woody debris sites. They also determined adult *Pomoxis* spp. and Largemouth Bass were more abundant at grouped structure sites implemented in rows and suggested these sites provided continuous habitat used for orientation and cover (Lynch and Johnson 1988b). Presence of macrophytes and proximity of structure are two important factors considered in habitat structure research and management because they provide broader spatial complexity and habitat connectivity (Eadie and Keast 1984; Pratt and Smokorowski 2003).

Despite the multitude of habitat structure enhancement projects, the research and assessment of these projects have yet to provide a complete understanding of species utilization between multiple installed structure types and the effectiveness of added complexity in a single system. This information is critical for the development of management strategies (Allen et al. 2014). In addition, complete assessment and evaluation of structure enhancement projects over time is limited by available funding. The urban setting of Onondaga Lake and history of habitat degradation provide an excellent opportunity to study the effectiveness of structure at attracting and providing habitat complexity for fish. The potential for long-term assessment of multiple structure types in a single, well-studied system make this research unique and applicable to other remediated systems or urban lakes and reservoirs.

Existing habitat structure in Onondaga Lake is concentrated in the northern and eastern shorelines and has limited natural replenishment. Prior to remediation, Parsons et al. (2011) surveyed 657 structures, roughly two structures per acre, in the non-remediated, shallow (<2.0 m in depth) littoral zone of Onondaga Lake. Types of structure include rocky debris from
protective jetties, rip-rap stabilizing shoreline, and remnant, submerged pier footings. LWD is most abundant in and limited to forested shoreline in the north basin and the Ley Creek inlet, along the southeastern shore. Other structures include fishing and marina docks and structure of anthropogenic origin: discarded cement blocks and tires, traffic cones, and the remains of old barges (Parsons 2010). As a consequence of dredging and capping, the remediated areas in the south and western shorelines were primarily barren of natural structure. The amount of structure in Onondaga Lake did meet the suggested percent coverage of 30% to 50% that is optimal for fisheries enhancement (Houser 2007). Therefore, the habitat structure plan was a major component in the habitat enhancement design.

Remediated areas in Onondaga Lake were projected to receive 1,137 structures in nearshore and offshore littoral habitat up to 7.0 m in depth (Parsons 2009; Parsons 2018). All remediated structure installations are expected to be completed by spring 2018, therefore, this research was limited to assessment of existing and preliminary installed structure sites. Remediated structure types include rock piles and jetties, boulders, LDW, and offshore woody structures designed by the Pennsylvania Fish and Boat Commission called the “Pennsylvania Porcupine Crib”. Porcupine cribs are a lattice-built structure made of 50-5.0 cm X 5.0 cm X 1.2 m poplar or hemlock. They are designed for durability and to increase offshore angler CPUE and habitat complexity (Houser 2007). Since centrarchid species dominate the warmwater fish community in Onondaga Lake, we hypothesized these fish will utilize and be attracted to existing and newly implemented structures. The objectives of this research were to:

1. Provide baseline assessment of fish utilization and attraction to structures by determining the species richness and diversity of catches and visits, centrarchid catches and visits, and adult black bass catches and visits at each structure and non-structure site.
2. Determine if utilization or attractiveness of structure sites is greater than non-structure sites, and to determine if there is a difference in utilization or attractiveness between structure sites grouped by type, location, or the presence of surrounding vegetation.

3. Determine if the attractiveness of grouped porcupine cribs was greater than isolated porcupine cribs.

4. Determine the feasibility of sampling structures in Onondaga Lake by comparing three methods that examine fish assemblages either utilizing or attracted to structure sites: gill netting (utilization), electrofishing (utilization), and video recording (attraction).

Methods

General Sampling Procedures

Twelve structure and two control sites were sampled by gill netting, electrofishing, and video recording from July 16, 2017 and August, 28 2017. Three sampling rounds were completed within five consecutive days. Each structure was sampled by all three methods during each sampling round. Gill netting, electrofishing, and video recording procedures were completed during the hours of 0800-1500 to reduce temporal variability in fish activity.

All sites were sampled during calm, clear weather and with water clarity at Secchi depths greater than 1.25 m to reduce variability in conditions. Each round of sampling was completed during five-day periods with little to no precipitation and high water clarity.
Structure Descriptions (Table 1; Figure 1)

The 12 structure sites included existing and new structure types implemented in October 2016 and July 2017. Structures and control sites were distributed throughout the littoral zone of Onondaga Lake at depths ranging from 1.2 m to 4.5 m. Each sample site is additionally described by structure category (control, dock, jetty, pier footing, and porcupine crib), location (north or south basin), presence or absence of sub-aquatic vegetation, and proximity to other structure or not (grouped or isolated).

Table 1. Descriptions and illustrated locations of habitat structure for Onondaga Lake in 2017, including site name, structure type (dock, jetty, pier footing, and porcupine crib), location by basin (north, south), presence of vegetation (yes, no), structure depth (m), and proximity to other similar structure (yes, no).

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Structure Type</th>
<th>Basin (North/ South)</th>
<th>Vegetation (Yes/No)</th>
<th>Depth (m)</th>
<th>Proximity (Yes/No)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCONTROL</td>
<td>N/A</td>
<td>North</td>
<td>No</td>
<td>1.21</td>
<td>No</td>
</tr>
<tr>
<td>NDOCK1</td>
<td>Dock</td>
<td>North</td>
<td>Yes</td>
<td>1.4</td>
<td>No</td>
</tr>
<tr>
<td>NDOCK2</td>
<td>Dock</td>
<td>North</td>
<td>No</td>
<td>1.25</td>
<td>No</td>
</tr>
<tr>
<td>NJETTY1</td>
<td>Jetty</td>
<td>North</td>
<td>Yes</td>
<td>1.5</td>
<td>No</td>
</tr>
<tr>
<td>NJETTY2</td>
<td>Jetty</td>
<td>North</td>
<td>Yes</td>
<td>1.21</td>
<td>No</td>
</tr>
<tr>
<td>NPIER1</td>
<td>Pier Footing</td>
<td>North</td>
<td>Yes</td>
<td>1.25</td>
<td>No</td>
</tr>
<tr>
<td>NPIER2</td>
<td>Pier Footing</td>
<td>North</td>
<td>No</td>
<td>1.21</td>
<td>No</td>
</tr>
<tr>
<td>SCONTROL</td>
<td>N/A</td>
<td>South</td>
<td>No</td>
<td>1.21</td>
<td>No</td>
</tr>
<tr>
<td>SDOCK1</td>
<td>Dock</td>
<td>South</td>
<td>Yes</td>
<td>1.4</td>
<td>No</td>
</tr>
<tr>
<td>SJETTY1</td>
<td>Jetty</td>
<td>South</td>
<td>No</td>
<td>1.25</td>
<td>No</td>
</tr>
<tr>
<td>SPIER1</td>
<td>Pier Footing</td>
<td>South</td>
<td>Yes</td>
<td>1.21</td>
<td>No</td>
</tr>
<tr>
<td>SPORK1</td>
<td>Porcupine Crib</td>
<td>South</td>
<td>No</td>
<td>3.6</td>
<td>No</td>
</tr>
<tr>
<td>SPORK2</td>
<td>Porcupine Crib</td>
<td>South</td>
<td>No</td>
<td>2.5</td>
<td>No</td>
</tr>
<tr>
<td>SPORK3</td>
<td>Porcupine Crib</td>
<td>South</td>
<td>No</td>
<td>4.5</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Figure 1. Sample site locations of habitat structures for Onondaga Lake in 2017. Legend indicates structure type by symbol. Porcupine crib sites distinguished by placement method: grouped or isolated.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Structure Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>Control</td>
</tr>
<tr>
<td>⭕</td>
<td>Dock</td>
</tr>
<tr>
<td>🗿</td>
<td>Jetty</td>
</tr>
<tr>
<td>⛱️</td>
<td>Pier Footing</td>
</tr>
<tr>
<td>▲</td>
<td>Porcupine Crib, isolated</td>
</tr>
<tr>
<td>▲</td>
<td>Porcupine Crib, grouped</td>
</tr>
</tbody>
</table>

*Control sites: no structure*

NCONTROL was a non-structure site located within the northeastern littoral zone at 1.21 m. This north basin site was devoid of vegetation.

SCONTROL was a non-structure site located within the southeastern littoral zone at 1.21 m. This south basin site was devoid of vegetation.
Dock sites: above-water cover

NDOCK1 was an existing structure site located within the northeastern littoral zone at 1.4 m. This north basin site was generally dominated by vegetation including Ceratophyllum demersum, Potamogeton nodosus, and Myriophyllum spicatum. This site was not in close proximity to other structure.

NDOCK2 was an existing structure site located within the northeastern littoral zone, north of NDOCK1, at 1.25 m. This north basin structure was not in close proximity to vegetation or other structure.

SDOCK1 was a new structure site constructed in May 2017 within the southwestern littoral zone at 1.4 m. This south basin site was generally dominated by Ceratophyllum demersum and Myriophyllum spicatum vegetation. This site was not in close proximity to other structure.

Jetty sites: large boulder debris

NJETTY1 was an existing structure site located within the northern littoral zone along the Onondaga Lake outlet to the Seneca River at 1.5 m. This north basin site was generally dominated by Ceratophyllum demersum, Potamogeton nodosus, and Myriophyllum spicatum. This site was not in close proximity to other structure.

NJETTY2, constructed in part of the Honeywell Remedial Design and referred to as the Permanent Habitat Module, was an existing structure site located within the northwestern littoral zone at 1.21. This north basin site was dominated by Ceratophyllum demersum, Potamogeton nodosus, and Myriophyllum spicatum. This site was not in close proximity to other structure.
SJETTY1 was a new structure site constructed in Remediation Area D in November 2016 and located within the southwestern littoral zone at 1.25 m. This south basin structure was not in close proximity to vegetation or other structure.

*Pier footing sites: submerged rocky debris*

NPIER1 was an existing structure site located within the northwestern littoral zone at 1.25 m (Table 1). This north basin structure was not in close proximity to vegetation or other structure.

NPIER2 was an existing structure site remnant of the 1908 fishing pier and located north of NPIER1 within the northwestern littoral zone at 1.21 m (Table 1). This north basin structure was dominated by *Ceratophyllum demersum* and *Myriophyllum spicatum*. This site was not in close proximity to other structure.

SPIER1 was an existing structure located within the southwestern littoral zone at 1.21 m (Table 1). This south basin structure was dominated by *Potamogeton nodosus* and *Myriophyllum spicatum*. This site was not in close proximity to other structure.

*Porcupine Crib sites: lattice woody structure*

SPORK1 was a new structure site implemented in Remediation Area E in August 2016 located within the southeastern littoral zone at 3.6 m (Table 1). This south basin structure was not in close proximity to vegetation or other structure.

SPORK2 was a new structure site implemented in Remediation Area E in August 2016 located within the southwestern littoral zone at 2.5 m (Table 1). This south basin structure was not in close proximity to vegetation or other structure.

SPORK3 was a new structure site implemented in Remediation Area C in July 2017 located within the southwestern littoral zone at 4.5 m (Table 1). This south basin structure site
was devoid of vegetation. Rows of porcupine cribs along the same bathymetric depth were grouped in close proximity (roughly 1.21 m apart).

**Species Utilization: Gill Netting**

All structure sites were sampled by experimental gill nets during sampling rounds from July, 17 2018 through August, 28 2018. Four 8.22 m X 2.43 m individual experimental gill nets of 2-, 3-, 4- or 5-inch stretched mesh sizes were deployed for 30-minute sets in pairs perpendicular to each other. Individual nets were extended immediately from the corners of all twelve structure sites. At control sites, nets were set 10 m apart, parallel to each other, and perpendicular to the shoreline beginning at 1.21 m in depth. Nets were paired by 2- and 4-inch stretch sizes and 3- and 5-inch stretch sizes.

All fish were collected in a live well, processed, and released at each site. Fish processing included species identification and total length measurements. All centrarchid individuals greater than 100 mm were marked to distinguish any recaptures between sampling rounds. These fish (Largemouth Bass, Smallmouth Bass, Rock Bass, Bluegill, Green Sunfish and Pumpkinseed) received a right half-pelvic fin clip. Black bass greater than 200mm in length were also marked with T-bar anchor tag containing a unique numerical code and contact information. Each tag was implanted next to the third spine of the first dorsal ray. Tagged fish were recorded as a recapture, re-measured, and released.

**Data Analysis**

Due to the inconsistency in catches, the gill net data were not used for comparison. However, marked individuals were recorded and used to determine origins of recaptures.
**Species Utilization: Electrofishing**

Electrofishing was conducted by a 5.49 m Smith-Root electrofishing boat with a 7.5 GPP electrofishing unit. A generated 20 to 15 A was produced by 170 V pulsed at 120 Hz. Nine shallow structure sites and two control sites were electrofished during each sampling round from July 16, 2017 to August 25, 2017. The perimeters of each structure site, including all docks, pier footings, and jetties, were fished for six-minutes.

Three crew members were aboard, including one operator and two netters. Netters were positioned at the front left and right corners of the vessel and instructed to collect all observed species. Fish were kept aboard in a live well for the duration of sampling and subsequently processed and released at each site. Fish processing followed the same procedures as described in the gill net sampling methods.

**Data Analysis**

In this study, electrofishing data were used to determine the mean catches around habitat structure. Electrofishing data are commonly used to sample fish assemblages around shallow structure (Allen et al. 2014). The porcupine crib sites were not included in electrofishing assessment due to their greater depths. Response variables including species richness, diversity, number of adult black bass (>200 mm), and number of centrarchids were calculated and averaged at each sample site. Black bass are considered adults at roughly 200 mm total length.
The following Shannon Diversity Index equation was used to calculate species diversity at each site:

\[ H = - \sum_{i=1}^{R} p_i \ln(p_i) \]

Where:

- \( H \) = Shannon Diversity Index
- \( p_i \) = fraction of the entire population made up of species, \( i \)
- \( R \) = number of species encountered, species richness

Response variables were first compared between structure and non-structure sites using a 2-sample t-test on Minitab software. Structure site data were then isolated from control sites (Table 1). All mean responses at structure sites were grouped and compared using the following factors: structure category, location (north or south basin), and the presence or absence of vegetation (Table 1; Figure 1). The location and vegetation groupings were statistically tested for differences in mean responses using a 2-sample t-tests, and the structure category was statistically tested for a difference in mean response for at least one category using a One-Way Analysis of Variance (ANOVA) test on Minitab17 software.

*Species Attraction: Camera Assessment*

GoPro Hero4 waterproof cameras set to high resolution and wide viewing screen were used to record video at all structure and control sites. Cameras were mounted to a GoPro 3-in-1 Adjustable Arm. Each camera and arm were attached to a weighted mount by hose clamps. The weighted mounts were welded in the SUNY ESF Analytics Lab using stainless steel parts. The
base of each mount was recycled galvanized steel, with 1-inch nuts welded to the bottom corners and one 24-inch stainless steel 1.25 in X 0.4 in carbon steel rod projecting upward from the center (Figure 2). Each mount was double coated with Rustoleum primer and triple coated with flat black Rustoleum paint to eliminate exposure of zinc coated and galvanized steel to water and reduce rust and conspicuousness of the mount. A 90° twist shackle was welded to the top of each centered rod for attachment to buoys.

In addition, a weighted 750c Aqua-Vu camera was set on an additional mount attached to the center rod of each camera mount by a carbon steel C-clamp with a locknut (Figure 3). These holders were created using polyvinyl chloride piping.

Figure 2. One of five complete 2017 weighted camera mounts used for attachment of GoPro 3-in-1 Arm and GoPro Hero 4 video recording.
Figure 3. The 2017 Aqua-Vu 750c mount and clamp. A.) Bottom view of unpainted clamp attachment to PVC piping. B.) Top view of complete clamp attachment to PVC piping.

Figure 4. Representation of Aqua-Vu 750c placement on weighted camera and Aqua-Vu 750c mounts.
Video recording was conducted in calm, clear weather conditions and when water clarity was greater than 1.25 m Secchi depth. For consistency, cameras were placed roughly 1.0 m from structure sites and positioned to include half structure and half open water on video screens. Control sites were set to record open water footage perpendicular to shore. An Aqua-Vu camera, attached to a viewing screen by a waterproof cable, was temporarily submerged with each camera mount to ensure the desired viewing screen (Figure 4). After placement was corrected, the Aqua-Vu camera was brought aboard. Cameras and mounts, identified above water by an attached buoy, were left to record for 60 minutes. At each site, water clarity and placement depth were recorded.

Data Analysis

Each one-hour video recording was viewed for 30 minutes, allowing for a 15-minute lag between placement of cameras and data collection. The sampling unit of this assessment was the frequency of visits, or the entrance of an individual into the viewing screen, by each species and measured the attractiveness of structure to species. Therefore, if one fish swam through the viewing screen and then returned from off screen, then two visits by that species were recorded. These species would potentially have many visits compared to a mobile species, meaning they were more attracted to sites.

The following responses were calculated for each site: species richness of visits, diversity of visits, adult black bass visits, and centrarchid visits. Black bass ages were estimated based on appearance. The camera assessment differed from electrofishing by sampling unit. Electrofishing data provided sample catches of species that measured abundances of fish utilizing structure, while camera data provided sample frequencies of visits per species that measured fish attraction to structure. Sites were grouped into structure and non-structure
categories and statistically tested for a difference in mean responses by category using a 2-sample t-test on Minitab17 software. Then, structure site data were isolated from non-structure sites (Table 1).

All structure sites were grouped by structure depth (shallow and deep; greater or less than 2.0 m) and statistically tested for a difference in mean responses using a 2-Sample t-test on Minitab17 software. Because there was no significant difference in mean responses based on structure depth, all structure types were then grouped by the following factors: structure category, location (north or south basin), and the presence or absence of vegetation (Table 1; Figure 1). The location and vegetation groupings were statistically tested for a difference in mean responses using a 2-sample t-tests, and the structure category groups statistically tested for a difference in mean responses for at least one category using a One-Way ANOVA test on Minitab17 software.

In addition, data for porcupine crib structures were isolated. The porcupine cribs represented new structure specifically designed for the habitat improvement plan on Onondaga Lake. Crib sites were grouped by placement method (grouped or isolated) (Table 1; Figure 1). Grouped and isolated cribs were statistically tested for differences in mean responses using a 2-sample t-test on Minitab17 software.
Results

Species Utilization: Gill Netting

Thirty five adult black bass (>200 mm) were captured by gill nets and tagged with anchor t-tags. One Largemouth Bass (>200 mm) was tagged by gill net at the NPIER2 site and recaptured while electrofishing at the NJETTY2 site (Table 2). No additional gill net data were used for analysis of structure.

Table 2. Summary of 2017 tagged and recaptured Largemouth Bass near habitat structure in Onondaga Lake (>200 mm). *indicates individual was recaptured by methods in addition to structure assessment.

<table>
<thead>
<tr>
<th>Tag Number</th>
<th>Recapture Method</th>
<th>Tag Date</th>
<th>Recapture Date</th>
<th>Tag Location</th>
<th>Recapture Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>6949</td>
<td>Electrofishing (Day)</td>
<td>7/5/2017</td>
<td>8/24/2017</td>
<td>NPIER2</td>
<td>NJETTY2</td>
</tr>
<tr>
<td>7543</td>
<td>Electrofishing (Day)</td>
<td>7/5/2017</td>
<td>7/18/2017</td>
<td>NJETTY2</td>
<td>NJETTY2</td>
</tr>
<tr>
<td>7583</td>
<td>Recreational Angler</td>
<td>7/18/2017</td>
<td>9/10/2017</td>
<td>NJETTY1</td>
<td>NJETTY1</td>
</tr>
<tr>
<td>7659</td>
<td>Electrofishing (Day)</td>
<td>8/21/2017</td>
<td>8/24/2017</td>
<td>NJETTY2</td>
<td>NJETTY2</td>
</tr>
<tr>
<td>7684</td>
<td>Electrofishing (Night)</td>
<td>8/24/2017</td>
<td>11/13/2017</td>
<td>NCONTROL</td>
<td>NCONTROL</td>
</tr>
</tbody>
</table>

Species Utilization: Electrofishing

Ninety one black bass (>200 mm) were tagged with anchor t-tags by electrofishing. Four Largemouth Bass (>200 mm) were tagged while electrofishing and recaptured by multiple methods. Two of these fish were recaptured while electrofishing structures (day). Both these individuals were tagged and recaptured at NJETTY2. The remaining two fish were recaptured while electrofishing for population estimates (night) and by a recreational angler. These fish were tagged and recaptured at the NCONTROL and NJETTY1 sites, respectively (Table 2).
Species richness was greatest at NJETTY1 with a mean value of 10 followed by NJETTY2, NPIER1, and NDOCK1 with mean values from 9.0 to 8.3 species (Table 3). The greatest species diversity was found at the NJETTY2 site with a mean value of 1.90. The highest mean adult black bass (>200 mm) catch was 21 individuals NJETTY1. NPIER2 and NJETTY1 sites were high in mean adult black bass (>200 mm) catches; however, they also had larger standard deviations (Table 3). The greatest mean catch of centrarchids was at the NJETTY1 site and had a small standard deviation. Conversely, the NDOCK2 site had the lowest mean diversity, adult black bass catch (>200 mm), and centrarchid catch out of all structure sites. Additionally, these mean responses were less than the SCONTROL, non-structure site.

Table 3. A summary of electrofishing mean and standard deviation values for species richness and diversity and for catches of adult black bass (>200 mm) and centrarchids at each sample site (each site was sampled n= 3 times) for Onondaga Lake in 2017.

<table>
<thead>
<tr>
<th>Site</th>
<th>Mean Richness (St. Dev.)</th>
<th>Mean Diversity (St. Dev.)</th>
<th>Mean Number of Black Bass (St. Dev.)</th>
<th>Mean Number of Centrarchids (St. Dev.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDOCK1</td>
<td>8.3 (0.6)</td>
<td>1.67 (0.14)</td>
<td>12 (5.0)</td>
<td>16 (4.58)</td>
</tr>
<tr>
<td>NDOCK2</td>
<td>5.3 (1.2)</td>
<td>0.87 (0.24)</td>
<td>2.3 (1.5)</td>
<td>3.0 (1.0)</td>
</tr>
<tr>
<td>SDOCK1</td>
<td>5.3 (2.1)</td>
<td>1.34 (0.51)</td>
<td>6.7 (4.1)</td>
<td>10 (7.0)</td>
</tr>
<tr>
<td>NJETTY1</td>
<td>10 (2.7)</td>
<td>1.70 (0.17)</td>
<td>21 (10)</td>
<td>39 (3.1)</td>
</tr>
<tr>
<td>NJETTY2</td>
<td>9.0 (1.0)</td>
<td>1.90 (0.14)</td>
<td>8.7 (2.1)</td>
<td>19 (6.1)</td>
</tr>
<tr>
<td>SJETTY1</td>
<td>6.7 (1.5)</td>
<td>1.25 (0.51)</td>
<td>3.3 (4.0)</td>
<td>8.0 (9.5)</td>
</tr>
<tr>
<td>NPIER1</td>
<td>8.3 (1.5)</td>
<td>1.72 (0.26)</td>
<td>6.7 (2.3)</td>
<td>11 (2.1)</td>
</tr>
<tr>
<td>NPIER2</td>
<td>7.0 (1.7)</td>
<td>1.54 (0.11)</td>
<td>13 (11)</td>
<td>16 (10)</td>
</tr>
<tr>
<td>SPIER1</td>
<td>5.0 (1.7)</td>
<td>1.15 (0.49)</td>
<td>14 (6.7)</td>
<td>19 (8.1)</td>
</tr>
<tr>
<td>NCONTROL</td>
<td>5.0 (0.6)</td>
<td>1.57 (0.11)</td>
<td>5.0 (1.7)</td>
<td>5.7 (1.5)</td>
</tr>
<tr>
<td>SCONTROL</td>
<td>5.0 (1.5)</td>
<td>1.46 (0.20)</td>
<td>0.3 (0.6)</td>
<td>2.7 (2.1)</td>
</tr>
</tbody>
</table>
There were multiple significant differences found between structure and non-structure sites (Table 4). Mean species richness, adult black bass (>200 mm) catch and centrarchid catch were all greater at structure sites. The mean species richness was 7.2 at structure sites and 5.5 at non-structure (control) sites (df= 16, t= 2.85, p= 0.012; Table 4; Figure 5).

Table 4. A summary of electrofishing statistical analyses of structure site observations (n= 27) for Onondaga Lake in 2017. P-values indicate a significant difference in mean responses (species richness and diversity, adult black bass catch, and centrarchid catch) for factor groups: structure, structure category, basin, and vegetation. α= 0.05; NS= not significant. 1Tukey pairwise test output for Jetty- Dock comparison. *structure (yes, no) analysis compared structure (n=27) to control sites (n= 6).

<table>
<thead>
<tr>
<th>Sampling Method</th>
<th>Responses (mean catch)</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Structure (Yes, No)</td>
<td>Category (Pier Footing, Dock, Jetty)</td>
</tr>
<tr>
<td>Electrofishing (n= 27*)</td>
<td>Species Richness</td>
<td>p= 0.012</td>
</tr>
<tr>
<td></td>
<td>Species Diversity</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Black Bass</td>
<td>p= 0.001</td>
</tr>
<tr>
<td></td>
<td>Centrarchid</td>
<td>p= 0.000</td>
</tr>
</tbody>
</table>

Figure 5. The mean (+/- standard deviation) species richness at 2017 structure (n= 27) and no structure (n= 6) site categories in Onondaga Lake. Significant differences indicated by different letters (p= 0.012).
Similarly, mean adult black bass (>200 mm) and centrarchid catches were 9.7 and 16 at structure sites and 2.7 and 4.2 at non-structure sites, respectively (df= 22, t= 3.81, p= 0.001; df= 30, t= 4.97, p= 0.000, respectively; Table 4; Figure 6).

Fewer differences were found between mean catches at structure types and lake basins. The jetty structure category had a mean catch of 22 centrarchids, which was significantly greater than a mean catch of 9.7 centrarchids at dock structures (Tukey pairwise comparison p= 0.048; Table 4; Figure 7). Based on location, north basin structures had a mean species richness of eight that was significantly greater than the south basin structures with a mean species richness of six (df= 18, t= 3.11, p= 0.006; Table 4; Figure 8).
Figure 7. The mean (+/- standard deviation) centrarchid catches at 2017 Dock (n= 9), Jetty (n= 9), and Pier Footing (n= 9) structure categories in Onondaga Lake. Tukey pairwise comparison significant differences indicated by different letters (One-Way ANOVA output: df= 2; f= 3.16; p= 0.060; Tukey Dock- Jetty pairwise comparison output: p= 0.048).

Figure 8. The mean (+/- standard deviation) species richness at 2017 north (n= 18) and south basin (n= 9) structure locations in Onondaga Lake. Significant differences indicated by different letters (p= 0.006).
Figure 9. The mean (+/- standard deviation) species diversity at 2017 vegetation (n= 18) and no vegetation (n= 9) structure categories in Onondaga Lake. Significant differences indicated by different letters (p= 0.039).

Lastly, the presence of vegetation at structure sites resulted in greater mean species diversity and centrarchid catches. Sites with vegetation had a mean diversity of 1.59, while no vegetation sites had a mean diversity of 1.22 (df= 5, t= 2.26, p= 0.039; Table 4; Figure 9). In addition, vegetated structure sites had a mean catch of 19 centrarchids, while non-vegetation sites had a mean catch of 8.9 centrarchids (p= df= 19, t= 2.61, 0.017; Table 4; Figure 10).

Figure 10. The mean (+/- standard deviation) centrarchid catches at 2017 vegetation (n= 18) and no vegetation (n= 9) structure categories in Onondaga Lake. Significant differences indicated by different letters (p= 0.017).
Species Attraction: Camera Assessment

All Sites and Observations

Site visit species richness was highest at NJETTY2 with a mean value of 6.3 followed by NDOCK1 and SPORK3, both with a mean value of 4.3 (Table 5). Mean diversity of visits was also highest at NJETTY2 with a value of 1.36 and second highest at SPORK3 with a mean value of 1.13. NPIER1 had the highest mean value of 32 adult black bass visits followed by NJETTY1. Both these averages also had high standard deviations. Similarly, the highest mean of centrarchid visits was 187 at NPIER2, however, the standard deviation was 289. This value may have been skewed by the large numbers of schooling YOY Largemouth Bass visiting this site. The next highest mean value was 82 centrarchid visits at NDOCK1.

Table 5. A summary of camera assessment mean and standard deviation values for species richness and diversity of site visits and for visits by adult black bass (>200 mm) and centrarchids at each site (each site was sampled n= 3 times) for Onondaga Lake in 2017. *indicates large number of visits skewed by schooling YOY black bass.

<table>
<thead>
<tr>
<th>Site</th>
<th>Mean Richness (St. Dev)</th>
<th>Mean Diversity (St. Dev.)</th>
<th>Mean Number of Black Bass (St. Dev)</th>
<th>Mean Number of Centrarchids (St. Dev)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDOCK1</td>
<td>4.3 (1.5)</td>
<td>0.80 (0.33)</td>
<td>1.3 (2.3)</td>
<td>82 (21)</td>
</tr>
<tr>
<td>NDOCK2</td>
<td>3.0 (0)</td>
<td>0.66 (0.30)</td>
<td>0.0 (0.0)</td>
<td>17 (22)</td>
</tr>
<tr>
<td>SDOCK1</td>
<td>2.0 (1.5)</td>
<td>1.01 (0.14)</td>
<td>8.3 (10)</td>
<td>54 (32)</td>
</tr>
<tr>
<td>NJETTY1</td>
<td>5.0 (2.0)</td>
<td>1.06 (0.34)</td>
<td>19 (24)</td>
<td>50 (22)</td>
</tr>
<tr>
<td>NJETTY2</td>
<td>6.3 (2.5)</td>
<td>1.36 (0.26)</td>
<td>2.7 (3.1)</td>
<td>68 (24)</td>
</tr>
<tr>
<td>SJETTY1</td>
<td>2.7 (1.5)</td>
<td>0.49 (0.48)</td>
<td>3.0 (1.7)</td>
<td>22 (19)</td>
</tr>
<tr>
<td>NPIER1</td>
<td>5.3 (2.5)</td>
<td>1.03 (0.71)</td>
<td>32 (20)</td>
<td>60 (24)</td>
</tr>
<tr>
<td>NPIER2</td>
<td>5.3 (1.7)</td>
<td>0.02 (0.04)*</td>
<td>1.3 (1.5)</td>
<td>187 (289)*</td>
</tr>
<tr>
<td>SPIER1</td>
<td>3.3 (2.1)</td>
<td>0.62 (0.64)</td>
<td>6.0 (4.6)</td>
<td>17 (7.6)</td>
</tr>
<tr>
<td>SPORK1</td>
<td>4.0 (1.0)</td>
<td>0.83 (0.03)</td>
<td>3.0 (3.5)</td>
<td>54 (62)</td>
</tr>
<tr>
<td>SPORK2</td>
<td>3.0 (1.7)</td>
<td>0.64 (0.66)</td>
<td>1.0 (1.0)</td>
<td>24 (38)</td>
</tr>
<tr>
<td>SPORK3</td>
<td>4.3 (0.6)</td>
<td>1.13 (0.06)</td>
<td>12 (3.5)</td>
<td>33 (11)</td>
</tr>
<tr>
<td>NCONTROL</td>
<td>5.0 (2.6)</td>
<td>1.05 (0.51)</td>
<td>6.7 (4.0)</td>
<td>22 (16)</td>
</tr>
<tr>
<td>SCONTROL</td>
<td>5.0 (1.0)</td>
<td>0.63 (0.33)</td>
<td>0.0 (0.0)</td>
<td>20 (9.3)</td>
</tr>
</tbody>
</table>
Table 6. A summary of camera assessment statistical analyses of all structure observations (n=36) for Onondaga Lake in 2017. P-values indicate a significant difference in mean responses (species richness and diversity of visits, adult black bass visits, and centrarchid visits) for factor groups: structure, structure category, basin, and vegetation. $\alpha = 0.05$; NS= not significant.
*structure (yes, no) analysis compared structure (n=36) to control sites (n=6).

<table>
<thead>
<tr>
<th>Sampling Method</th>
<th>Responses (mean of visits)</th>
<th>Structure (Yes, No)</th>
<th>Category (Pier Footing, Dock, Jetty, Porcupine Crib)</th>
<th>Basin (North, South)</th>
<th>Vegetation (Yes, No)</th>
<th>Factors</th>
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</thead>
<tbody>
<tr>
<td>Camera Observation (n=36*)</td>
<td>Species Richness</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>p= 0.006</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Species Diversity</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>p= 0.026</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Black Bass</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>p= 0.046</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Centrarchid</td>
<td>p= 0.027</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

Site visit species richness was lowest at SDOCK1 with a mean value of two species (Table 5). Mean diversity of visits was lowest at NPIER2, however, similar to the mean centrarchid visit count at this site, this value may have been skewed by large amounts of schooling YOY Largemouth Bass. NDOCK2 and SCONTROL were the only sites with no adult black bass visits, while NCONTROL had a mean value of 6.7 visits. Interestingly, NCONTROL site had greater mean of visits by adult black bass than seven structure sites. The lowest mean of centrarchid visits were at the SPIER1 and NDOCK2 sites.

Similar to electrofishing results, camera data determined centrarchids were more attracted to structure sites. The mean of visits to structure sites was 56 centrarchid visits, while non-structure sites had a mean value of 21 visits (df= 39, t= -2.29, p= 0.027; Table 6; Figure 11).

Vegetated sites also influenced mean species richness, diversity, and adult black bass visits. Mean values of 4.8 species richness of visits, 0.63 diversity of visits, and 12 black bass visits were all significantly greater at sites with vegetation (df= 29, t= 2.96, p= 0.006; df= 33, t= 2.32, p= 0.026; df= 20, t= 2.10, p= 0.046, respectively; Table 6; Figures 12-14).
Figure 11. The mean (+/- standard deviation) of centrarchid visits to 2017 structure (n= 36) and no structure (n= 6) site categories in Onondaga Lake. Significant differences indicated by different letters (p= 0.027).

Figure 12. The mean (+/- standard deviation) species richness of visits to 2017 vegetation (n= 18) and no vegetation (n= 18) structure categories in Onondaga Lake. Significant differences indicated by different letters (p= 0.006).
Figure 13. The mean (+/- standard deviation) species diversity of visits to 2017 vegetation (n=18) and no vegetation (n=18) structure categories in Onondaga Lake. Significant differences indicated by different letters (p=0.026).

Figure 14. The mean (+/- standard deviation) of adult black bass visits to 2017 vegetation (n=18) and no vegetation (n=18) structure categories in Onondaga Lake. Significant differences indicated by different letters (p=0.046).
For all structure sites, the pier footing structure category was observed to have higher means of visits by adult black bass and centrarchids. However, these differences in means of visits were not significant (Table 6; Figure 15).

Figure 15. The mean of visits by adult black bass and centrarchids to 2017 Dock (n= 9), Jetty (n= 9), Pier Footing (n= 9), and Porcupine Crib (n= 9) structure categories.
Porcupine Crib Sites and Observations

Observationally, species richness in visits ranged from one to five species at porcupine crib sites. The mean richness of visits for all sites were predominantly centrarchid species visits (Blue Gill, Rock Bass, Smallmouth Bass and Largemouth Bass), with the exception of Common Carp and Freshwater Drum (Table 5).

The porcupine crib sites were grouped based on their proximity to other cribs (Table 1). SPORK3 was the only site with grouped crib placement. Mean adult black bass visits was greatest at SPORK3 with a mean value of 12 visits (df= 3, t= -4.45, p= 0.020; Table 6; Figure 16). This site was also the only porcupine crib site to have adult Smallmouth Bass visits.

Figure 16. The mean (+/- standard deviation) adult black bass visits to 2017 Porcupine Crib structures with differing proximity to other cribs: isolated (n= 6) or grouped (n= 3). Significant differences indicated by different letters (p= 0.020).
Discussion

Gill nets were used as a method to examine fish utilization of structure at all depths, while electrofishing assessment of fish utilization was limited to shallow structure. We found the gill net method was not effective, therefore, we did not include these data in our analysis of centrarchid utilization of structure and non-structure sites. Our statistical assessment compared fish utilization or attraction to structure and non-structure sites by electrofished catches or video recorded visits, respectively. Since these data differ by sampling unit, we could only generally compare the two methods.

Installed habitat structures are thought to provide cover used as refugium and shade for protection (Moring and Nicholson 1994) and for orientation and schooling (Bohnsack and Sutherland 1989). In particular, centrarchid species use structure for orientation and protection for reproduction and recruitment (Wills et al. 2004). Expectedly, we found the mean species richness and mean adult black bass (>200 mm) and centrarchid catches were significantly greater at structure sites than non-structure sites. We also found the mean of centrarchid visits was significantly greater at structure sites than non-structure sites. These findings affirm that centrarchid fishes utilize and are attracted to structure in Onondaga Lake. Our additional analyses of structures revealed differences in fish utilization and attraction to structure types, locations, and other habitat features.

We hypothesized that north basin structure would have higher richness and diversity because the north end of Onondaga Lake was less directly impacted by historical pollution and degradation and disturbance during remediation work. As expected, there was significantly greater mean species richness utilizing north basin structure than south basin structure. However, we did not find significant differences in centrarchid utilization and attraction to
structure between the north and south basins. In 2017, there was an even distribution of mean juvenile centrarchid catches and adult Largemouth Bass (>300 mm) between the north and south basins. We suspect we did not find any significant differences in centrarchid utilization or attraction to sites differing by basin because all structures were available to an even distribution of centrarchids (ESF, unpublished data).

Centrarchid utilization of structure was significantly different depending on structure type. We found the mean centrarchid catch at jetty sites was significantly greater than dock sites but not significantly greater than pier footing sites. Although there were no significant differences in fish attraction to any structure type, we observed higher mean centrarchid and adult black bass visits at the pier footing sites. The jetty and pier footing structures have similar features that may have influenced their use or attractiveness to centrarchids. Lynch et al. (1988) found the slope of shoreline affects the species and age of fish present. Legally sized Bluegill and Crappie were higher in abundance at 3:1 ft slopes. Additionally, Bassett (1994) determined any type of “drop-off” or boundary line between structural complexity and open water tends to be utilized by adult fish for navigation, including black bass. The pier footing and jetty sites are both continuous structures and create a steep drop-off to open water. These characteristics could explain the observed greater mean centrarchid and adult black bass visits at pier footing sites and the significantly greater mean centrarchid catch at jetty sites versus dock sites.

In addition to these differences, we found vegetation and grouping influenced the utilization and attractiveness of structure. Submerged littoral macrophytes increase species diversity (Eadie and Keast 1984; Werner et al. 1977). Expectedly, we found mean species diversity of catches and visits were both significantly greater at vegetated structure sites. We also found that the mean centrarchid catch was significantly greater at vegetated structure sites,
and the mean richness of visits and of adult black bass visits were significantly greater at vegetated structure sites.

Our assessment of new, implemented structure included the comparison of grouped and isolated porcupine crib sites. We found the mean of adult black bass visits at the grouped porcupine crib site was significantly greater than the mean of visits at the isolated crib sites. Similar to the jetty and pier footing structure types, grouped porcupine cribs created habitat connectivity and a boundary between complexity and open water. Additionally, all porcupine crib sites were at greater depths where habitat complexity and cover were less prevalent. Lynch and Johnson (1988a) found grouped structure provided continuous habitat complexity utilized by more centrarchids than isolated structures. Adult black bass may have been attracted to the continuous structural boundary between grouped porcupine crib habitat and open water for navigation or hunting purposes. Further assessment of porcupine cribs and structures at greater depths was limited by available structure sites, and the porcupine cribs were the only sites in this study at depths greater than 2.0 m.

Prince and Maughan (1979) found Largemouth Bass prefer structure at 4.0 m to 6.0 m deep. Conversely, we did not find a significant difference in the mean of black bass visits between structures at shallow (<2.0 m) and deep (>2.0 m) sites. Allen et al. (2014) determined the number of black bass utilizing structure was influenced by the interaction of depth and visibility. Black bass are visual predators, and Allen et al. (2014) suggested their use of deeper structure, as a boundary for navigation and hunting in open water, could be influenced by visibility. Alternatively, Allen et al. (2014) suggested this finding may have been a result of limitations to species recognition and identification in poor visibility. Our video assessment encountered low visibility at porcupine crib sites, and we were unable to determine if our
comparison of fish attraction to structures at shallow versus deep sites was influenced by visibility or by the small sample size of deep structure sites.

Despite a limited sample size and visibility of new structure, our preliminary assessment identified differences in attractiveness to centrarchid species. To enhance this component of our study, we recommend examination of additional grouped and isolated porcupine cribs and new structure sites at different shallow (<2.0 m) and deep (>2.0 m) littoral zone depths. Future habitat structure implementations throughout Onondaga Lake include grouped porcupine crib sites and rock piles at multiple depths. These new structure types could also be compared. The lattice structure of porcupine cribs was designed to provide smaller interstitial space options that enhance littoral habitat complexity. Lynch and Johnson (1989) found that structures with small (40 mm) interstice size had significantly greater mean juvenile and adult Bluegills. They suggested more juveniles and adult panfish utilize structures with smaller interstice as cover. We observed a high frequency of Bluegill visits at both grouped and isolated porcupine crib sites. Fish attraction to different structural interstice and complexity could be assessed by comparison of porcupine crib and rock pile sites.

In addition to the analysis of fish utilization and attraction to structures categorized by types, location, and surrounding vegetation or additional structure, one objective of this research was to compare different methods used for structure assessment. The most effective methodology to assess fish use and densities surrounding structure of various types and depths is often debated. Shallow structures have been typically sampled by electrofishing, while deeper structures have been indirectly measured by angling and pop net surveys (Allen et al. 2014; Lynch and Johnson 1988a; Paxton and Stevenson 1979). Scuba survey is a developing method used to visually examine fish abundance surrounding structures without limitations at depth.
Since we were not permitted to dive in remediated areas, and electrofishing is limited to shallow structure, we chose camera assessment as an appropriate method for visually determining fish attraction to structure.

Visual scuba and camera assessments are criticized for over estimating abundance of dominant and seasonally dominant species and underestimating species less visible with poor water clarity. Our analysis of camera assessment incorporated dominancy in the sampling unit. Allen et al. (2014) diver observations observed that black bass were highly mobile around structures. Based on these observations, we assumed individuals could be swimming in and out of view multiple times and determined this attributed to the attractiveness of a sample site to a particular species. In particular, we assumed centrarchid fish were repeatedly visiting structure sites. To support this claim, we found all marked adult Largemouth Bass (>200 mm) captured by gill netting and electrofishing were recaptured at the same sample site, with the exception of one recapture that occurred at a structure site closest to the original capture site. The duration of time between mark and recapture ranged from a week to roughly four months. We suggest these Largemouth Bass (>200 mm) were staying local to preferred habitat from July through mid-November.

We also recognized that water clarity limited our viewing depth. In 2017, central New York experienced greater than average precipitation throughout the month of June, but we do not assume this influenced our sampling efforts. The UFI AMP in the south basin recorded above average turbidity in the epilimnion from June through early July and below average turbidity in the epilimnion from mid-July through mid-August (UFI 2017, unpublished data). We suspect visibility during our assessment was representative of the average visibility in Onondaga Lake. Since we sampled during consistent, poor water clarity, our cameras were deployed in close
proximity to structure, and each observation screen included half structure and half open water. This set-up allowed for identification of smaller species in direct proximity to structure and mobile species in open water. For these reasons, we concluded our analyses were likely an accurate assessment of fish attraction to structure and non-structure sites in Onondaga Lake.

We found that camera assessment provides valuable information on attractiveness of structure, specifically for management objectives aiming to enhance angler success and centrarchid sportfish habitat. Our video analysis confirmed past research and other methods that determined the significance of habitat complexity and connectivity provided by vegetated and grouped structures to centrarchids and species diversity. Even though our sampling unit incorporated multiple visits by structurally-oriented species, we still found a greater mean richness and diversity of visits to vegetated structure sites. These findings suggest multiple species, in addition to centrarchids, are more equally attracted to vegetated sites. We also found a significantly greater mean of visits by adult black bass at vegetated and grouped sites. We suspect these adult predators are attracted to a higher diversity of prey at vegetated sites or are using grouped sites for offshore navigation and hunting. These findings affirm that structure provides essential habitat complexity and connectivity for a greater richness and diversity of species and favorable habitat for centrarchid species.

Camera analysis was the only effective method that included all structure sites in Onondaga Lake. This method would be most effective for continued research and for the assessment of additional rock piles and porcupine cribs at greater depths. This research found that existing and preliminary implemented structure in a remediated, urban lake is essential habitat that provides complexity, connectivity, and an open water boundary for centrarchid species and a diverse fish community. We expect additional habitat installations in the lake will
continue to attract fish. We recommend further assessment to understand and identify long-term trends in centrarchid attraction to structure in a recovering system. However, it is unlikely that visual observation of structures will independently determine a correlation between attractiveness of implemented structure and enhanced fish production. We recommend an integrated approach, including long-term assessment of habitat structure and centrarchid population densities and distributions, reproduction, and recruitment.
References


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Chapter 3: Implications for continued assessment and considerations for management of an evolving fishery

Implications for continued assessment

The main objectives of this research were to identify changes in centrarchid productivity, including population estimates, reproduction, and juvenile recruitment, and their utilization and attraction to habitat and structure as the conditions in Onondaga Lake transformed from a highly degraded and perturbed system to a newly remediated system. The biological monitoring program on the lake is expected to continue for multiple years, and a portion of the intensive sampling efforts described by this research will continue for at least four more sampling seasons. To successfully monitor centrarchid production in response to new habitat enhancements, we recommend a combination of these methods, conducted annually or intermittently, in the future.

Due to past limitations in shoreline availability, we recommend population estimates by mark and recapture study in the late spring continue for at least two more seasons. These additional seasons will improve population estimate accuracy for the entire lake and north and south basins and help determine a probable catchability for adult Largemouth Bass (>300 mm) in Onondaga Lake. Then, the catchability can be applied to simplify data collection and to monitor changes in the population over time.

We recommend the continued assessment of juvenile assemblages at the 2017 sites, as outlined in the biological monitoring scope projected for the next four years, and intermittent centrarchid nest sampling. Centrarchid nest abundance per segment of shoreline and by quadrant were the main measurements of this research. These measurements should be sampled annually or every other year for the next four years to provide more information on the annual fluctuation of nest abundances. If time and funding permits, we recommend detailed assessment of substrate
type and macrophyte abundance in relationship to nest locations and distributions. This information will provide additional detail on centrarchid use and macrophyte recolonization of the new habitat layer.

We also recommend continued camera assessment of centrarchid attraction to structure in combination with these aforementioned methods. Camera assessment was time intensive, so we recommend sampling efforts be conducted when time and funding permit. More structures, including rock piles (deep and shallow), grouped porcupine cribs (deep and shallow), boulders and stumps are expected to be added to remediation zones, along the eastern shoreline between Iron Bridge and Ley Creek, and to Maple Bay on the north end of the lake. We recommend future examinations include structures that can test differences in attraction based on structure type, depth and, location. In addition, we recommend including vegetated non-structure sites to test differences in attraction based on habitat complexity. Continued monitoring of the attractiveness of structure, population estimates or catchability of Largemouth Bass (>300 mm), and reproduction and recruitment of centrarchids could provide novel assessment of the response of centrarchid production to habitat and structure enhancement projects.

**Considerations for managing an evolving sport fishery**

Another remediation objective is to enhance the recreational opportunities on Onondaga Lake. The urban location and comparably small size of makes Onondaga Lake highly accessible to anglers traveling to and within the lake. Increased recreational angling and boat traffic will require the continued monitoring of population, reproduction, and recruitment of sportfish in an evolving fishery. Angling can have negative effects on nest guarding species. The physiological impacts of angled adult black bass are well documented, and research has found adverse effects on adult condition and the ability for adults to guard nests and protect young. Kieffer et al.
(1995) determined the energy expenditure was more severe between Largemouth Bass fished for 2 minutes versus 20 seconds. The of impacts longer fishing durations on released fish reduce the ability of adult black bass to respond to external stress, such as predator avoidance, and replenish energy stores for prey capture (Priede 1985). In addition, removing adults from nests during spawning periods can leave eggs, larvae, and juveniles exposed to predators.

The ecological threat of invasive species affects centrarchid reproductive and recruitment success, specifically for Largemouth and Smallmouth Bass. As with many systems in the Great Lakes region, the species composition of Onondaga Lake includes invasive species such as the Round Goby. The Round Goby originates from the Ponto-Caspian Sea and was first documented in the region in 1990 (Jude et al. 1992). These benthic fish occupy rocky substrate and are egg predators. Egg predation has often caused black bass nests to fail by consumption of broods or by adult abandonment (Lukas and Orth 1995; Swenson 2002). Rates of egg predation increase with water temperature and at nest sites with larger gravel and cobble substrate (Steinhart et al. 2004). The energetic costs of nest guarding from Goby have also been suggested to adversely impact the condition of male bass. Removal of protective males by angling leaves nests susceptible to predation. The energetic costs from angling also reduce the ability of returning adults to protect nests for several hours during recovery (Kieffer et al. 1995). Since Onondaga Lake is small in size, anglers traveling by boat can access multiple locations within minutes. The combined effects of angling during nesting season and egg predation could impact centrarchid populations and emphasize the importance of continued monitoring and management of sportfish in Onondaga Lake.
References


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